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DISSERTATION

MECHANISMS OF ORGANIZATIONAL ADAPTATION TO SOCIAL DISRUPTION CAUSED BY THE FULL-SCALE RUSSIAN INVASION OF UKRAINE

054 «Sociology»
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The dissertation contains the results of the author's original research. The use of ideas, results, and texts from other authors is properly acknowledged and referenced to their respective sources.

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ABSTRACT

Serdyuk A. I. Mechanisms of organizational adaptation to social disruption caused by the full-scale russian invasion of Ukraine. – Dissertation research submitted as a manuscript.

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Organizations are the primary structures through which societies coordinate economic activity, deliver services, and sustain collective life. On February 24, 2022, russia's full-scale invasion of Ukraine shattered the conditions on which ordinary organizational life depends. The result is a social disruption: a rapid, externally imposed breakdown of the institutional arrangements that coordinate social life within a given territory. Two qualitatively different pathways of organizational adaptation now operate simultaneously on the same finite social fabric: the organizational pathway, through formal institutions (regulation, taxation, mobilization orders), and the self-organizational pathway, through informal institutions (trust-based partnerships, voluntary action, coordination without central direction). Under sustained warfare, the two pathways compete for the same resources and can interfere with each other. Institutional theory specifies how formal mechanisms produce conformity. Network theory predicts that inter-organizational ties shape recovery after disruption. The crisis-agency framework (L. Bevzenko) distinguishes the two pathways and predicts their mutual interference. None of these frameworks specifies how the mechanisms interact at the population level or where the thresholds between adaptive regimes lie.

The **object** of research is organizational adaptation to social disruption caused by the full-scale russian invasion of Ukraine. The **subject** is the mechanisms of this adaptation and the regime structure their interaction produces. The research operates at the meso-level of organizational populations.

The **purpose** is to establish how formal institutional and informal self-organizational mechanisms interact as a complex adaptive system to produce population-

level outcomes in order to adapt to social disruption caused by the full-scale russian invasion of Ukraine. The **research tasks** are: to identify the mechanisms through qualitative interviews and establish their population-level distributions through a quantitative survey; to formalize them in an agent-based model and calibrate it against Ukrainian wartime data; to validate the model and map its empirically credible scope; and to establish through computational experimentation the regimes, tipping points, and reversibility of the wartime transformation.

The theoretical foundation integrates the crisis-agency framework (L. Bevzenko), institutional theory (P. DiMaggio, W. Powell, C. Oliver), and network theory (D. Aldrich, R. Burt) within a complex adaptive systems logic (D. Byrne), supplemented by the Ukrainian sociology of emergencies (S. Makeiev, O. Pugachova), disaster sociology (P. Sorokin, E. Quarantelli), and organizational ecology (M. Hannan, J. Freeman).

The empirical investigation comprises 37 semi-structured interviews with owners and managers of Ukrainian organizations (two waves, 2022–2023) and a structured CAWI survey of 35 organizations (February 2026). Twenty-seven empirically grounded mechanisms are computationally formalized in an agent-based model in NetLogo 7.0.3 with 38 behavioral rules. Validation combines pattern-oriented testing against 43 criteria across eight empirical domains, multi-model structural comparison, counterfactual scenario analysis, and complex systems diagnostics, across approximately 22,200 simulation runs in four experimental batteries. The empirical basis is supplemented by aggregate wartime data from the International Organization for Migration, the State Statistics Service, the Ministry of Finance of Ukraine, World Bank RDNA assessments, and Center for Strategic and International Studies (CSIS) and Centre for Eastern Studies (OSW) military analyses.

Findings. The results show an institutional paradox. Government is necessary for organizational survival under warfare, but beyond a threshold, it crowds out the informal adaptation on which survival also depends. Under full government provision, domain expansion drops by 25.5 percentage points relative to the no-government condition. The self-organizational pathway outperforms the organizational pathway across all tested configurations, and decentralized configurations outperform centralized ones at every level of government capacity. Adaptation is dispositional rather than reactive: pre-existing prosocial dispositions determine outcomes more strongly than crisis severity. Three tipping points bound the system's viability: military attrition, institutional capacity, and network connectivity; network fragmentation, not direct threat exposure, is the proximate cause of organizational death. The two pathways' interaction produces four regimes, visualized in the phase diagram: Viable, Stressed, Degraded, and Collapsed. War damage is selectively irreversible: material infrastructure recovers when the threat recedes, but solidarity capital is consumed by the activation this adaptation requires. This is resilience without adaptation (Pugachova, 2025b): the system retains material capacity while losing the social fabric on which future adaptation would depend.

Scientific novelty (original contribution). To our knowledge, this study is the first to show that organizational adaptation under sustained warfare behaves as a complex adaptive system with two interacting pathways rather than as a linear response to external disruption; the dissertation specifies how the pathways interact at the population level and where the thresholds between them lie. The study further develops the crisis-agency framework (L. Bevzenko) by computationally specifying and quantifying the institutional paradox. To our knowledge, this is the first demonstration of the structural advantage of the self-organizational pathway across the tested range of government capacity, threat intensity, and pre-invasion institutional structure under sustained warfare. The study further develops disaster scholarship by showing that organizational adaptation is dispositional rather than reactive. To our knowledge, this study is the first to establish network connectivity as an immediate condition of organizational survival rather than a resource for post-disaster recovery. The three-phase model of social tension (L. Bevzenko) is further developed by identifying a fourth (Degraded) regime, in which organizations persist at permanently reduced capacity without the relational infrastructure to recover. The pattern of resilience without adaptation (Pugachova, 2025b) is further developed through its computational specification and quantification.

This study provides a systematic inventory of mechanisms of organizational adaptation under sustained warfare. The 27 empirically grounded mechanisms, 11 of which were discovered abductively without a prior theoretical template, constitute a new empirical base for computational formalization. The methodological contributions improve existing agent-based modeling practice through an eight-criterion assessment of ABM appropriateness and a validation-method selection framework covering 76 scenarios.

Practical significance. The findings can inform state policy on organizational resilience under wartime conditions and post-war reconstruction, in particular by specifying the limit of regulatory and mobilization burden beyond which institutional provision begins to suppress self-organizational adaptation.

The dissertation was prepared within the research topic «Sociocultural Transformations and Dynamics of Social Inequalities in Ukrainian Society» (state registration number 121U112229) at the Department of Sociology, National University of Kyiv-Mohyla Academy. The dissertation consists of an introduction, six chapters, conclusions, a list of references (176 sources), and six appendices.

Keywords: agent-based modeling, computational social science, mechanisms, organizational adaptation, social reintegration, political transformations, Ukraine, russo-Ukrainian war, war in Ukraine, full-scale invasion, war, armed conflict, complexity paradigm, quantitative methods, political trust.

АНОТАЦІЯ

Сердюк А. І. Механізми організаційної адаптації до соціального розриву, спричиненого повномасштабним російським вторгненням в Україну. – Кваліфікаційна наукова праця на правах рукопису.

Дисертація на здобуття наукового ступеня доктора філософії за спеціальністю 054 «Соціологія» (05 – Соціальні та поведінкові науки). – Національний університет «Києво-Могилянська академія», Київ, 2026.

Організації – основні структури, через які суспільства координують економічну діяльність, надають послуги та підтримують суспільне життя. 24 лютого 2022 року повномасштабне російське вторгнення в Україну зруйнувало умови, на яких тримається звичайне життя організацій. Результатом став соціальний розрив – швидкий, спричинений ззовні розлад інституційних механізмів, що координують суспільне життя на певній території. На тій самій обмеженій соціальній тканині одночасно діють два якісно різні шляхи організаційної адаптації: організаційний – через формальні інституції (нормативно-правові приписи, оподаткування, мобілізаційні накази), та самоорганізаційний – через неформальні інституції (довірчі взаємодії, добровільна дія, координація без центрального керівництва). В умовах тривалої війни два шляхи конкурують за ті самі ресурси і можуть пригнічувати один одного. Інституційна теорія пояснює, як формальні механізми породжують злагодженість. Мережева теорія передбачає, що міжорганізаційні зв'язки визначають відновлення після соціального розриву. Теорія кризової агентності (Л. Бевзенко) розрізняє ці два шляхи і прогнозує їхнє взаємне пригнічення. Проте жоден із цих теоретичних підходів не пояснює, як саме механізми взаємодіють на популяційному рівні та де пролягають межі між режимами адаптації.

Об'єктом дослідження є організаційна адаптація до соціального розриву, спричиненого повномасштабним російським вторгненням в Україну. **Предметом** дослідження є механізми цієї адаптації та структура режимів, що виникає внаслідок їхньої взаємодії. Дослідження проводиться на мезорівні організаційних популяцій.

Мета дослідження – встановити, як формальні інституційні та неформальні самоорганізаційні механізми взаємодіють як складна адаптивна система, породжуючи наслідки на рівні популяції в процесі адаптації до соціального розриву, спричиненого повномасштабним російським вторгненням в Україну. **Дослідницькі завдання**: виявити механізми за допомогою якісних інтерв'ю та встановити їхні розподіли через кількісне опитування; формалізувати їх в агентній моделі та відкалібрувати її на українських даних; валідувати модель і окреслити сферу її достовірного застосування; встановити в обчислювальних експериментах режими, точки зламу та зворотність воєнної трансформації.

Теоретичну основу дослідження становлять: теорія кризової агентності (Л. Бевзенко), інституційна теорія (П. ДіМаджо, В. Пауелл, К. Олівер) та мережева теорія (Д. Олдрич, Р. Берт) у логіці складних адаптивних систем (Д. Берн), а також концепції української соціології надзвичайностей (С. Макеєв, О. Пугачова), соціології катастроф (П. Сорокін, Е. Кварантеллі) та організаційної екології (М. Геннен, Дж. Фріман).

Емпіричне дослідження містить 37 напівструктурованих інтерв'ю з власниками та керівниками українських організацій (дві хвилі, 2022–2023 рр.) і структуроване онлайн-опитування (CAWI) 35 організацій (лютий 2026 р.). Емпіричну базу доповнюють агреговані дані Міжнародної організації з міграції, Державної служби статистики України, Міністерства фінансів України, оцінки збитків і потреб Світового банку, а також військово-аналітичні матеріали Центру стратегічних та міжнародних досліджень (Center for Strategic and International Studies; CSIS) і Центру східних студій (Ośrodek Studiów Wschodnich; OSW).

В обчислювальній агентній моделі у NetLogo 7.0.3 формалізовано 27 емпірично виявлених механізмів із 38 правилами поведінки. Валідація поєднує патерн-орієнтоване тестування за 43 критеріями у восьми емпіричних доменах, мульти-модельне структурне порівняння, аналіз гіпотетичних сценаріїв та діагностику складних систем; програма експериментів охоплює близько 22 200 запусків моделі у чотирьох батареях тестів.

Результати. Центральним результатом дослідження є інституційний парадокс: держава потрібна для виживання організацій в умовах війни, проте після певного порогу вона починає пригнічувати неформальну адаптацію, від якої теж залежить виживання. За повного державного забезпечення розширення сфери діяльності зменшується на 25,5 відсоткового пункту порівняно з повною відсутністю держави. Самоорганізаційний шлях перевершує організаційний в усіх протестованих конфігураціях, а децентралізовані конфігурації перевершують централізовані за будь-якого рівня державної спроможності. Адаптація є диспозиційною, а не реактивною: наявні просоціальні диспозиції впливають на результати більшою мірою, ніж гострота кризи. Три точки зламу обмежують життєздатність системи: воєнні втрати, інституційна спроможність і мережева зв’язність; саме фрагментація мережі, а не пряма дія загрози, є безпосередньою причиною загибелі організацій. Взаємодія двох шляхів породжує чотири режими, відображені на фазовій діаграмі: «Життєздатний», «У стані стресу», «Деградований» і «Зруйнований». Наслідки війни є вибірково незворотними: матеріальна інфраструктура відновлюється після зниження загрози, проте капітал згуртованості вичерпується через активацію, необхідну для адаптації. Це стійкість без адаптації (Pugachova, 2025b): система зберігає матеріальну спроможність, але втрачає соціальну тканину, від якої буде залежати майбутня адаптація.

Наукова новизна. Вперше показано, що організаційна адаптація в умовах тривалої війни поводиться як складна адаптивна система з двома шляхами, що взаємодіють, а не як лінійна реакція на зовнішнє порушення; дисертація визначає, як шляхи взаємодіють на популяційному рівні і де пролягають пороги між ними. Набула подальшого розвитку теорія кризової агентності (Л. Бевзенко) шляхом обчислювальної формалізації та кількісної оцінки інституційного парадоксу. Вперше продемонстровано структурну перевагу самоорганізаційного шляху в усьому протестованому діапазоні державної спроможності, інтенсивності загрози та довоєнної інституційної структури в умовах тривалої війни. Набули подальшого розвитку уявлення соціології катастроф: показано, що організаційна адаптація має диспозиційний, а не реактивний характер. Вперше мережеву зв’язність встановлено як безпосередню умову виживання організацій, а не як ресурс післявоєнного відновлення. Набула подальшого розвитку трифазна модель соціальної напруженості (Л. Бевзенко): виявлено четвертий (деградований) режим, у якому організації існують за стійко зниженої спроможності, не маючи мережі зв'язків, потрібної для відновлення. Набув подальшого розвитку патерн стійкості без адаптації (Pugachova, 2025b) шляхом його формалізації засобами агентного моделювання та кількісної оцінки.

Вперше створено систематичний перелік механізмів організаційної адаптації в умовах тривалої війни. 27 емпірично виявлених механізмів, з яких 11 виявлено абдуктивно, без попереднього теоретичного прогнозу, становлять нову емпіричну базу для обчислювальної формалізації. Удосконалено практику агентного моделювання шляхом розробки восьмикритеріальної оцінки доцільності застосування агентного моделювання та схеми вибору методу валідації, що охоплює 76 сценаріїв.

Практичне значення. Результати можуть слугувати основою для державної політики стійкості організацій в умовах війни та повоєнної відбудови, зокрема для визначення межі регуляторного й мобілізаційного навантаження, за якою інституційне забезпечення починає пригнічувати самоорганізаційну адаптацію.

Дисертацію виконано в межах науково-дослідної теми «Соціокультурні трансформації та динаміка соціальних нерівностей в українському суспільстві» (державний реєстраційний номер 121U112229) на кафедрі соціології Національного університету «Києво-Могилянська академія». Дисертація складається зі вступу, шести розділів, висновків, списку використаних джерел (176 найменувань) і шести додатків.

Ключові слова: агентне моделювання, обчислювальні соціальні науки, механізми, організаційна адаптація, соціальна інтеграція, політичні трансформації, Україна, російсько-українська війна, війна в Україні, повномасштабне вторгнення, війна, збройний конфлікт, парадигма складності, кількісні методи, політична довіра.

LIST OF THE CANDIDATE'S PUBLICATIONS

List of scientific publications in which the primary research results of the dissertation are published:

1. Serdyuk, A. (2023). Organizational adaptation to a disruption caused by the full-scale russian invasion of Ukraine. *NaUKMA Research Papers. Sociology*, 6, 39–49. https://doi.org/10.18523/2617-9067.2023.6.39-49
2. Serdyuk, A. (2025). Choosing validation methods for agent-based models: A practical framework. *NaUKMA Research Papers. Sociology*, 8, 4–15. https://doi.org/10.18523/2617-9067.2025.8.4-15
3. Serdyuk, A. (2026). Choosing agent-based modelling as a method of social research: Practical recommendations. *Ukrainian Society*, 1(96), 43–60. https://doi.org/10.15407/socium2026.01.043

List of scientific publications confirming dissemination of the dissertation findings:

1. Serdyuk, A. (2025). Validation strategies for agent-based models in social science: Insights from modeling of migration caused by the full-scale russian invasion of Ukraine. In *Russian war against Ukraine: Transformations of social institutions and practices: Proceedings of the academic and practical conference* (pp. 182–187). National University of Kyiv-Mohyla Academy. https://ekmair.ukma.edu.ua/handle/123456789/36677

2. Serdyuk, A. (2025). Agent-based simulating of Ukrainian universities adaptation to a full-scale russian invasion. In *Proceedings of the XV International Scientific and Practical Conference "Sociology, social work and social security: Regulation of social problems"* (pp. 68–73). https://doi.org/10.5281/zenodo.15635368

3. Serdyuk, A. (2025). Policy responses and organizational adaptation of Ukrainian universities during the full-scale russian invasion: An agent-based approach. In T.

Nahorniak & I. Zaichenko (Eds.), *Interdisciplinary expertise for the recovery and development of Ukraine: Proceedings of the International Scientific and Practical Conference* (pp. 216–221). National University of Kyiv-Mohyla Academy. https://doi.org/10.5281/zenodo.16421646

Table of Contents

INTRODUCTION

Justification for the choice of the research topic. Organizations are the primary structures through which societies coordinate economic activity, deliver services, and sustain collective life. When these structures break down, the consequences affect entire populations. Understanding how organizations respond to large-scale disruption is a central question for sociology.

The global context makes this question urgent. Armed conflicts have been increasing after decades of decline. In 2023, the number of state-based armed conflicts reached 59, the highest level since 1946 (Davies et al., 2024; Gleditsch et al., 2002). This trend unfolds within what Beck (1992) called a risk society, where risks exceed the capacity of institutions to manage them, and within conditions of instability and uncertainty that Bauman (2000) described as liquid modernity.

Before the full-scale invasion, Ukrainian organizations had developed adaptive capacity shaped by the russian-Ukrainian war that started in 2014 with the annexation of Crimea and the invasion of eastern Ukraine, and by the COVID-19 pandemic. These experiences prepared organizations unevenly but gave many of them practical experience with crisis response.

On February 24, 2022, russia's full-scale invasion of Ukraine shattered the conditions on which ordinary organizational life depends. Schools, hospitals, workplaces, civic organizations, and commercial enterprises faced destruction or paralysis at the same time. The result is a social disruption: a rapid, externally imposed breakdown of the institutional arrangements that coordinate social life within a given territory. Existing frameworks for organizational crisis response were formulated for natural disasters with bounded durations and identifiable endpoints (Quarantelli, 1997; Kreps & Bosworth, 1993). War breaks these assumptions because it produces cascading disruptions across distinct phases and involves an adversary that adapts to exploit systemic vulnerabilities (Pescaroli & Alexander, 2016).

The invasion created a situation in which two qualitatively different mechanisms of organizational adaptation operate simultaneously on the same finite social fabric. Formal institutional mechanisms (compliance with regulation, alignment with state directives, hierarchical coordination) continue to operate because the Ukrainian state retained partial capacity. Informal self-organizational mechanisms (networks, voluntary action, trust-based cooperation) became essential because formal mechanisms could not meet all the demands the war generated. Under bounded disasters, the two pathways cooperate in time-limited ways; under sustained warfare they compete for the same resources and can suppress each other (Chapter 1).

The crisis-agency framework (Bevzenko, 2022) distinguishes the two pathways and suggests their mutual suppression. Institutional theory (DiMaggio & Powell, 1983; Oliver, 1991) specifies how formal mechanisms produce conformity. Research on inter-organizational networks (Burt, 2005) and on social capital under disaster (Aldrich, 2012) specifies how interactions build relational infrastructure at the dyadic level. None of these frameworks addresses what these interactions produce at the population level. The problem involves nonlinear interaction, threshold dynamics, and regime transitions characteristic of complex adaptive systems (Byrne, 1998), and requires computational investigation (Epstein, 2006).

The scientific problem is twofold. The primary conceptual problem concerns the behavior of organizational populations (sets of organizations that share a common form and depend on the same environment for resources; Hannan & Freeman, 1989) under sustained warfare. Resolving it requires identifying the operative mechanisms, specifying how they interact at the population level, locating the thresholds between adaptive regimes, and determining whether wartime shifts are reversible. The secondary methodological problem is how to empirically parameterize these mechanisms for computational formalization, given that no existing agent-based model addresses this context.

Object and Subject of Research. The **object** is organizational adaptation to social disruption caused by the full-scale russian invasion of Ukraine: the process by which organizations modify their behavior, structure, and inter-organizational relationships in response to sustained externally imposed institutional breakdown.

The **subject** is the mechanisms of this adaptation and the regime structure produced by their interaction. A mechanism is a recurrent causal sequence connecting environmental conditions to organizational responses and their aggregate consequences (Hedström & Bearman, 2009). The mechanisms could operate through organizational (mediated by formal institutions) or self-organizational (mediated by informal institutions) pathways.

The research operates at the meso-level of organizational populations. Organizations are the units of analysis, their interactions constitute the mechanisms, and population-level outcomes (survival, network structure, regime classification) are the dependent phenomena.

Purpose and Research Tasks. The **purpose** is to establish how formal institutional and informal self-organizational mechanisms interact as a complex adaptive system to produce population-level outcomes in order to adapt to social disruption caused by the full-scale russian invasion of Ukraine. The further **methodological purpose** is to identify these mechanisms empirically, formalize them computationally, and test their interaction experimentally.

To achieve this purpose, the following **research tasks** are set:

1. To synthesize the theoretical frameworks for organizational adaptation within the crisis-agency analytical frame and to formulate a working definition of mechanisms for computational formalization.
2. To determine the defining features of the Ukrainian wartime emergency as a complex system with adversarial threat, overlapping timeframes, and dual demand structure.
3. To establish the temporal structure of the crisis, identifying its phases and consolidating them into a regime-level framework.
4. To identify the mechanisms of organizational adaptation through qualitative interviews and to establish their population-level distributions through a quantitative survey.

5. To formalize the empirically identified mechanisms into an agent-based model and to calibrate it against Ukrainian wartime data.
6. To validate the model against qualitative evidence and aggregate empirical patterns and to determine its empirically credible scope.
7. To establish through computational experimentation how the mechanisms interact: the conditions under which the organizational pathway enhances or suppresses self-organizational adaptation, the regimes the system can occupy, the tipping points that bound its viability, and the reversibility of the wartime shift.

Research Questions. The overarching **research question** is: how do formal institutional and informal self-organizational mechanisms interact as a complex adaptive system to produce population-level outcomes of organizational adaptation to social disruption under sustained warfare?

- RQ1. What characterizes the wartime emergency as a context for organizational adaptation, and what temporal structure does it exhibit? (Chapters 1–2)
- RQ2. Which mechanisms of organizational adaptation operate through the organizational pathway, which through the self-organizational pathway, and which bridge between them? (Chapter 3)
- RQ3. Under what conditions does the organizational pathway enhance adaptation, under what conditions does it suppress self-organizational adaptation, and where is the threshold? How do different pre-invasion configurations shape resilience trajectories? (Chapter 6)
- RQ4. Where are the viability boundaries of the system, and is the wartime shift reversible? (Chapter 6)

Research Methods. The dissertation uses a theory-driven sequential mixed-methods design in which empirical findings generate the research instrument: an agent-based simulation that formalizes empirically identified mechanisms into executable code.

Theoretical foundation (Chapters 1–2) integrates the crisis-agency framework (Bevzenko, 2022), institutional theory (DiMaggio & Powell, 1983; Oliver, 1991), and network theory (Aldrich, 2012; Burt, 2005) within a complex adaptive systems logic (Byrne, 1998). Supplementary concepts come from Ukrainian sociology of emergencies

(Makeiev, 2022, 2024; Pugachova, 2025a), disaster sociology (Sorokin, 1942; Quarantelli, 1997), and organization ecology (Hannan & Freeman, 1984).

Empirical investigation comprises 37 semi-structured interviews with owners and managers of Ukrainian organizations (two waves, 2022–2023) and a structured CAWI survey of 35 organizations (February 2026). The interviews were analyzed through deductive mechanism coding, followed by abductive analysis of empirical patterns that did not fit the mechanisms derived from the prior theoretical frameworks. The survey provides population-level parameter distributions for the model.

Computational formalization implements the mechanisms in an agent-based model in NetLogo 7.0.3, with 38 behavioral rules drawn from six established models. The validation and experimentation phase (Chapters 5–6) uses approximately 22,200 simulation runs across four experimental batteries.

Calibration uses Morris elementary effects screening, one-factor-at-a-time analysis, and four-layer empirical calibration (direct anchoring, survey commitment, Latin Hypercube Sampling, genetic algorithm optimization). Validation combines pattern-oriented validation against 43 criteria across eight empirical domains, multi-model structural comparison, counterfactual scenario analysis, and complex systems diagnostics (tipping points, phase diagrams, hysteresis, early-warning signals, network percolation). Statistical analysis uses Wilcoxon rank-sum tests, Cliff's delta, Kruskal-Wallis tests, Kendall's tau, Hartigan's dip test, logistic regression, Moran's I, and bootstrap confidence intervals.

The empirical basis is supplemented by aggregate wartime data from the IOM, the State Statistics Service, the Ministry of Finance, World Bank RDNA assessments, and CSIS and OSW military analyses.

Scientific novelty and originality of the research findings. The scientific novelty of the obtained results consists in the following.

Obtained for the first time. For the first time, the dissertation establishes the structural advantage of the self-organizational pathway over the organizational pathway under conditions of sustained warfare. Across the tested range of government capacity, threat intensity, and pre-invasion institutional structure, the self-organizational pathway produces higher organizational survival than the organizational pathway. The finding shows that, under sustained shock, the informal pathway is not merely supplementary to formal institutions but is the more reliable mechanism of organizational survival.

For the first time, network connectivity is established as an immediate condition of organizational survival under sustained warfare rather than as a resource for post-disaster recovery. The results show that the population tipping point closely converges with the network percolation threshold, while network fragmentation, rather than direct exposure to threat, becomes the proximate cause of organizational death.

The dissertation establishes the first systematic inventory of mechanisms of organizational adaptation under sustained warfare. The inventory identifies 27 empirically grounded mechanisms, including 11 mechanisms identified through abductive analysis without a prior theoretical template. They are voluntary military support, domain expansion, the three-phase temporal pattern, COVID pre-adaptation, intermediated government interaction, mobilization workforce shock, civilian-military permeability, HR repurposing, the Jungle-to-Zoo transition, selective relocation destination, and return-home intention.

For the first time, organizational adaptation to social disruption under sustained warfare is formalized as an agent-based model which operationalizes empirically identified mechanisms and makes possible testing their interaction experimentally.

Further developed: This dissertation further develops the crisis-agency framework (Bevzenko, 2022) by computationally specifying and quantifying the institutional paradox. Beyond a measurable threshold, government institutional provision suppresses the self-organizational mechanisms it was designed to support. The threshold occurs at intermediate levels of altruism (0.3–0.5); under full government provision, domain expansion drops by 25.5 percentage points relative to the no-government condition.

The dissertation further develops disaster scholarship by showing that organizational adaptation is dispositional rather than reactive. Pre-existing prosocial dispositions and the structural conditions that allow them to operate determine adaptation outcomes more strongly than the severity of the crisis itself. This contradicts the implicit assumption that adaptation responses scale with the magnitude of the shock.

The three-phase model of social tension (Bevzenko, 2018) is further developed through the identification and quantitative localization of a fourth regime: the Degraded regime, in which organizations persist at a stably reduced level of capacity. This extends the three-phase model to include a condition of organizational persistence without recovery.

The pattern of resilience without adaptation described by Pugachova (2025b) is further developed through its computational specification and quantitative assessment. The dissertation shows that material infrastructure may recover after the threat recedes, while cultural diversity and solidarity decline and do not recover. This identifies a mechanism by which short-term organizational adaptation depletes the solidarity required for future adaptive capacity.

Improved: Existing agent-based modeling practice is improved through two methodological frameworks developed by the author: an eight-criterion framework for assessing the appropriateness of agent-based modeling as a research method (Serdyuk, 2026) and a validation-method selection framework for agent-based models covering 76 modeling scenarios (Serdyuk, 2025b).

Dissemination of the dissertation findings. The findings of the dissertation were presented at eight academic conferences in Ukraine, Romania, the Netherlands, and Canada between February 2025 and January 2026:

- Academic and practical conference “Russian war against Ukraine: Transformations of social institutions and practices” (National University of Kyiv-Mohyla Academy, Kyiv, 24 February – 7 March 2025);
- Student and Postgraduate Academic Conference of the Department of Sociology “Ukrainian society and the challenges of the russian–Ukrainian war” (National University of Kyiv-Mohyla Academy, Kyiv, 28 February 2025);
- Sesiunea Națională de Comunicări Științifice "Ecouri din Social 2025," Babeș-Bolyai University (Cluj-Napoca, Romania, 10 May 2025);

- XV International Scientific and Practical Conference “Sociology, social work and social security: Regulation of social problems” (Lviv, 15–16 May 2025);
- International Scientific and Practical Conference "Interdisciplinary expertise for the recovery and development of Ukraine" (National University of Kyiv-Mohyla Academy, Kyiv, 5 June 2025);
- Social Simulation Conference 2025, Delft University of Technology (Delft, the Netherlands, 29 August 2025);
- XVIII All-Ukrainian Academic Conference “Sociology and modern social transformations,” Taras Shevchenko National University of Kyiv (Kyiv, 10 November 2025);
- International Graduate Student Symposium “New Perspectives in Ukrainian Studies: Transnational, Transcultural, and Translocal Insights,” University of Toronto (Toronto, Canada, 24 January 2026).

Publications. The main scientific results of the dissertation are published in three articles, all published in Ukrainian professional scientific journals of Category B. The approbation of the dissertation materials is attested by three publications in conference proceedings.

Integration with the research programs, grants and themes. The dissertation was prepared within the research topic *"Sociocultural Transformations and Dynamics of Social Inequalities in Ukrainian Society"* (state registration number 121U112229), conducted at the Department of Sociology of National University of Kyiv-Mohyla Academy, during the period from July 2020 through December 2025.

Practical implications of the research findings. The findings can inform state policy on organizational resilience under wartime conditions and post-war reconstruction. The central result, the institutional paradox, marks a concrete policy limit. Government support sustains organizations up to a point. Beyond it, the same regulatory and mobilization burden begins to suppress the self-organizational adaptation on which survival also depends. Policy should treat this limit as a planning constraint, not assume that more state provision is always better.

The analysis also identifies three viability thresholds: military attrition, institutional capacity, and network connectivity. These can serve as early-warning indicators for policy monitoring. Because network fragmentation, not direct threat exposure, is the proximate cause of organizational death in the model, measures that preserve ties between organizations may matter more than measures protecting individual ones.

For post-war reconstruction, the pattern of resilience without adaptation carries a warning. Material infrastructure recovers once the threat recedes, but solidarity capital, the stock of trust and willingness to cooperate, is consumed by the activation adaptation requires and does not return on its own. Reconstruction that rebuilds only physical capacity may leave unrepaired the social fabric on which future adaptation depends. Decentralized configurations outperformed centralized ones at every level of government capacity, suggesting that distributed coordination is a more reliable basis for resilience than central direction.

The findings are also useful to civil-society organizations, volunteer initiatives, and business associations. Across all tested configurations, the self-organizational pathway outperformed the formal pathway. This supports continued investment in trust-based partnerships and voluntary coordination, not treating them as temporary substitutes for formal institutions. The dispositional character of adaptation, with prosocial orientation mattering more than crisis severity, suggests that the capacities carrying organizations through a shock are built beforehand, not improvised during it.

For researchers, the dissertation offers reusable tools. The eight-criterion assessment of when agent-based modeling is appropriate and the validation-method selection framework covering 76 scenarios can guide other modeling studies in the social sciences. The inventory of 27 empirically grounded mechanisms of organizational adaptation provides an empirical basis for further computational work. The model can be reused or extended for monitoring and scenario analysis in later research. These tools can also serve as teaching material in graduate courses on computational social science, agent-based modeling, and the sociology of war.

Structure and Scope of the Dissertation. The dissertation consists of an introduction, six chapters, conclusions, a list of references, and six appendices. The total volume is 379 pages, of which the main text occupies 178 pages. The reference list contains 176 sources. The dissertation includes 24 figures, 17 tables, and 6 appendices.

Chapter 1 establishes the theoretical framework, distinguishes sustained warfare from bounded disasters, presents the crisis-agency framework, and specifies the organizational and self-organizational pathways.

Chapter 2 specifies the Ukrainian wartime environment as a complex system, develops a six-phase periodization consolidated into three regimes (crisis, protracted adaptation, consolidation), and characterizes how each pathway operated after the invasion.

Chapter 3 reports the interview study and the CAWI survey, identifies 27 mechanisms (11 through adbuctive analysis), classifies them by pathway, and provides population-level parameter distributions.

Chapter 4 describes the developed agent-based model (38 behavioral rules from six established ABMs), justifies the use of ABM as the research method, and describes the model per the Overview, Design concepts and Details (ODD) protocol.

Chapter 5 validates the model through mechanism validation, sensitivity analysis, four-layer calibration, and pattern-oriented validation against 43 criteria across eight domains.

Chapter 6 reports computational experiments in four batteries: mechanism exploration, counterfactual scenarios, complex systems analysis, and robustness testing.

Data and code availability. All the model's code, data, and scripts needed to reproduce the computational results reported in this dissertation are openly available at https://doi.org/10.5281/zenodo.20787850.

CHAPTER 1

THEORETICAL FRAMEWORK

This chapter argues that the full-scale russian invasion of Ukraine requires a theoretical framework that classical sociology does not provide: one that can theorize two qualitatively different mechanisms of social coordination operating simultaneously on the same finite social fabric, competing with each other, and suppressing each other beyond identifiable thresholds.

The chapter establishes what makes sustained warfare different from bounded disasters, then shows why existing frameworks cannot name the resulting problem, introduces the crisis-agency framework as the tool that can, and specifies the internal machinery of the two pathways through institutional theory, network theory, and supporting frameworks.

1.1. Sustained Warfare as Social Disruption

Establishing how sustained warfare differs from bounded disasters begins with the prior question of how the invasion is classified in sociological terms. Britton (1986) classified disruptive events along three dimensions: the number of people affected, the breadth of population involvement, and the severity of disruption to the social system. An accident is localized and produces no disruption to broader social structures; an emergency involves a wider area but leaves the overall social structure intact; a disaster produces a widespread breakdown in established social processes, routines, and institutions (Britton, 1986). The full-scale invasion exceeded all three thresholds: it affected the entire Ukrainian population, destroyed physical and social infrastructure across the country, and disrupted every major domain of social life simultaneously. Britton’s central point is that disaster is a social product, and its severity is determined as much by the organizational capacities and prevailing understandings of the affected society as by the scale of the external threat.

The essential question for this dissertation is what makes the disruption produced by sustained warfare qualitatively different from that of bounded disasters such as earthquakes, floods, or terrorist attacks. The answer lies in the social fabric: the shared medium of material resources, routine practices, and institutional channels on which both formal and informal coordination depend. In bounded disasters, this fabric is strained but survives. In the multi-organizational response to the World Trade Center disaster, organizational improvisation operated through pre-existing institutional structures, professional identities, and trust relationships that remained functional throughout the response (Wachtendorf, 2004). However, in multiple post-disaster recovery cases, communities recovered through networks that the disaster had disrupted but not destroyed (Aldrich, 2012). In both cases, the fabric survived the event and could be used for recovery. This dissertation argues that sustained warfare is different: it damages the fabric itself, in ways that bounded disasters do not.

Sustained warfare differs from bounded disasters in a further respect: the disruption is produced by a deliberate enemy. Unlike natural disasters or pandemics, the russian state continuously adapts to exploit the vulnerabilities that emerge during the response (Pugachova, 2025a). The disruption is not a fixed problem to be solved but an evolving strategic challenge with no identifiable endpoint.

Materially, the social fabric consists of physical infrastructure, workforce, energy, and communications. These are degraded continuously, not once. Continuous degradation matters because latent vulnerabilities embedded in interdependent systems propagate failure across scales: one component breaks, others follow (Pescaroli & Alexander, 2016, building on Holling’s panarchy theory). When vulnerabilities align across multiple scales, a single trigger can set off a sequence of failures across energy, transportation, communications, healthcare, and economic systems, with each failure making the next more likely. Under sustained warfare, an enemy deliberately targets these vulnerabilities, and the cascading does not end with the initial trigger. Infrastructure is struck, partially restored, and struck again; the workforce is mobilized, partially replaced, and mobilized again.

The routine dimension of the social fabric, the everyday practices through which organizations get work done, is disrupted as well. Bevzenko (2018) described this through the concept of habitual crisis, in which established practices of social interaction collapse, previously adequate behavioral patterns stop working, and people and organizations lose the reference points they relied on for everyday coordination. In a bounded disaster, new routines can form and stabilize within weeks or months (Wachtendorf, 2004). Under sustained warfare, the conditions keep changing: routines that worked in 2022 (immediate displacement, basement operations) stopped working in 2023 (energy attacks required different responses), and those stopped working in 2024 (drone warfare, intensified mobilization). These routines do not stabilize long enough for new patterns to become reliable.

The institutional dimension, formal rules, channels, and authority structures within which organizations operate, is damaged by the state's own response to the crisis. Calamities (famines, pestilences, wars, and revolutions) tend to produce governmental centralization (Sorokin, 1942). State regulation expands, civil liberties are restricted, and bureaucratic control grows. Makeiev (2022) described this more precisely through his concept of the emergency institutional state. The state and the army monopolize legitimate violence, while other institutions lose functional capacity due to material, financial, and organizational damage. Under martial law, the state intensifies regulation, taxation, mobilization, and compliance demands because the war requires resources. But every act of intensification draws on the same social fabric that organizations need for informal coordination. Makeiev (2024), drawing on Marx, Schmitt, and Agamben, identified this as a defining feature of states of exception: emergency measures adopted in response to a crisis generate new contradictions of their own. Makeiev identified the institutional dimension of emergency as the least theoretically developed area in the field.

Disruption produces contradictory social effects. Sorokin's law of polarization captures this. Calamities (Sorokin's term, covering wars, revolutions, famines, and pestilences) simultaneously push one portion of the population toward moral degeneration and another toward ethical renewal and solidarity (Sorokin, 1942, p. 13). The wartime pattern documented by Ukrainian monitoring studies is consistent with this prediction. Interpersonal and institutional trust rose sharply after the invasion (Chepurko, 2025). Centrifugal forces operate along multiple fault lines (Reznik, 2024).

This dissertation argues that the deeper consequence of sustained warfare, and the one that existing frameworks do not address, is that the social fabric through which these processes operate (the networks, routines, and institutional channels) is itself being degraded. Whether and under what conditions this degradation becomes self-reinforcing, and under what conditions recovery is possible, are questions that the rest of the research is designed to answer.

Ukrainian sociologists working in the field of the sociology of emergencies have documented these processes extensively, and this dissertation builds on their work by moving from documentation to explanation. This dissertation defines social disruption as an environmental shift of sufficient magnitude to destabilize the institutional conditions on which organizational functioning depends, forcing organizations to modify their goals, structures, resource strategies, or relational configurations to survive.

The resulting situation is one of higher-order complexity (Pugachova, 2025a). Societal endurance is produced and eroded through nonlinear interactions that linear causal models cannot capture. Organizational-level properties such as adaptability and resilience are emergent, arising from interaction patterns among participants rather than from the attributes of any single actor. A distinction between restricted and general complexity (Byrne, 1998, drawing on Morin, 2008) clarifies the challenge. Restricted complexity treats complex phenomena as the product of interactions among simple components, while general complexity treats emergence, phase transitions, and self-organization as irreducible properties of the system. The crisis-agency framework draws on complexity theory. It uses concepts such as phase transitions, self-organization, and bifurcation to describe how social coordination changes during a crisis. The dissertation operationalizes these concepts through agent-based modeling, which sits closer to the restricted end of Byrne's spectrum: it makes the theoretical claims testable by simulating interactions among agents following specified rules. Computational experiments can identify the conditions under which specific patterns (mutual suppression, threshold effects, regime transitions) appear or fail to appear. They do not claim to reproduce emergence from first principles. The existing structure-agency tradition faces a different problem: it cannot see the competing pathways at all.

1.2. Limitations of Existing Frameworks

Consider a manufacturing firm in Dnipro in the second year of the full-scale invasion. The firm has several dozen employees. The state sends mobilization summons for some of them: formal law, military commissariat, and legal penalties for non-compliance. The same firm has been running an informal supply chain to a frontline brigade through the director’s personal contacts, using company vehicles and some of those same employees on weekends: no mandate, no contract, organized through trust. Both activities serve the war effort, and both draw on the same people, the same vehicles, the same hours. When the state mobilizes employees via military conscription, the firm loses production capacity and the people who were running the volunteer logistics. When the firm invests its director’s time and vehicles in the informal supply chain, it reduces the output that generates the tax base for formal military funding.

This is not a coordination failure that better management could fix. The state cannot stop mobilizing because it needs soldiers. The firm cannot stop running its supply chain because the formal logistics system does not reach that brigade. Both pathways are doing what the war requires. They compete because the resources they draw on are finite. The question this section addresses is whether existing sociological frameworks can explain what is happening in cases like this. They cannot, and the reasons are informative.

The disaster research tradition has observed parts of this problem in other settings. Quarantelli (1997) separated agent-generated demands (caused by the disaster itself) from response-generated demands (caused by the response efforts). He observed that "if the focus is on the effects of a disaster agent, this misses the point that even more important problems can and do arise when managing the response" (Quarantelli, 1997, p. 42). This is the right observation: the formal response can itself create new problems. But Quarantelli treated response-generated demands as a planning failure that better-prepared managers could, in principle, avoid. He did not ask whether the formal response might structurally compete with informal adaptation for the same resources, because his framework does not treat formal and informal coordination as separate pathways operating on the same social fabric.

The World Trade Center disaster response documented the opposite of competition. Wachtendorf (2004) showed that formal and informal coordination worked together. Planning and improvisation were symbiotic. She showed that even creative improvisation, where no plan existed, was shaped by prior organizational cultures, professional knowledge, and shared repertoires (see also Kendra and Wachtendorf, 2003). But this symbiosis held under specific conditions: the response was bounded in time, the responding organizations were separate from the affected ones, resources were not contested between the planned and improvised elements, and there was no enemy adapting to defeat the response. When Wachtendorf and Kendra (2005) later analyzed Hurricane Katrina, they found the formal response actively blocking informal adaptation: FEMA trucks waited for instructions instead of unloading, offers of transport were turned down, and available resources sat idle. They described this as a failure of collective sense-making, but the pattern went beyond that. Formal coordination was consuming resources and time that informal adaptation needed.

Comparative disaster research showed that the social fabric is finite and can be competed for. Aldrich (2012), comparing recovery across four major disasters, found that in post-Katrina New Orleans, well-organized neighborhoods used their coordination capacity to block FEMA emergency housing, pushing temporary shelters into less organized communities. Aldrich observed that social ties can function as "a double-edged sword (Aldrich and Crook 2008) or a Janus-faced resource (Szreter 2002)" (Aldrich, 2012, p. 21). In New Orleans, "this resistance slowed down the overall recovery, since planners had to expend resources and energy to find more amenable neighborhoods, ones that often had lower levels of social resources and resistance" (Aldrich, 2012, p. 54). But Aldrich documented this competition between communities, not between two coordination modes within the same organization facing the same crisis.

The institutional logics perspective (Thornton, Ocasio, and Lounsbury, 2012) offers a more developed framework for this kind of situation. It describes societies as interinstitutional systems composed of multiple institutional orders (state, market, community, profession, family, religion, corporation), each carrying its own logic of action, its own source of legitimacy, and its own basis of authority. Actors embedded in multiple orders simultaneously experience contradictions that can become sources of institutional change. The framework has a developed theory of how change happens: actors transpose schemas from one institutional order to another, recombine elements of different logics, and produce new institutional arrangements through what Thornton and colleagues call institutional entrepreneurship.

Applied to the mobilization case, the framework can identify the two logics at work. The state logic says: comply with mobilization, pay wartime taxes, follow martial law regulations. The community logic says: help the brigade, support your neighbors, use your resources for informal defense. Both are legitimate, both are available to the director, and the director knows what both require. Thornton and colleagues showed that actors negotiate such situations through interpretation: which logic is most salient, which identity is activated, which framing guides the decision. The framework can even predict institutional change: as contradictions between state and community logics intensify, actors recombine elements from both, producing new hybrid arrangements.

But the mobilization problem is not a problem of interpretation. The director does not need help deciding which logic to follow. She needs to decide which of her employees will go to the commissariat and which will drive supplies to the front. The competition is not cognitive but material: both logics need the same person who can only be in one place. Institutional logics theory handles what happens when different institutional orders compete for the actor's attention and identity. It does not handle what happens when they compete for the finite material base the actor needs to operate at all. The framework assumes that the institutional orders themselves persist as stable background structures while actors move among them. Under sustained warfare, the institutional orders are not a stable background. Their material base is being consumed by the crisis: workforce mobilized, infrastructure destroyed, routines overwritten, networks thinned by displacement.

The dominant structure-agency tradition in sociology cannot describe this competition either. Giddens's (1984) structuration theory treats structure and agency as two aspects of a single recursive process. Formal institutional coordination and informal network-based coordination, in his framework, are not separate forces that can work against each other. Sewell (1992) corrected Giddens by bringing material resources into the definition of structure and by introducing the concept of intersecting structures. In his account, different structural complexes can claim the same resources, and "structures are at risk, at least to some extent, in all of the social encounters they shape" (Sewell, 1992, p. 19). Sewell can describe the mobilization case as two intersecting structural complexes claiming the same employees. But his framework cannot predict when this competition becomes destructive because it lacks a concept of thresholds. It cannot account for the asymmetry between a pathway backed by coercive power and one backed only by trust and solidarity. And it cannot describe the depletion: a mobilized employee is not being interpreted differently by two structures; that person is removed from the pool both pathways drew on.

The morphogenetic approach corrects Giddens from a different direction. Archer (1995, 2017) separates structure and agency into sequential temporal cycles. In her more recent work, she frames the central dynamic as competition between morphogenesis (positive feedback that changes social form) and morphostasis (negative feedback that restores it) (Archer, 2017, p. 3). But this competition is between change and stability. In the Ukrainian case, both pathways are mechanisms of change, and both are forms of adaptation to the same war. Archer's vocabulary has no space for two change processes suppressing each other, because all adaptation falls on the same side of her morphogenetic divide.

These frameworks converge on the same gap: they can see structures intersect, logics compete, and stability give way to change, but none can describe two adaptive pathways depleting a shared resource pool. What is needed is a framework that names the two coordination pathways, identifies the shared social fabric they depend on, and predicts when cooperation gives way to competition. The crisis-agency framework, developed within the Ukrainian sociology of emergencies, provides these tools.

1.3. Crisis-Agency Framework

The crisis-agency framework, developed by Bevzenko (2022) within the Ukrainian sociology of emergencies and the complexity paradigm, provides the tools the mobilization case requires: it names the two coordination pathways, identifies the social fabric on which both depend, and predicts when cooperation gives way to suppression.

The framework requires a precise definition of institutions. North defines them as "the humanly devised constraints that structure political, economic and social interaction" (North, 1991, p. 97). They consist of both informal constraints (sanctions, taboos, customs, traditions, and codes of conduct) and formal rules (constitutions, laws, property rights). This formal/informal distinction serves as the criterion to classify behaviors into the two pathways of the crisis-agency framework.

The framework's central claim is that social order is produced and modified through two qualitatively different mechanisms. The organizational mechanism operates through formal institutions: laws, regulations, executive orders, contractual obligations, and the sanctioning power of the state. Its logic is top-down. Authorized agents modify formal institutional rules through established channels of power. The self-organizational mechanism operates through informal institutions: spontaneous practices that spread via interpersonal and inter-organizational networks, gradually establishing new behavioral standards that may complement, modify, or replace formal rules. Its logic is bottom-up and lateral. Innovation arises from local interaction and spreads through network ties without central coordination.

The two mechanisms are not two types of actors; they are two pathways through which the same actor can produce social change. A government ministry operates through the organizational mechanism when it issues regulations, but through the self-organizational mechanism when its employees develop informal workarounds that spread to other ministries. Volunteer groups operate through the self-organizational mechanism when they improvise logistics, but through the organizational mechanism when they formalize their procedures and seek legal registration.

Both mechanisms operate on the same actors and through the same social fabric. Bevzenko (2018) defines the social fabric (соціальна тканина) through three components: the density of social networks, the stability of network interactions, and the capacity of society's members to satisfy their needs through these interactions. The fabric is not a metaphor. It is composed of measurable elements on which both mechanisms depend. Formal coordination operates through it: laws need administrators, regulations need compliance agents, and mobilization needs communication networks. Informal adaptation operates through it equally: trust requires repeated interaction, partner search requires a connected community, and mutual aid requires network density.

The balance between the two mechanisms shifts with institutional stability. Bevzenko (2022) identifies three configurations. In stable environments, individuals adapt within established rules without seeking to change them, and the organizational mechanism dominates while the self-organizational mechanism remains latent. Under moderate instability, both mechanisms are active and may cooperate: formal authorities drive reforms from above while informal activism pushes for change from below. Under high instability, when formal institutions lose functional capacity, informal mechanisms become dominant: self-organized groups, improvised practices, and trust-based networks replace the institutional channels that can no longer coordinate action.

The framework predicts that under conditions of institutional disruption, the two mechanisms do not merely coexist; they can suppress each other. When the organizational mechanism intensifies its demands through emergency legislation, increased taxation, and expanded mobilization, it can suppress the self-organizational mechanism by extracting resources, constraining autonomy, and imposing compliance requirements that leave organizations with insufficient capacity for informal adaptation. When the self-organizational mechanism generates effective responses outside formal channels, it can undermine the organizational mechanism by demonstrating that institutional compliance is unnecessary. This mutual-suppression prediction generates the central research question: under what conditions does each pathway sustain or undermine organizational survival, and where is the threshold between the two regimes?

The framework draws on two additional concepts that describe how the transition between configurations occurs. Bevzenko (2018) proposed social tension as a parameter of phase transitions between stability, constructive-adaptive instability, and destructive instability. These transitions are threshold effects, not increments along a continuous scale. The concept of habitual crisis (Bevzenko, 2018) describes the experience that arises when established practices of social interaction collapse: a sense of disorientation, loss of reference points, and inability to rely on previously adequate behavioral patterns. For organizations, a habitual crisis is the moment when existing routines, models, and planning assumptions stop working, and the search for alternatives becomes urgent.

With the framework defined, the remaining terms require specification. Organizations are the actors through which both pathways operate. Following Scott and Davis (2016), this dissertation defines **organizations** as social structures created by individuals to support the collective pursuit of specified goals, consisting of participants whose contributions must be elicited and coordinated, embedded in wider material-resource and institutional environments. Organizational decision-making operates under bounded rationality (March and Simon, 1958): formalized procedures compensate for cognitive limits, and when routine programs prove inadequate, search behavior is triggered, but search is typically local, incremental, and biased by existing frames. As uncertainty increases, organizations require increasingly adaptive approaches (Stacey, 2002). In conditions approaching chaos, self-organizing responses take precedence over optimization (Pugachova, 2025a).

Organizations require legitimacy, which Scott (2014) specifies through three pillars: legal compliance (regulative), moral endorsement (normative), and conformity to shared cognitive templates (cultural-cognitive). These three sources of legitimacy are relevant because the organizational and self-organizational pathways draw on different ones. Formal compliance generates regulative legitimacy. Informal adaptation generates normative and cultural-cognitive legitimacy through demonstrated competence and shared values.

This dissertation defines **organizational adaptation** as the process by which organizations modify their goals, internal structures, resource strategies, relational configurations, or domains of activity in response to environmental change, whether through deliberate strategic action or emergent self-organizational processes, producing a changed alignment between the organization and its environment. Adaptation is not assumed to succeed. Organizations may adapt in ways that prove maladaptive.

This dissertation uses the term **mechanism** in the sense established by analytical sociology. Following Machamer, Darden, and Craver (2000), Hedström and Bearman define a mechanism as "a constellation of entities and activities that are organized such that they regularly bring about a particular type of outcome" (Hedström and Bearman, 2009, p. 5). Mechanisms of organizational adaptation are recurrent causal sequences connecting environmental conditions to organizational responses and their aggregate consequences.

The organizational and self-organizational pathways require operational definitions rigorous enough to classify specific behaviors. North’s formal/informal separation provides the criterion. Organizational adaptation follows the **organizational pathway** if it is mediated by formal institutions: written laws, regulations, contractual obligations, and formally sanctioned enforcement. It follows the **self-organizational pathway** if mediated by informal institutions: norms, conventions, peer-to-peer trust, voluntary participation, and reputation-based sanctions. A **bridging** behavior either has a formal and an informal channel working in parallel or shifts between pathways depending on circumstances. Filing tax returns is organizational: mediated by formal regulation, with non-compliance formally sanctioned. Volunteering vehicles to a military unit through a personal network is self-organizational: mediated by interpersonal trust, with no formal sanction for non-participation. The Dnipro manufacturing firm from the preceding section does both simultaneously: it files wartime tax returns through the organizational pathway and runs a supply chain to a brigade through the self-organizational pathway. Cooperating with a regional government to host displaced employees is bridging: a formal program and an informal moral expectation coexist, and organizations use one or both depending on local conditions.

1.4. Organizational Pathway

The organizational mechanism operates through formal institutions. These include laws, regulations, executive orders, contractual obligations, and the state’s sanctioning power.

Institutional theory begins with an observation that runs against efficiency-centered assumptions: many formal organizational structures do not arise from the technical demands of production. Meyer and Rowan (1977) argued that organizations incorporate rationalized institutional rules as structural elements because conformity confers legitimacy, access to resources, and improved survival prospects. Formal structures function as myths: widely shared accounts of how organizations should be constituted, carrying normative force independent of any demonstrated connection to performance. When conformity to institutional rules conflicts with the demands of actual work, organizations respond by decoupling: maintaining formal structures for external display while adjusting their internal operations. Under wartime conditions, this generates a prediction: organizations should display formal compliance with state demands while adapting their actual practices, and the gap between display and operation should widen as disruption intensifies. The Dnipro manufacturing firm illustrates this pattern: it maintains formal compliance with wartime regulations while reorganizing its actual operations around the informal supply chain that keeps the brigade supplied.

Structural convergence under crisis follows predictable patterns. DiMaggio and Powell (1983, p. 150) identified three mechanisms through which organizations within the same field converge on similar structures. Coercive isomorphism arises when organizations are pressured to conform by other organizations they depend on, most often the state. Mimetic isomorphism emerges when organizations face uncertainty and model themselves after others they perceive as successful. Normative isomorphism stems from professionalization and the spread of shared cognitive frameworks through professional networks and training. Under wartime conditions, coercive isomorphism should dominate as the state intensifies regulatory and mobilization demands. Organizations should converge on similar compliance patterns regardless of how different they were before the invasion. The Dnipro firm's compliance template (submitting to mobilization, filing wartime tax returns, complying with martial-law reporting) is identical to that of every other registered enterprise in the region, regardless of sector, size, or pre-invasion strategy.

Organizations do not respond passively to institutional pressures. Oliver (1991) identified a repertoire of strategies ranging from acquiescence through compromise and avoidance to defiance and manipulation. The chosen strategy depends on the multiplicity of institutional demands, the organization's dependence on the source of pressure, and the perceived legitimacy of the requirements. Under sustained wartime pressure, the distribution of strategic responses should shift toward avoidance and defiance as conformity costs grow. But institutional theory does not specify the threshold beyond which conformity ceases to be adaptive. In the Dnipro case, this shift is concrete. The director consented to an early mobilization warrant but progressively moved toward seeking exemptions and quiet negotiation as the firm lost a critical mass of skilled employees.

Institutional theory raises a related paradox: if institutions shape the interests and identities of the actors who inhabit them, those same actors should be unable to mobilize to change institutional arrangements. Seo and Creed (2002) resolved this through a dialectical framework in which contradictions accumulate within and between institutional systems, gradually transforming embedded actors into agents of change. Under sustained warfare, the contradictions are material: the state simultaneously needs organizations to produce economic output (which requires retaining employees and maintaining operations) and to provide military manpower (which requires extracting employees and absorbing organizational resources). These contradictions intensify over time and are one of the forces driving the shift from manageable tension to mutual suppression between the two pathways.

Structural inertia reinforces the organizational pathway's hold on organizations that have invested in formal compliance. Hannan and Freeman (1984) proposed that inertial pressures are strong enough that organizational diversity is produced mainly by selection rather than by individual adaptation. Internally, sunk costs, information constraints, and political equilibria resist change. Externally, legal regulations, exchange relationships, and legitimacy costs constrain restructuring. Inertia is both a precondition for and a consequence of selection: forms fitting prevailing conditions survive, those that do not are eliminated. The specialist-versus-generalist trade-off is relevant here. Fine-grained environments (rapidly changing conditions) favor specialists because the costs of restructuring exceed the benefits. Coarse-grained environments (long-duration states) favor generalists because failure to adapt to a persistent state can be fatal. Two predictions follow. First, structural inertia should constrain organizational change under wartime conditions, but whether inertia protects or kills should depend on the crisis phase: rigid structures may protect during the initial shock but become dangerous during prolonged attrition. Second, wartime conditions should favor the rapid founding of many small organizations (the r-strategy in ecological terms, which suggests favoring quantity over investment per unit) over fewer, resource-intensive entries. The Dnipro firm illustrates the phase-dependent character of inertia. In 2022, established routines and supplier relationships allowed the firm to keep operating through the initial shock. By 2024, those same structures constrained its ability to reorganize around a depleted workforce.

The organizational pathway, seen through these frameworks, operates as a self-reinforcing system. Organizations adopt formal structures for legitimacy, converge under coercive pressure, respond strategically when costs rise, accumulate contradictions that push toward change, and are held back by inertia. Under sustained warfare, each of these processes intensifies: the state demands more compliance, compliance costs grow, contradictions deepen, and inertia makes it harder to shift course. The organizational pathway's grip on the social fabric grows stronger even as the costs of that grip increase.

1.5. Self-Organizational Pathway

The self-organizational pathway operates through informal institutions: norms, trust, voluntary participation, and reputation-based sanctions. But informal institutions do not float in the air. They need a material infrastructure to work through, and that infrastructure is the network of ties connecting organizations and individuals to each other. Without ties, there is no channel for trust to operate through, no route for information to travel, no way for improvised practices to spread across a population.

Inter-organizational ties carry different resources and operate through different mechanisms. Bonding ties are dense connections within homogeneous groups: family, neighborhood, professional community. Coleman (1988) showed that dense closure within such networks enables enforceable norms without formal contracts, because everyone knows everyone and reputational sanctions work. Bridging ties connect actors across group boundaries. Burt (1992) showed that actors positioned at structural holes between otherwise disconnected clusters gain access to wider and earlier information and influence its diffusion. Linking ties are vertical connections between civic organizations and formal state institutions (Szreter and Woolcock, 2004). They channel resources and policy demands across the vertical distance separating civil society from the state.

Comparative disaster research demonstrated that what matters for recovery is the mix of tie types, not the absolute level of any single one (Aldrich, 2012). Communities combining dense bonding and active bridging recovered fastest. The mix on which an organization can draw is therefore a structural condition for self-organization, alongside the trust relations that activate the ties and the network structure that determines whether self-organization can scale.

Ties are the channels, but what flows through them is trust. A tie is just a connection. Whether anything useful moves through it depends on whether the parties trust each other to act in good faith. The director of the Dnipro manufacturing firm does not have a contract with the brigade commander. She has a personal relationship built through repeated interaction and a shared commitment to the same cause. Trust is what turns a tie into a functioning partnership.

Trust under crisis does not work the same way as trust under stable conditions. Hung et al. (2004, p. 4) identified three routes through which trust forms. Under stability, the peripheral route dominates: people rely on reputation, professional credentials, and role-based cues. Habitual trust, built through years of positive contact, operates automatically. Both break down under sustained warfare. Institutional credentials lose meaning when the institutions themselves are disrupted. Habitual trust assumes a continuity that war removes: people are displaced, organizations dissolve, and networks are thinned. What remains is the central route: direct personal knowledge from repeated interaction. It is slow, demanding, and cannot be scaled quickly. But it produces the most robust partnerships, because it is grounded in experience rather than assumption. The Dnipro director's relationship with the brigade commander illustrates this. There is no institutional credential underwriting the partnership, nor is there a professional registry that attests to either party. The trust between them was built through repeated direct contact over the months when the supply chain was being established, and it cannot be transferred to a successor on either side without that process repeating from the beginning.

Trust also changes what people look for in a partner. Larson (2012) identified two dimensions of partner selection: compatibility (shared values, ideology, worldview) and complementarity (non-overlapping capabilities that make partners mutually useful). Under stable conditions, compatibility dominates: organizations partner with those who share their values. Under an acute crisis, urgency compresses ideological differences, and complementarity takes over: organizations partner with whoever can provide what they need right now. As conditions stabilize, compatibility filtering resumes, and partnerships formed under urgency dissolve if the partners discover they do not share enough common ground.

Whether self-organization can scale beyond individual partnerships depends on the architecture of the population-level network. Watts and Strogatz (1998) formalized the small-world property: networks that combine high local clustering (which supports trust and coordinated action within groups) with short global path lengths (which allow information to reach distant parts of the network quickly). Effective networks require both closure within groups and brokerage across groups, though no single organization can maximize both at once (Burt, 2005).

Not everything spreads the same way through a network. Centola and Macy (2007) showed that awareness of a new practice spreads efficiently through bridging ties, because a single contact is enough (simple contagion). But actually adopting that practice requires reinforcement from multiple contacts within a dense cluster (complex contagion). Knowing that another firm has reorganized its supply chain is simple contagion. Actually reorganizing your own requires coordination among your employees, suppliers, and partners, which is a complex contagion. This generates a structural prediction: below some minimum level of network connectivity, the population fragments into isolated clusters and self-organization fails regardless of how capable individual organizations are. This percolation threshold is a property of the network architecture, not of the organizations within it.

The question of how organizations actually reorganize under crisis has been addressed in disaster sociology. The DRC typology (Kreps and Bosworth, 1993) provides the classification. Established organizations carry out regular tasks (Type I). Expanding organizations take on new tasks within existing structures (Type II). Extending organizations apply existing capabilities to new domains (Type III). Emergent organizations build new structures around new tasks (Type IV). The normal structural ordering (Domain-Tasks-Resources-Activities) inverts under crisis to Activities-Resources-Tasks-Domain: organizations start doing things before anyone assigns them a role, mobilize resources to support those activities, formalize tasks around what is working, and only later define a new organizational domain. Kendra and Wachtendorf (2003) showed that this improvisation is not random. Prior preparedness, legitimate roles, and pre-existing relationships are the raw material from which creative responses are assembled. Planning forms the basis for improvisation.

The Dnipro firm is a Type III case. Its pre-invasion domain was manufacturing for civilian markets. It has not abandoned that domain, and it has not built a new structure to handle wartime logistics. Instead, it applies existing capabilities (vehicles, drivers, supplier relationships, the director's coordination capacity) to a new domain (frontline supply) that did not exist for the firm before February 2022. The structural inversion Kreps and Bosworth described is visible: the activity (driving supplies to the brigade) preceded any formal assignment of the task, the resources (company vehicles, weekend hours) were mobilized to support the activity, the task definition emerged from what was already working, and the new domain was named only retroactively.

The capacity to reorganize is not equally distributed. Teece (2007, p. 1319) identified three capabilities that determine how readily an organization can adapt: sensing (scanning for threats and opportunities), seizing (mobilizing resources to act), and reconfiguring (realigning assets to fit changed conditions). All three are constrained by path dependence: an organization's history shapes what it can sense, what resources it can reach, and how readily it can reorganize. Reconfiguration capacity is dispositional; it is built before the crisis, not improvised during it. The Dnipro firm's reconfiguration capacity may have been built before it became necessary. The director's pre-invasion contacts served as the channel to the brigade, the firm's pre-invasion flexibility enabled weekend reallocation of vehicles and personnel, and the supplier base was apparently diverse enough to substitute under wartime constraints. None of these capacities could have been improvised under fire. A firm without them would not have been able to assemble the supply chain at all, regardless of how committed its director was.

The self-organizational pathway, seen through these frameworks, operates as a layered system. Ties are the infrastructure. Trust is what activates them. The population-level architecture determines whether self-organization can scale. The DRC typology describes what reorganization looks like in practice. Dynamic capabilities specify what constrains each organization's ability to adapt. Under sustained warfare, each layer is stressed: ties are disrupted by displacement and institutional failure, trust must be rebuilt through the slow central route, the network risks fragmentation at the percolation threshold, the distribution of organizational responses shifts across crisis phases, and reconfiguration capacity becomes the boundary between survival and failure.

Chapter 1 Conclusions

This chapter developed the theoretical framework for investigating organizational adaptation under sustained warfare. It identified the central analytical problem, showed that existing frameworks cannot resolve it, introduced the crisis-agency framework as the tool that can, and specified the internal machinery of the two pathways the framework describes.

The analytical problem is direct. Two coordination pathways (organizational and self-organizational) operate on the same finite social fabric, and under sustained disruption, they can suppress each other. Disaster sociology documented pieces of this competition. Quarantelli named response-generated demands that can be more damaging than the disaster itself. Wachtendorf and Kendra showed that formal-informal symbiosis breaks down under a protracted crisis. Aldrich documented the competitive character of the social fabric. The institutional logics perspective described competing demands from different institutional orders but treated the competition as cognitive rather than material. Structuration theory, in its strongest form, described the intersection of structures but could not predict when that intersection would turn into mutual suppression. Archer's morphogenetic framework framed the competition as change versus stability rather than change versus change.

The crisis-agency framework (Bevzenko, 2022) provides the missing tools. It names the two pathways, identifies the shared social fabric on which both depend, and predicts mutual suppression under high instability. North's formal/informal institution separation provides the operational criterion for classifying behaviors into the two pathways.

Specifying the organizational pathway through institutional theory and population ecology generated several predictions. Under wartime pressure, legitimacy-driven decoupling should widen the gap between formal compliance and actual practice. Coercive isomorphism should produce convergence regardless of pre-invasion organizational differences. Strategic responses should shift from acquiescence toward avoidance and defiance as conformity costs grow. Contradictions between incompatible institutional demands should accumulate. Structural inertia should constrain change, but whether it protects or kills should depend on the crisis phase.

Specifying the self-organizational pathway through network theory, trust formation, and dynamic capabilities generated a parallel set of predictions. Trust should be rebuilt through the slow central route when peripheral and habitual routes break down. Partner selection should be driven by complementarity in the acute phase, with a shift to compatibility filtering as conditions stabilize. Below a percolation threshold, population-level self-organization should fail regardless of individual organizations' capacity. Reconfiguration capacity should be dispositional, built before the crisis rather than improvised during it.

These predictions specify what the theory expects from each pathway individually. They do not specify how the pathways interact, where the threshold between cooperation and suppression lies, or what organizational and population-level outcomes result from their competition. These are the questions the dissertation addresses through empirical investigation and computational experimentation. The following chapter grounds the framework in the Ukrainian institutional case. It addresses the pre-invasion baseline, the emergency state, and the wartime changes that set the conditions for pathway competition.

CHAPTER 2

THE ENVIRONMENT OF ADAPTATION: UKRAINE AFTER THE FULL-SCALE RUSSIAN INVASION

The preceding chapter established the theoretical framework: two qualitatively different mechanisms of social coordination operating simultaneously under sustained warfare, with the crisis-agency framework specifying their interaction and predicting mutual suppression beyond identifiable thresholds. These predictions are abstract. They must be situated in a specific empirical context to become testable.

This chapter applies the crisis-agency framework to the full-scale russian invasion of Ukraine. The analysis establishes the type of emergency the invasion created, describes the spatial, economic, and demographic conditions under which organizations operate, and traces the temporal structure of the crisis across six phases and three regimes. Both the organizational and self-organizational adaptation pathways are then documented, and the chapter assesses which theoretical predictions the descriptive evidence supports.

2.1. Institutional Environment

The full-scale invasion reduced the functional capacity of Ukraine's formal institutions to the point where they could no longer sustain social coordination on their own. The coordination load shifted onto informal mechanisms. Volunteer networks, civic groups, local self-governance, and the interpersonal ties that Ukrainian society had built over the preceding decade absorbed what the formal system could no longer carry. This is the pattern Makeiev (2022) identifies as the emergency state, in which the state and the army retain their monopoly on legitimate violence while other institutions lose functional capacity. The measures taken to restore that capacity tend to generate new contradictions of their own (Makeiev, 2024). Three lines of evidence document this pattern in the Ukrainian case: the surge of social trust in the war's first months, the simultaneous decline in formal institutional capacity, and the fragmentation pressures that now threaten the informal mechanisms that absorbed the load.

Informal coordination depends on social trust, the readiness of people to rely on others outside their immediate circle. When formal institutions weaken, whether that trust can substitute for institutional channels determines whether social coordination is maintained or lost. Three monitoring instruments track this capacity through different facets: confidence in fellow citizens, declining cynicism toward public institutions, and identification with the broader civic community. Within weeks of the invasion, all three shifted sharply in the same direction.

Trust in neighbors rose by 13 percentage points, trust in fellow community members by 14, general interpersonal trust by 9, and trust in acquaintances by 6, comparing October 2021 with June 2022 (Chepurko, 2025, p. 61). The Cynicism scale, an adapted version of the MMPI measure, captures pervasive institutional distrust and has been part of the Institute of Sociology's monitoring since 1992. The share of the population classified as cynical dropped from 68.1% to 22.5% in a single year, the largest synchronous decline across all regions in the monitoring history (Reznik, 2023, pp. 64–65). Civic identification as a citizen of Ukraine rose from 62.6% before the invasion to 79.7% in December 2022 and remained at 79.5% a year later (Stepanenko, 2024, p. 151). A society whose societal community had been considered fragmented produced an immediate, broad-based solidarity response.

This transformation is sociologically remarkable because everything in Ukraine's pre-invasion profile pointed in the opposite direction. In a comparative study of 27 countries across five regime types, Ukraine ranked near the bottom of the organizational membership scale: 0.59 memberships per person (Howard, 2003, p. 168). Only Bulgaria scored lower. The post-authoritarian mean was 1.86, the older democracy mean was 2.60. Three factors explained the weakness across the post-communist region, and all three applied to Ukraine with particular force. Decades of coerced participation in communist-era organizations left citizens deeply averse to joining anything resembling a formal collective. Dense informal friendship networks, inherited from the Soviet practice of solving everyday problems through personal connections rather than institutional channels, substituted for formal civic participation. Post-communist disappointment, the gap between the expectations of 1991 and the realities of oligarchic governance and institutional dysfunction, eroded whatever residual trust in collective action might have survived the first two factors (Howard, 2003, p. 121). The Institute of Sociology's longitudinal monitoring confirmed the persistence of this pattern year after year: high anomic demoralization, chronically weak institutional trust, and a population that solved its problems informally rather than through organizations (Reznik, 2023).

These formal-membership indicators are accurate, but they miss the self-organizational capacity that developed outside formal structures. The Revolution of Dignity (2013–2014) established a pattern of heterarchical, peer-to-peer coordination that deliberately rejected top-down command (Wynnyckyj, 2020). The volunteer movement that emerged during the Donbas war after 2014 provided direct experience with civilian-driven military support and humanitarian logistics. The decentralization reform created 1,469 financially autonomous local communities with their own budgets and administrative capacity. These precedents showed that Ukrainians had practiced self-organization under crisis conditions for a decade before the full-scale invasion, even though the formal indicators of organizational membership remained weak. The trust surge of 2022 did not emerge from nothing. It activated capacities that formal civic participation measures had not captured.

In pre-invasion Ukraine, formal institutional rules were widely distrusted, and informal rules (personal networks, codes of mutual aid, habitual workarounds) carried the actual weight of social coordination. What the invasion disrupted was not a well-functioning formal system but a system already running on informal supplements. Within the crisis-agency framework, the organizational mechanism creates and enforces formal rules from above, while the self-organizational mechanism creates and reproduces informal rules from below, through network interaction (Bevzenko, 2020). The trust surge signaled a rapid activation of informal coordination, not a newfound confidence in formal institutions.

Ukraine’s formal institutions did not collapse under the invasion, but they entered a state of limited operationality. Tax extraction capacity declined, regular legislative and electoral processes were suspended under martial law, and by 2024, nearly half of state expenditures depended on external financing. On the informal side, volunteer participation surged from 26% to 56% (Omelianiuk et al., 2025), reinforcing the trust shift documented above. Formal capacity degraded sharply in 2022 and remained constrained through 2024, while informal coordination shifted in the opposite direction. Neither side has returned to its pre-invasion baseline.

The state survived this degradation of formal capacity because the self-organizational mechanism filled the gaps. In the first weeks of the invasion, before international humanitarian organizations arrived, newly formed civic groups and preexisting NGOs organized evacuations, supply chains, and local governance on their own (Konrad et al., 2024). Volunteer networks provided last-mile delivery during energy blackouts, served as substitutes for absent state services in liberated territories, and built a parallel logistics system for the military. By 2023, 56% of citizens had participated in volunteering, compared with 26% before the full-scale invasion (Omelianiuk et al., 2025). Formal institutions continued to operate, but they could not sustain society’s adaptive response without this informal supplementation. Limited operationality, in practice, means that formal institutions function only because informal mechanisms compensate for their deficits. The interaction between the two mechanisms, when the organizational pathway supports the self-organizational one and when it suppresses it, is the central empirical puzzle the dissertation investigates.

Solidarity dominated the initial response, but the structural conditions for fragmentation were embedded in the war from its first days. The costs of the invasion were distributed unequally: between frontline regions and the rear, between those displaced and those who absorbed them, between those who left the country and those who stayed, between those mobilized and those who were not. Reznik (2024), analyzing the 2024 monitoring data, showed that these differential costs constituted a structural recomposition of societal fault lines. The traditional geopolitical cleavage between pro-

European and pro-russian orientations largely collapsed as the invasion eliminated the social base for pro-russian identification on government-controlled territory. Yet it was not replaced by a single new axis of division; instead, multiple tensions coexist, with their relative intensity shifting across phases and across regions. As the war extended into its third and fourth years, these differential costs crystallized into measurable social divisions. By February 2025, 13% of respondents nationally reported social tensions between groups in their communities, rising to 23% in western oblasts that absorbed the largest IDP inflows. Among displaced persons, 43% cited discrimination by host communities; among hosts, 30% cited perceived inappropriate behavior by newcomers (IOM, 2025). Mobilization became the most-cited source of social conflict: 50.4% of respondents identified it as a primary driver, ahead of political and military decisions by the authorities (47.6%), the language question (45.0%), and socioeconomic inequality (44.6%) (Chepurko, 2025, pp. 73–75). In a separate expert survey, population fatigue from prolonged stress received the highest destabilization rating (3.83 out of 5) and the highest realization probability (4.03 out of 5) (Chepurko, 2025, pp. 76–77).

Civic identification remained high but began to decline from its wartime peak: from 79.7% in December 2022 to 79.5% in 2023 and 73.8% in 2024 (Stepanenko, 2024, p. 151). New fault lines appeared where the old geopolitical cleavage had been: between civilians and the military, between those mobilized and those who evade, between IDPs and host communities, and between those abroad and those who stayed. The emerging pattern is not a return to the pre-invasion cleavage structure but a transition toward a more fragmented and regionally differentiated set of tensions without a dominant axis.

This is Makeiev's emergency state in action: the institutions that should coordinate the response are themselves destabilized, and the measures taken to restore institutional capacity generate new contradictions of their own. Trust surge and fragmentation pressures are not sequential phases but concurrent processes operating at different speeds and at different social levels. Accumulated contradictions can push a society toward either deeper cohesion or fracture, depending on which actors and mechanisms dominate the transition (Bevzenko, 2025, p. 39). Whether Ukrainian society consolidates, fractures, or finds a new and more differentiated equilibrium depends on the mechanisms by which organizations and self-organized groups interact with each other and with the state. Describing those mechanisms is the task of the remaining sections.

2.2. Material Environment

The wartime environment is defined not by the magnitude of any single shock but by the compound interaction of three dimensions: the spatial distribution of threats, macroeconomic disruption and fiscal adaptation, and the displacement and partial return of the civilian workforce.

The spatial dimension evolved from fluid to static. In the first month of the invasion, russian forces occupied up to 27% of Ukrainian territory through rapid multi-axis advances that created a porous, spatially heterogeneous frontline (Kofman & Lee, 2022). Ukrainian counteroffensives contracted the occupied area to roughly 18% by late 2022. From mid-2023 onward, the war settled into positional attrition measured in meters per day rather than kilometers. The stabilization of the front, however, did not reduce the threat to the civilian rear. A sustained campaign of long-range strikes against energy, transport, and housing infrastructure meant that organizations hundreds of kilometers from the frontline faced episodic destruction as severe in its local impact as sustained combat. By December 2025, cumulative damage to the energy system alone reached $24.8 billion, with total reconstruction needs estimated at $588 billion over a decade (World Bank Group et al., 2026). The resulting threat landscape does not decay smoothly with distance from the front. Near-frontline regions experience continuous cumulative destruction. Rear regions face lower average threat but periodic high-intensity strikes that can be locally equivalent: a destroyed substation in Lviv leaves the surrounding population without power just as effectively as one destroyed in Kharkiv. This non-monotonic distribution is a distinctive feature of the Ukrainian war, and one that conventional spatial conflict models do not capture.

The economic shock was catastrophic in scale but partially contained through fiscal adaptation. GDP fell by an estimated 29% in 2022 (World Bank et al., 2024). Recovery was modest: 3.2% growth in 2024, decelerating to 1.8–2.2% in 2025 as energy destruction, labor shortages, and mobilization constraints accumulated (IMF, 2026). The resulting budgetary structure reflected near-total subordination to defense. War-related expenditures reached 36.4% of GDP in 2024, making Ukraine's military burden the highest of any country (Centre for Economic Strategy, 2025; SIPRI, 2025). Domestically generated revenue covered only 54% of total state expenditures. The remaining 46%, encompassing education, healthcare, and social protection, depended entirely on international financial assistance (Centre for Economic Strategy, 2025). The state's fiscal extraction capacity, measured by excise revenue, dropped from 3.3% to 2.2% of GDP in 2022, then partially recovered under an IMF-backed revenue mobilization framework (Bogdan, 2024). For organizations, the economic dimension meant operating under simultaneous inflation pressure, labor scarcity, and a state that needed to extract more from a diminished base.

The invasion triggered the largest displacement crisis in Europe since the Second World War. Within the first two months, approximately 13 million people, nearly a third of the pre-invasion population, were forced from their homes: 7.7 million internally and over 5 million abroad (Mykhnenko et al., 2022). By early 2026, 3.7 million remained internally displaced, and 5.9 million were registered as refugees (IOM, 2025; World Bank et al., 2026). Two features of this displacement bear directly on organizational adaptation. The first is asymmetry between flight and return. Flight is driven by safety and is rapid. Return is an economic calculation weighed against the accumulation of host-country human capital, and it is slow. In the United Kingdom, 68% of Ukrainian visa holders expressed a desire to remain even if Ukraine became completely safe (ONS, 2024). A portion of the diaspora loss is permanent. The second feature is spatial restructuring. Displacement did not produce a simple East-to-West transfer. Western border oblasts absorbed inflows from the east while simultaneously losing their own residents to international emigration, functioning as a demographic funnel rather than a stable destination (Iradukunda et al., 2025). As the war became protracted, displacement shifted toward shorter distances, with over half of newly displaced persons moving within frontline oblasts rather than to the safer west (IOM, 2025). The workforce available to any given organization depended on its location within this shifting demographic landscape.

These three dimensions interacted in reinforcing ways. Energy destruction deepened the economic contraction and accelerated displacement. Depopulation degraded the tax base and complicated reconstruction. Fiscal constraints limited the state's ability to restore infrastructure, which in turn slowed workforce return. The compound character of these interactions, rather than the magnitude of any single dimension, defined the environment within which the organizational and self-organizational mechanisms were documented.

2.3. Temporal Structure

Any organizational analysis requires knowing not just what conditions organizations faced, but when those conditions changed. The standard framework in emergency management is the four-phase cycle of mitigation, preparedness, response, and recovery, codified by the National Governors' Association (1979) and adopted by FEMA as the backbone of disaster planning in the United States. Neal (1997) showed that this framework, while useful as a heuristic, carries assumptions that limit its analytical value: the phases are treated as mutually exclusive and sequential, activities within each phase are poorly defined, and different groups may experience the phases at different times. Disaster sociology has since proposed more nuanced models, but the basic sequential architecture, moving from shock through adaptation to recovery, persists across fields.

These models were developed for bounded events: hurricanes, earthquakes, or floods. They assume that the crisis has a beginning and an end, that response gives way to recovery, and that the environment stabilizes enough for a coherent progression between stages. The Ukrainian war has no recovery phase while the enemy continues to strike. Different domains change on different schedules: the frontline stabilized in late 2022, the energy infrastructure campaign began months later, and the displacement plateau did not form until 2024. For this dissertation, a different criterion is needed: a phase transition occurs when the environment presents organizations with a qualitatively new set of demands, requiring capabilities that the previous phase did not.

One analytical distinction from the disaster literature proves useful under this criterion. Quarantelli (1997) distinguished agent-generated demands, directly caused by the disaster, from response-generated demands, caused by society's own organizational responses. In a bounded disaster, response-generated demands are secondary complications. Under sustained invasion, they become primary. The enemy deliberately targets the response infrastructure, and the state's own mobilization extracts the same workforce that organizations need to adapt. Mobilization is the clearest case: it is the state's own response to the invasion, yet it generates demands on organizations (workforce loss, role conflicts, compliance burdens) that can be as disruptive as the invasion itself. Pugachova (2025a) adds a further consideration from complex systems theory: phase transitions are potential turning points at which the system's trajectory can split. Small changes near these points can push the system toward radically different outcomes. Phase boundaries, on this view, are not merely descriptive markers but moments when the system is most sensitive to intervention.

Six phases can be distinguished on the demand-category criterion. Table 2.1 summarizes the proposed periodization.

The immediate phase (February–April 2022) was an existential emergency. russian forces attacked on multiple fronts, millions of civilians fled, and the state declared martial law and general mobilization. The dominant demand was survival under near-total uncertainty. Thousands of volunteer groups emerged spontaneously, creating a response network that filled the gaps in formal coordination but also generated new problems as roles blurred between civilian and military functions. Come Back Alive, the largest volunteer foundation, received 1.6 billion UAH in donations during the first month of the war alone (Come Back Alive, 2023).

Once the front stabilized after the withdrawal from the north, the acute phase (April–October 2022) began. Its dominant demand shifted from survival to sustained operation under conventional warfare. Western military aid created response-generated demands: training bottlenecks, jurisdictional conflicts, and coordination with multiple international partners (Zabrodskyi et al., 2022). In liberated territories, volunteer organizations substituted for absent state structures.

The attrition phase (Fall 2022–Summer 2023) was defined by the systematic campaign against civilian energy infrastructure (ISW, 2026). Organizations faced a new dominant demand: continuity amid rolling disruptions, operating through blackouts, managing fragmented supply chains, and coordinating across regions intermittently cut off from each other. Volunteer hubs diversified into multifunctional spaces combining logistical, psychological, and information functions.

The counteroffensive phase (Summer–Winter 2023) introduced a different demand. Resource-intensive offensive operations intensified competition for scarce equipment and personnel, straining casualty management while achieving minimal territorial gains (Watling & Reynolds, 2023).

By Winter 2023–2024, the offensive option was exhausted. The resulting stalemate phase saw response-generated demands accumulate: elite units operating with increasing autonomy, Western support wavering, and mobilization becoming the dominant source of social tension.

From 2024 onward, the diminishing external support phase brought a shift in international financing from US-led bilateral aid to an EU-dominated multilateral framework with different conditionalities. Volunteer participation declined from its peak, but the movement had evolved into a durable infrastructure running alongside the state (Omelianiuk et al., 2025).

Table 2.1. War Phases, Types of Demands, and Impacted Institutions

War Phase	Agent-Generated Demands	Response-Generated Demands	Most Affected Institutions
1. Immediate (Feb-Apr 2022)	- Urgent defense of cities - Mass evacuation and shelter - Food, water, medical aid for civilians - Massive volunteer	- Volunteer coordination problems - Information overload - Role conflicts between civilian and military functions	- Ukrainian Armed Forces and Territorial Defense - Emergency responders and volunteers (74% of young volunteers mobilized post-Feb 24;

	mobilization surge (56% participation by 2023)		78% without formal registration)
2. Acute (Spring-Oct 2022)	- Heavy weapons and ammunition - Liberation of occupied territories - Basic repairs in liberated areas	- International aid coordination - Training bottlenecks - Jurisdictional conflicts over resources - Volunteer state-substitution in liberated territories	- Military leadership - National and local government - Volunteer networks substituting for state services in liberated areas
3. Attrition (Fall 2022-Summer 2023)	- Electricity, heat, water restoration - Medical care for combat casualties - Civilian endurance support	- Blackout coordination complexity - Resource allocation conflicts - Communication challenges - Volunteer adaptation to multifunctional hubs	- Energy sector operators - Local communities and emergency services - Volunteer organizations adapting to multifunctional hubs
4. Counter-Offensive (Summer-Winter 2023)	- Specialized breakthrough equipment - Ammunition and vehicle replacement - Additional trained soldiers	- Internal resource competition - Command structure conflicts - Casualty management systems	- Frontline brigades (UAF) - Defense Ministry and allies
5. Stalemate (Winter 2023-Winter 2024)	- Alternative funding sources - Cross-border logistics - Prisoner management	- Coordination of independent operations - Inter-institutional resource competition - Diplomatic communication challenges	- Special forces & elite units - Diplomatic corps and presidency
6. Diminishing Support (Winter 2024 onward)	- Massive reconstruction needs ($588B over next decade) - Veteran healthcare and rehabilitation - Independent security arrangements - Shift to EU-centered financing architecture (ERA loans, Ukraine Facility)	- Reconstruction coordination problems - Reintegration administrative bottlenecks - New alliance management - EU/IMF conditionality and reform requirements - Volunteer formalization and sustainability challenges (41% sustained active engagement)	- Reconstruction agencies and civil society - Ukrainian security sector - Volunteer networks consolidating as permanent civic infrastructure - Financial and fiscal institutions navigating EU-centered multilateral framework

Whether these proposed boundaries correspond to actual breaks in empirical trajectories is a separate, testable question. A phase boundary is empirically supported when multiple environmental domains register simultaneous breaks. It is weakly supported when domain trajectories continue smoothly across it. Seven domains were examined: population displacement, enterprise survival, civilian-military cooperation, military force structure, fiscal adaptation, infrastructure damage, and volunteer mobilization. These domains reflect the environmental conditions organizations face, not organizations' internal adaptive responses. The distinction matters: domains capturing internal adaptation would be the dependent variable, not independent evidence for periodization.

The results reveal a strongly asymmetric pattern. Boundary B1 (April 2022) produces breaks across all seven domains: displacement outflows dropped sharply, business operations began resuming, the military completed the shift to full general mobilization, and volunteer coordination scaled nationwide. At the other end, B5 (Winter 2024) produces breaks across five domains. Military formation rates slowed. Major volunteer organizations pivoted from crowdfunding to institutional government grants (Come Back Alive, 2025). The displacement plateau solidified at 3.7 million IDPs (IOM, 2025). Fiscal tightening continued, and volunteer effort shifted toward reconstruction. The intermediate boundaries, B2 through B4, each affect one to three domains. B4 (Winter 2023) produces no observable breaks in any domain: the shift from offensive to defensive posture was gradual rather than discrete. Table 2.2 reports the results of this validation. Each cell records whether the corresponding domain registered an observable break at the proposed boundary.

Table 2.2. Empirical support for proposed phase boundaries across seven domains

Domain	**B1: P1/P2 (Apr 2022)**	**B2: P2/P3 (Oct 2022)**	**B3: P3/P4 (Sum 2023)**	**B4: P4/P5 (Win 2023)**	**B5: P5/P6 (Win 2024)**	**Sources**
Displacement	strong	-	-	-	visible	IOM (2022, 2024, 2025, 2026)
Enterprise survival	strong	-	-	-	-	NBU (2025) Business Activity Expectations Index
Civil-mil cooperation	strong	visible	visible	-	strong	Konrad et al. (2024)
Military force	strong	-	-	-	strong	Watling & Reynolds (2023); Watling (2025)

Fiscal adaptation	strong	-	strong	-	strong	Bogdan (2024); Centre for Economic Strategy (2025)
Infrastructure	visible	strong	-	-	-	ISW (2026); World Bank Group et al. (2026)
Volunteer mobilization	strong	visible	-	-	visible	World Bank et al. (2024); World Bank Group et al. (2026)
Domains affected	7/7	3/7	2/7	0/7	5/7	

This asymmetry supports a three-regime reduction rather than a six-discrete-phase model. *Crisis* (February–April 2022) is characterized by synchronized disruption across all domains. *Protracted adaptation* (mid-2022 through 2023) involves staggered transitions in individual domains without system-wide coherence. *Consolidation* (2024 onward) is marked by the cumulative weight of institutional changes and a shift to a new operational baseline. The resemblance to classical sequential models is superficial. Only the first and last boundaries produce system-wide breaks. The middle regime is defined precisely by the absence of cross-domain synchrony: each domain transitions on its own schedule, and organizations face a patchwork of evolving conditions rather than a uniform environment. This three-regime structure corresponds to Pugachova's (2025b) survival, resilience, and adaptation framework. Figure 2.1 maps the six phases, five boundaries, and three regimes onto a single timeline, with the predicted balance between organizational and self-organizational mechanisms indicated for each regime.

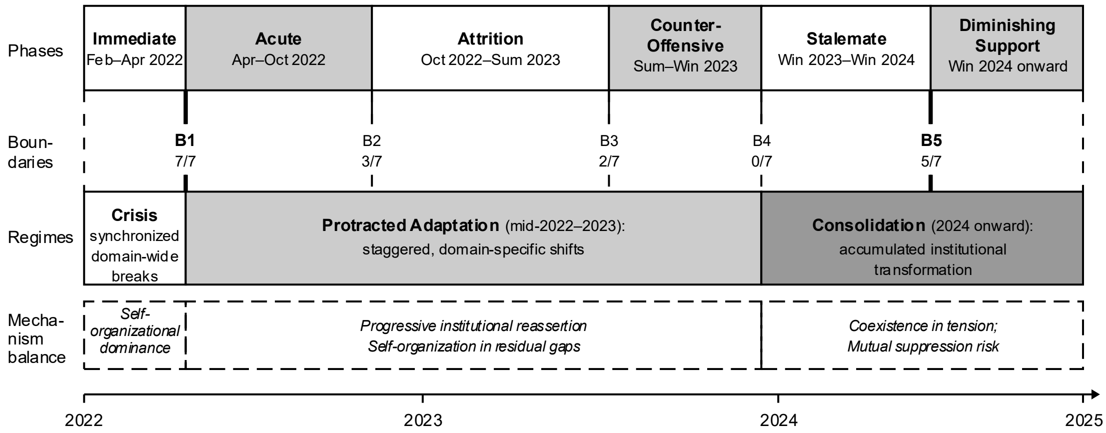

Figure 2.1. Timeline of the six war phases, five phase boundaries (B1–B5), the three-regime empirical reduction, and the predicted crisis-agency mechanism balance for each regime

The three regimes map onto the crisis-agency framework's prediction of shifting mechanism balance. In the crisis regime, formal institutions lost functional capacity, and self-organizational mechanisms dominated the initial adaptive response. During protracted adaptation, the state progressively reasserted institutional control by incorporating volunteer formations into the Armed Forces, restoring tax administration, and formalizing procurement channels. Self-organizational networks continued to operate where formal capacity remained inadequate, particularly in energy distribution and IDP assistance. In the consolidation regime, the two mechanisms coexist in tension. The organizational mechanism operates through fiscal extraction, mobilization enforcement, and regulatory compliance. Its self-organizational counterpart sustains a parallel volunteer and civic coordination infrastructure. Whether this coexistence is stable or whether one mechanism will suppress the other is a question the descriptive evidence raises but cannot resolve.

2.4. Organizational Pathway after the Invasion

The formal mechanism operates through three capacities: fiscal extraction, regulatory authority, and the state's monopoly on legitimate violence. In wartime Ukraine, all three were transformed across the three regimes.

In the first weeks of the invasion, the formal pathway operated by withdrawing its routine functions. The state suspended large parts of the regulatory framework that organizations normally faced. Tax obligations under the simplified system were reduced or eliminated for affected enterprises, and the regime itself was extended and broadened (Bogdan, 2024). The National Bank imposed capital controls and froze the exchange rate to prevent a currency collapse. Customs procedures were streamlined to allow rapid import of military and humanitarian goods. What defined this regime was not regulatory expansion but regulatory withdrawal: the formal pathway granted emergency exceptions to its own rules so that organizations could remain operational under conditions in which compliance with peacetime regulation would have been impossible.

The state's monopoly on legitimate violence operated in a similarly compressed mode. Martial law and general mobilization were declared on 24 February, but the actual exercise of military authority during the immediate phase relied on the absorption of emergent capacity rather than the projection of pre-existing institutional structure. Configured before the invasion as a professional and conscript force of roughly 250,000, the Armed Forces simultaneously performed defensive operations and integrated thousands of volunteers into newly formed Territorial Defense Forces and other irregular formations. In this regime, the formal pathway did not coordinate the response directly. It provided a legal and authoritative framework within which the response could be improvised.

By mid-2022, the formal pathway began reasserting itself through a different operational logic: formalizing what had emerged informally during the crisis regime. The fiscal trajectory illustrates this most clearly. As emergency measures were progressively rolled back, the state moved to restore revenue extraction. In March 2023, Ukraine entered an Extended Fund Facility arrangement with the IMF under which expansion of tax revenues became one of the program's benchmarks (IMF, 2024). By 2024, tax-to-GDP indicators had returned toward pre-invasion levels, though excise revenue remained depressed (Bogdan, 2024).

The repurposing of the "Affordable Loans 5-7-9%" program demonstrates how the formal pathway began actively shaping the spatial environment rather than simply reacting to it. Originally a small-business support scheme launched in 2020, the program was redesigned during protracted adaptation to incorporate geographic risk stratification: enterprises in regions closer to the front received more favorable terms (Centre for Economic Strategy, 2025). What had been a generic credit instrument was now being used as a tool of economic geography, an attempt to slow depopulation and economic withdrawal from threatened regions through state-subsidized capital. Maintaining the conditions for organizations to survive was no longer the formal pathway's only role; it now actively configured incentives for where and how organizations should operate.

Within the military, protracted adaptation involved a similar institutionalization of emergent capacity. Volunteer formations were progressively incorporated into the Armed Forces, with the legal framework provided by the Law on National Resistance (in force from January 2022). At the tactical level, AFU and National Guard units began applying the mission command principle, granting platoon and squad leaders significant autonomy in execution under a senior commander's general intent. This approach reflected a transition from Soviet-style centralized command toward NATO standards (Kupin, 2025). The defense of Kyiv (February–March 2022) and the Kharkiv counteroffensive (September 2022) served as cases where small-group autonomy enabled effective performance under conditions of significant information uncertainty.

To support the decentralized model, the Delta battle management system was deployed, integrating data from multiple sources to provide units with shared situational awareness (Kupin, 2025). In this regime, the formal pathway was institutionalizing decentralization: using the state's hierarchical authority to formalize the lateral coordination that had emerged spontaneously during the crisis.

By 2024, the formal pathway had consolidated into a configuration that combined high coordination capacity with heavy external dependency and growing tension with the informal pathway it had absorbed. This configuration fits what Artiukh and Fedirko

(2025, p. 58) call "dependent state formation," in which dependence on foreign aid and political decisions shapes the transformation of the dependent state itself.

The fiscal and defense structures illustrate the dependency. Defense expenditure reached 38 percent of GDP in 2023, eleven times its 2021 level, with the absolute figure rising to 68 billion dollars (Artiukh & Fedirko, 2025, p. 60). Of the 106 billion dollars of central state expenditure in 2023, over 61 percent was covered externally through grants, loans, and bonds (p. 61). While the state had assumed a much greater role in the economy, domestic revenues alone could not fund core wartime functions: they covered military salaries and welfare payments but only a small portion of weapons procurement. The formal pathway had become structurally dependent on external financing for its core defense function. Volatility in that financing, particularly the delays in US aid through the first half of 2024, translated directly into pressure on domestic mobilization and revenue extraction.

Mobilization policy in the consolidation regime developed the most visible tensions. The April 2024 reform lowered the conscription age, mandated digital registration through the new Oberih register, introduced punitive provisions for non-compliance, and required Ukrainians abroad to update their data or have their records removed (Hedenskog & Umland, 2025). Artiukh and Fedirko (2025, p. 63) note that the May 2024 mobilization law contained punitive provisions that the authors argue were borrowed from russian and Belarusian legislation, reflecting an increasing reliance on coercion. Despite the new legal apparatus, recruitment remained well below requirements: in early 2025, Ukraine needed roughly 300,000 new recruits but had managed to mobilize about 200,000, with monthly recruitment of 17,000 to 24,000 against russia's roughly 30,000 (Hedenskog & Umland, 2025). Desertion rose sharply, with 51,000 soldiers leaving units without permission in 2024, more than double the previous year.

The contradictions predicted by the crisis-agency framework are visible in this regime as structural rather than episodic features. Organizations were simultaneously required to retain workforce for economic production (which generates the tax base that funds the war) and to release workforce for military mobilization (which provides the manpower the war requires). These demands draw on the same finite pool of working-age men, and they cannot be resolved by better policy design because they reflect the underlying structure of demands placed on the formal pathway. Artiukh and Fedirko (2025, p. 68) characterize the resulting trajectory as a shift between unstable equilibria: from a wartime state that initially relied on voluntary citizen collaboration toward one that increasingly relied on coercive extraction from both economy and society.

One feature of the formal pathway that does not fit the regime structure but is essential for what follows is the pre-invasion decentralization reform. Between 2014 and 2020, Ukraine progressively transferred fiscal resources, planning authority, and service-delivery responsibility from central ministries to newly amalgamated local communities. This reform was not designed for wartime conditions, but it had the unintended consequence of distributing institutional capacity to local levels before the invasion. When central government communication was disrupted in February 2022, local communities had the legal authority, the budgets, and the administrative experience to organize evacuations, coordinate volunteer responses, and substitute for absent state functions. By extending its reach into local levels through decentralization, the formal pathway had created the social fabric on which the self-organizational pathway operated. Whether that fabric was used in ways that supported or competed with the formal pathway is the question the following section addresses.

2.5. Self-Organizational Pathway after the Invasion

The self-organizational mechanism operates through means different from the formal pathway: networks rather than hierarchy, trust rather than mandate, emergence rather than design. In wartime Ukraine, this pathway is most visible in the volunteer movement, the rapid formation of civic coordination networks, and the bottom-up defense innovation ecosystem. Like the formal pathway, the self-organizational pathway transformed across the three regimes, not just in scale but in operational logic. Unlike the formal pathway, it did not begin from a position of institutional strength. It began from the pre-invasion baseline of chronically low civic participation, and the speed of its activation required explanation.

The 2022 trust surge was not merely an attitudinal shift. It was the activation mechanism for the self-organizational pathway. The trust surge mentioned earlier across interpersonal trust, institutional cynicism, and civic identification was paralleled by an equally sharp rise in volunteer participation, from 26% before the invasion to 56% by 2023 (Omelianiuk et al., 2025, p. 20). These shifts created the conditions under which networks that had previously been used for private problem-solving, the informal workarounds Howard (2003) described as substitutes for formal civic participation, were redirected toward collective defense.

The organizational result was rapid and decentralized. Grassroots associations self-formed in the final days of February 2022 and became the primary channel for humanitarian aid during the first months of the war. Most of the assistance Ukrainians received in the initial period came from informal volunteer efforts rather than from international aid agencies or government programs (Konrad et al., 2024, p. 145). These associations were organic, fluid, and emerging: volunteers assumed roles without formal assignment, supply chains operated through personal contacts, and coordination depended on trust rather than procedure. Come Back Alive, already established since 2014, received 1.6 billion UAH in donations during the first month alone (Come Back Alive, 2023). In this regime, the self-organizational pathway substituted for the formal pathway where the latter had withdrawn, filling the gaps left by regulatory suspension and the absence of international humanitarian infrastructure.

As the war extended beyond its acute phase, the self-organizational pathway underwent a transformation that paralleled the formal pathway’s reassertion of authority. Spontaneous volunteer groups began to institutionalize. Come Back Alive evolved from grassroots fundraising into a licensed procurement operation, becoming the first Ukrainian NGO to purchase lethal weapons directly from manufacturers (Artiukh & Fedirko, 2025). Community foundations established "invincibility points" equipped with generators and heating during the energy crisis. Volunteer hubs that had begun as emergency distribution centers diversified into multifunctional spaces combining logistics, psychological support, and information services.

The defense innovation ecosystem provides a clear illustration of the self-organizational logic. Frontline operators, volunteers, and entrepreneurs self-organized to fill capability gaps in a decentralized "Jungle" model (Sweijs et al., 2026, p. 44). Drone manufacturers multiplied from a handful of workshops to over 200 companies by 2023, with 900 defense industry enterprises operating by 2025, most of them privately owned. Innovation flowed bottom-up through personal networks and field-level interactions, with units adapting commercial technology to battlefield needs faster than formal procurement channels could respond. The government recognized this ecosystem’s value and created platforms to channel it, most notably the Brave1 accelerator for defense technology certification (Sweijs et al., 2026). But the innovation itself originated in the self-organizational pathway, not in the formal one.

The self-organizational pathway in this regime was no longer simply filling gaps left by the formal pathway. It was generating capacities that the formal pathway then sought to absorb. Volunteer formations were incorporated into the Armed Forces. Crowdfunding organizations became partners in state-led defense procurement. Civilian-military supply networks operated as self-reinforcing trust systems in which units that received voluntary supplies responded with information and access, attracting further support (Kushnir et al., 2024). The boundary between the two pathways, which had been relatively clear during the crisis regime, became blurred.

By 2024, the self-organizational pathway had evolved into a durable parallel infrastructure, but its relationship with the formal pathway had shifted from complementarity toward competitive coexistence. Volunteer participation declined from its peak, but the movement had not dissolved; it had consolidated (Omelianiuk et al., 2025). The three largest fundraising organizations (United24, Come Back Alive, and Serhii Prytula Foundation) raised 53.13 billion UAH in 2022–2023 combined, equivalent to roughly 1.4 billion euros. This sum was comparable to the total military, financial, and humanitarian aid provided by several EU member states individually over the same period (Artiukh & Fedirko, 2025, p. 62).

The formal pathway increasingly sought to extract from the self-organizational infrastructure rather than simply partnering with it. Personal income tax was imposed on crowdfunding donations received via private bank accounts rather than registered charity accounts. Approximately 43 billion UAH was redirected from local authority budgets to a centralized drone procurement program, provoking protests from local authorities who had until then supported decentralized innovation (Artiukh & Fedirko, 2025, p. 62). These measures reflected the same fiscal pressure that operated on the formal pathway's side: a state structurally dependent on external financing and increasingly extracting from domestic sources, including from the very informal infrastructure that had sustained the early response.

The tension extended beyond fiscal extraction. Burnout accumulated among volunteers who had been operating continuously since February 2022. Donor-driven projectization imposed rigid reporting requirements on organizations that had adapted precisely by remaining flexible. The same individuals were simultaneously workers, volunteers, taxpayers, and potential military recruits, and these competing demands could not all be satisfied. For soldiers, the resentment was concrete. One soldier told Artiukh and Fedirko that civilians who donated felt they had "bought themselves the right not to serve" (Artiukh & Fedirko, 2025, p. 66).

The trajectory of the self-organizational pathway across the three regimes reveals a pattern that mirrors the formal pathway's trajectory but operates through inverse logic. Where the formal pathway contracted during the crisis and reasserted during protracted adaptation, the self-organizational pathway expanded during the crisis and was progressively absorbed during protracted adaptation. By consolidation, both pathways had stabilized into configurations that drew on the same finite pool of people, money, and organizational capacity. A key challenge for the defense innovation ecosystem (how to scale while preserving the advantages of decentralized organization, per Sweijs et al., 2026) applies to the self-organizational pathway as a whole. Whether the two pathways can sustain productive coexistence or whether one will suppress the other is the question of our further research.

2.6. Theoretical Expectations

The Ukrainian experience is consistent with the crisis-agency framework's basic architecture. Both pathways are observable, both draw on the same finite social fabric, and the competition between them evolved across regimes in ways the framework anticipated. The formal pathway contracted during the crisis, reasserted authority during protracted adaptation, and consolidated into a configuration of high coordination capacity with heavy external dependency. The self-organizational pathway expanded during the crisis, was progressively absorbed during protracted adaptation, and stabilized as a durable parallel infrastructure. By the consolidation regime, tensions between the two pathways are visible in fiscal extraction, mobilization policy, and the lived experience of individuals who function across both.

The situation also reveals patterns that the framework anticipated only partially. The inverse trajectory of the two pathways, where the formal contracts as the informal expands and then the reverse, is observable at the system level and consistent with the framework's prediction of shifting mechanism balance. But the temporal asymmetry, the finding that only the first and last phase boundaries produce system-wide breaks while the middle regime is defined by the absence of cross-domain synchrony, is a pattern the framework did not predict. The role of prior self-organizational experience from the Revolution of Dignity and the Donbas war in enabling the speed of the 2022 response is likewise a feature specific to the Ukrainian case that the framework's abstract formulation does not address. Trust surged in 2022 and remained elevated through 2023, well above the pre-invasion baseline. Civic identification followed the same pattern. Spatial threat exposure produced the front-rear divergence that the displacement and economic data document. These macro-level patterns are consistent with the framework's expectations but do not test them.

What the case cannot resolve is the framework's central question: whether the two pathways' coexistence is sustainable or whether one suppresses the other beyond an identifiable threshold. Aggregate evidence cannot locate this threshold because averaging across organizations conceals the differences between those on different sides of it. The case also cannot identify which specific mechanisms operate under which conditions, or how variation across organizations shapes the population-level result. These are questions that require organization-level fieldwork and computational experimentation. Table 2.3 lists the predictions that the analytical framework generates.

Table 2.3. Predictions from the analytical framework

Code	Prediction	Source
TP1	The two pathways suppress each other beyond an institutional capacity threshold	Crisis-agency theory (Bevzenko, 2022)
TP2	Adaptive traits follow a three-phase pattern across crisis, adaptation, and consolidation	Crisis-agency theory (Bevzenko, 2018)
TP3	Institutional capacity is necessary for organizational survival	Disaster response (Britton, 1986); crisis-agency theory (Bevzenko, 2020)
TP4	Coercive isomorphism produces convergence on war-oriented structures	Institutional theory (DiMaggio & Powell, 1983)
TP5	Decoupling widens the gap between formal compliance and actual practice	Institutional theory (Meyer & Rowan, 1977)
TP7	Complementarity drives partner selection in crisis; compatibility in recovery	Network theory (Larson, 2012)
TP8	All four DRC organizational types activate under sustained crisis	Disaster response (Kreps and Bosworth, 1993)
TP9	Hastily formed relief networks dissolve after the triggering event	Disaster response (Quarantelli, 1997)
TP10	Prior disruption experience accelerates adaptation	Dynamic capabilities (Teece, 2007)
TP11	Boundary reconfiguration is critical under resource depletion	Dynamic capabilities (Teece, 2007)
TP12	Specialists experience higher mortality than generalists	Organizational ecology (Hannan & Freeman, 1989)
TP13	Spatial threat exposure produces divergent front-rear trait profiles	Macro data
TP14	War intensity and duration damage different domains independently	Disaster sociology (Britton, 1986); macro data
TP15	War-induced changes are selectively irreversible	Complex systems theory (Pugachova, 2025b)
TP16	Cascading disruptions compound systemic damage	Disaster sociology (Pescaroli & Alexander, 2016)
TP17	Moderate military requisition damages the civilian economy	Wartime governance literature

TP18	The decentralization advantage is conditional on institutional weakness	Macro data
TP19	Organizational-mechanism-dominant configurations can bifurcate	Complex systems theory (Pugachova, 2025a); crisis-agency theory (Bevzenko, 2020)

The predictions listed in Table 2.3 set the agenda for the empirical and computational work that follows. Each prediction is given a code with the TP prefix (theoretical prediction). Chapter 6 returns to these predictions in Table 6.2 alongside five additional predictions coded EP1–EP5 (empirical-computational predictions) that emerged during the interview analysis, model-based experimentation, or both.

Chapter 2 Conclusions

This chapter applied the crisis-agency framework to wartime Ukraine. The analysis established what kind of emergency the full-scale invasion produced and characterized the wartime environment across spatial, economic, and demographic dimensions. Empirical validation of the proposed periodization revealed a temporal structure of three regimes with asymmetric domain synchrony. The chapter then traced the two pathways across these regimes.

The Ukrainian case satisfies the conditions the framework requires. Both pathways operate, both draw on the same finite social fabric, and, under the consolidation regime, observable tensions emerge in fiscal extraction, mobilization policy, and the lived experience of individuals who function in both pathways simultaneously. Across the three regimes, the two pathways followed inverse trajectories. On the formal side, the pathway contracted during the crisis regime, reasserted authority during protracted adaptation by formalizing what had emerged informally, and consolidated by 2024 into a configuration of high coordination capacity with heavy external dependency. Its self-organizational counterpart followed the opposite arc: expansion during the crisis, progressive absorption during protracted adaptation, and stabilization by 2024 into a durable parallel infrastructure under strain.

Both pathways have stabilized into configurations that draw on the same finite pool of people, money, and organizational capacity. The descriptive evidence shows that the framework's preconditions hold and that tensions between the pathways are visible. Whether these tensions stabilize, escalate, or resolve through the suppression of one pathway is not visible at the system level. The threshold between productive coexistence and mutual suppression cannot be located from aggregate data alone. Which organizational forms produce which adaptive outcomes, and how variation across organizations shapes the population-level result, are questions that require organization-level evidence and counterfactual experimentation, neither of which is available from the descriptive evidence presented here.

The descriptive evidence presented in this chapter operates at the system level. The next chapter shifts the unit of analysis to individual organizations and the people who run them, building a mechanism inventory of organizational adaptation behaviors from semi-structured interviews with owners and managers of Ukrainian commercial and non-commercial organizations.

CHAPTER 3

FROM EVIDENCE TO MECHANISMS: INTERVIEW AND SURVEY FINDINGS

The preceding chapter documented the wartime environment in which Ukrainian organizations operated, established that both adaptation pathways are simultaneously active, and assessed which theoretical predictions the descriptive evidence supports. Resolving the remaining open predictions requires moving from descriptive observation to systematic mechanism identification.

This chapter produces the empirical inputs for the computational model. Semi-structured interviews establish a mechanism inventory of organizational adaptation behaviors. Formalization translates the inventory into model rules. A structured survey calibrates the resulting specification with population-level parameter distributions. Cross-method validation assesses the convergence of the two empirical sources.

3.1. Research Design

The preceding chapters established a theoretical framework centered on the interaction between organizational and self-organizational mechanisms of adaptation under sustained warfare. Bevzenko's (2018) crisis-agency framework provides the core prediction. Under institutional disruption, self-organizational mechanisms become essential for survival, yet organizational mechanisms meant to support adaptation can suppress them. Institutional theory (DiMaggio & Powell, 1983; Oliver, 1991) specifies the organizational pathway through compliance, coercive isomorphism, and decoupling. Social networks theory (Aldrich, 2012) specifies the relational infrastructure through which self-organization operates. Dynamic capabilities, population ecology, and disaster response sociology contribute supplementary concepts.

These frameworks generated testable predictions but could not provide the behavioral parameters and decision rules relevant to sustained warfare. They could not specify which organizations relocate and when, how quickly planning horizons contract or whether they recover, whether military support is universal or sector-dependent, or whether compliance actually increases hierarchy. Theory also could not anticipate mechanisms specific to war that have no precedent in the disaster sociology or organizational theory literature. These are questions of empirical fact, and they can be answered only through primary research with organizations that have lived through the experience.

An agent-based model (a computational simulation in which autonomous software agents interact according to behavioral rules, producing emergent macro-level patterns) requires two categories of empirical input. The first is a mechanism inventory that specifies what agents do, under what conditions, and through which pathway. A second input is a set of parameter distributions that determine how many agents exhibit each behavior, at what thresholds they act, and with what intensity. Neither can be supplied by the theoretical framework alone.

The chapter uses a theory-driven sequential design that extends Creswell and Plano Clark's (2018) instrument-development framework. In this extension, the computational model, rather than a psychometric scale, is the instrument constructed from empirical findings. Semi-structured interviews (37 transcripts from 32 respondents across two waves) test theoretical predictions against the experiences of Ukrainian organizations and, through systematic residual analysis (coding passages that no existing mechanism can account for), identify mechanisms that theory did not anticipate. The resulting mechanism inventory is then translated into a model specification. A structured survey (n = 35) calibrates this specification with population-level parameter distributions.

Together, the two empirical phases accomplish what neither could accomplish alone. Interviews establish what organizations do under warfare conditions, test whether theoretical predictions hold, and identify what theory is missing. The survey provides distributional evidence from 35 organizations: population-level parameter distributions for the model and reference points for validation targets. Without the interviews, the model would formalize only what prior theory anticipated; without the survey, its parameters would rest on individual accounts rather than population distributions.

Figure 3.1 shows the full research pipeline. The empirical phase (top row) follows the instrument-development logic above. Five stages produce successive outputs that feed each other. Theoretical analysis generates testable predictions. Semi-structured interviews produce a mechanism inventory. Formalization translates the inventory into model rules. The CAWI survey calibrates the resulting parameters. Cross-method validation compares the two empirical sources and feeds design revisions back into the model specification.

The validated model is the instrument that the empirical phase constructs. Using it unfolds in the experimental phase (bottom row). Implementation translates the specification into running NetLogo code. Calibration and validation use the survey distributions and qualitative interview patterns to produce a credibility map showing where the model succeeds and where it fails. Counterfactual experiments then toggle mechanisms, vary parameters, and probe system-level dynamics to answer questions that empirical evidence alone cannot resolve. The experimental phase follows simulation methodology (Grimm & Railsback, 2012) rather than the mixed-methods framework. Its results extend and refine the theoretical predictions that began the cycle, closing the loop back to theory.

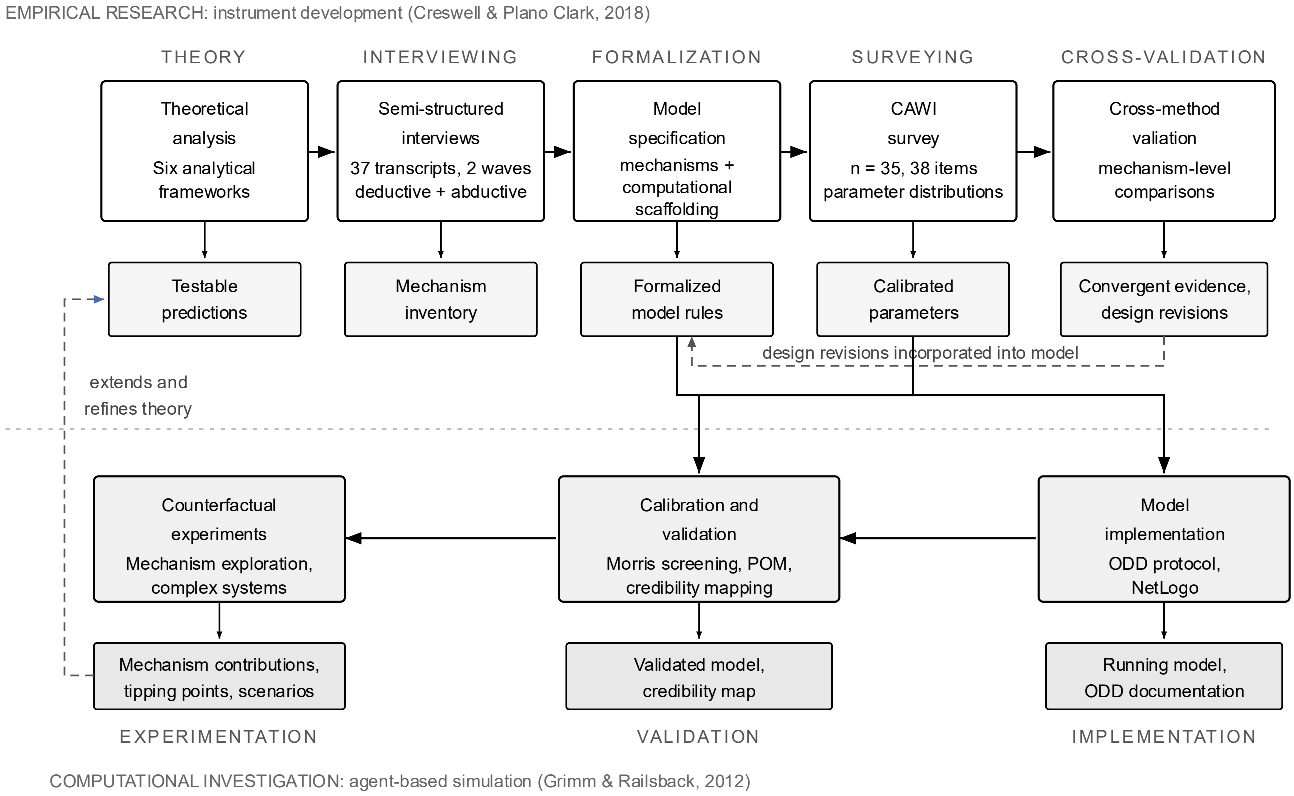

Figure 3.1. Research design and dissertation pipeline

3.2. Mechanism Inventory

The interview analysis used a deductive coding approach (testing data against pre-existing theoretical categories). All 37 transcripts were coded against a mechanism inventory derived from the theoretical frameworks of the preceding chapters. Each passage was coded using a four-code scheme. S (supported) indicates behavior consistent with the mechanism. C (contradicted) indicates behavior incompatible with it. N (nuanced) indicates partial support that reveals the complexity the model simplifies. X (unmatched) indicates organizationally relevant behavior with no corresponding mechanism in the inventory. The X-codes constituted the abductive component (discovering patterns not predicted by existing theory): mechanisms identified through systematic residual analysis of what theory could not account for.

The opening interview question was deliberately minimal: “What happened to your organization on and after February 24, 2022?” This invited respondents to construct their own narrative rather than respond to theoretical categories. Several disaster sociology frameworks served as analytical tools for classifying the coded findings (Dynes, 1970;

Kreps & Bosworth, 2007; Quarantelli, 1997; Wachtendorf, 2004). These frameworks organized the findings; they did not generate them.

The mechanism inventory was operationalized into a deductive codebook specifying, for each mechanism, what to look for in the text, what counts as supported, contradicted, or nuanced evidence, and boundary rules distinguishing adjacent mechanisms. Definitions, coding criteria, aggregate code counts, and boundary rules for each mechanism are documented in the deductive codebook (Appendix A).

Sample and data collection

The first wave comprised 26 semi-structured interviews conducted between September 2022 and April 2023 with owners and managers of Ukrainian commercial and non-commercial organizations. Respondents were recruited through convenience and snowball sampling starting from the author's professional network. Deliberate outreach diversified the sample across industries, regions, and sizes within the practical constraints of an active war.

Geographic distribution by headquarters included Northern Ukraine (Kyiv, Zhytomyr, Chernihiv, Rivne: 14 organizations), Western Ukraine (Lviv, Ivano-Frankivsk, Khmelnytskyi: 4), Eastern Ukraine (Kharkiv, Sumy: 2), and Southern Ukraine (Dnipro, Zaporizhzhia: 2). By sector, the sample included six IT companies, five industrial manufacturers, three volunteer and non-governmental organizations, two legal services firms, and six others spanning food service, food processing, equipment sales, residential management, travel, and an eco-community. IT and Northern Ukraine were overrepresented.

The second wave consisted of 11 interviews conducted between October and December 2023, approximately 20 months after the full-scale invasion. Five first-wave respondents were re-interviewed to capture longitudinal change. Six new respondents represented larger organizations (200 to 2,000 employees) and international subsidiaries, testing whether small-enterprise patterns held at a greater scale. Altogether, the two waves produced 37 transcripts from 32 distinct respondents.

The anonymized composition of the 32-respondent sample is documented in Table A.1 (Appendix A). The sample is services-dominant, spans all size bands and major Ukrainian regions, and consists primarily of owners and senior managers. Ethical procedures followed standard qualitative research protocols adapted to the wartime setting. All participants provided oral informed consent. Transcripts were reviewed and approved by respondents. The data are not publicly available. A combination of a small professional community, specific industry details, and wartime context created credible re-identification risk.

Context: disruption and demands

All 26 first-wave organizations experienced operational disruption. Thirteen had no formal contingency plan; among the nine with plans, only three reported their plans worked as intended. Five organizations reported no operational gap, typically IT firms with existing remote work capacity. Most organizations recovered basic operations within one to four weeks, though full recovery took three to six months where it occurred. In Quarantelli's (2006) classification, the invasion constituted a disaster for most respondents rather than a catastrophe: it overwhelmed some organizational functions but did not destroy the capacity for organized response.

The first-wave interviews identified six classes of organizational demands generated by the invasion (Serdyuk, 2023). This chapter extends the classification by mapping each demand to the mechanisms it activated, using evidence from both interview waves and the survey. Table 3.1 summarizes the demand classes. Following Quarantelli (1997, pp. 41-42), demands divide into agent-generated (produced by the hazard itself), response-generated (produced by the organizational response), and environment-generated (produced by the broader economic disruption).

Table 3.1. Classes of organizational demands generated by the full-scale russian invasion of Ukraine

Demand class	**Source type**	**Description**
Military support	Agent-generated	Pressure to contribute organizational resources to the war effort and support the armed forces

Employee safety	Agent-generated	Need to protect staff from physical danger arising from the invasion
Personnel burnout	Response-generated	Cumulative psychological exhaustion of staff managing sustained crisis operations
Social responsibility	Response-generated	Expanded duty of care toward stakeholders affected by the war: displaced families, mobilized employees, and their dependents
Cost-cutting	Environment-generated	Pressure to reduce operating costs under revenue collapse and supply chain disruption
New markets/products	Environment-generated	Pressure to find viable revenue sources as pre-invasion markets disappeared and wartime opportunities emerged

Construction of the inventory proceeded in two stages. The first stage turned theoretical expectations into testable mechanism definitions. Six analytical frameworks supplied the expectations: crisis-agency, institutional, network, disaster response sociology, dynamic capabilities, and population ecology. Each expectation was operationalized into a codebook entry with explicit rules for what counts as supported, contradicted, or nuanced evidence. A second stage identified mechanisms that theory did not anticipate. During coding, passages describing organizationally relevant behavior that did not fit any existing mechanism were flagged as unmatched (X-codes). When X-codes accumulated around recurring patterns, those patterns were formalized into new mechanism definitions and added to the codebook. Once completed, the codebook was applied to all 37 transcripts.

Deductive coding produced evidence for 27 mechanisms testable through interview data. Their origins divide into three categories. Theory-aligned mechanisms operationalize expectations from the six analytical frameworks. Mechanisms identified through residual analysis of X-coded passages have no prior theoretical template. Combined mechanisms integrate theoretical expectations with substantial empirical refinement. Table 3.2 summarizes the aggregate code counts. The Origin column records the provenance of each entry.

Each mechanism is classified by its role in the crisis-agency framework. “O (organizational)” marks mechanisms operating through formal institutional channels. “SO (self-organizational)” marks mechanisms operating through informal networks, voluntary action, and trust-based cooperation. “B (bridging)” marks mechanisms that describe the interaction between the two pathways or the transition from one to the other.

"E (environmental)" marks mechanisms that describe the conditions, cognitive architecture, or temporal structure within which both pathways operate. The Demand column records which demand classes from Table 3.1 each mechanism addresses; "n/a" marks demand-neutral mechanisms that operate regardless of which demand is active.

Table 3.2. Aggregate Interview Evidence by Mechanism

Code	Mechanism	Path way	Origin	Demand	S	C	N	Assessment
A1	Resource-exhaustion mortality	E	Theory	Employee safety + Cost-cutting	1	0	0	Weak evidence
A4	Endogenous risk-tolerance shift	E	Theory	Employfee safety	0	2	0	Reclassified
A5	Size-dependent vision range	E	Theory	n/a	1	0	0	Weak evidence
B1	Local perception anchoring	E	Theory	Employee safety	12	0	0	Supported
B4	Return-home intention	E	Novel	Employee safety	2	0	0	Weak evidence
B5	Multi-demand behavioral deliberation	E	Theory	n/a	10	0	0	Supported
B8	Horizon-dependent decision weighting	E	Combined	n/a	2	0	0	Weak evidence
C1	Planning horizon contraction	E	Combined	Employee safety + Cost-cutting	26	0	0	Supported
J3	COVID pre-adaptation	E	Novel	Employee safety + Cost-cutting + Military support	11	0	2	Supported
K1	Three-phase temporal pattern	E	Novel	n/a	16	0	0	Supported
K2	Structural inertia protection	E	Theory	Employee safety + Cost-cutting	3	0	0	Qualified
G4	Mobilization workforce shock	O	Novel	Military support	9	0	5	Supported
G5	Intermediated government interaction	O	Novel	Military support + Cost-cutting	10	0	2	Supported
A2	Cultural in-group favoritism	SO	Theory	n/a	2	0	0	Weak evidence

B2	Network information diffusion	SO	Theory	n/a	1	0	0	Weak evidence
B3	Trade-link relocation anchoring	SO	Combined	Employee safety	5	0	3	Supported
B7	Domain expansion	SO	Novel	Military support + Employee safety + Social responsibility	16	1	0	Supported
B9	Selective relocation destination	SO	Novel	Employee safety	3	0	0	Qualified
C2	Altruism activation	SO	Combined	Military support + Social responsibility	12	0	13	Supported
E2	Crisis-induced cooperation	SO	Combined	Cost-cutting + New markets/products	4	0	0	Supported
E4	Three-route trust formation	SO	Theory	n/a	3	0	4	Partial support
K3	HR repurposing	SO	Novel	Military support + Employee safety + Social responsibility	6	0	0	Supported
K4	Voluntary military support	SO	Novel	Military support	22	0	0	Supported
A3	Structural trait homophilic drift	B	Combined	n/a	10	0	5	Supported
B6	Compliance lock-in	B	Theory	n/a	1	0	1	Weak evidence
D1	Civilian-military permeability	B	Novel	Military support	8	0	2	Supported
D2	Jungle-to-Zoo transition	B	Novel	n/a	4	0	4	Partial

Note: Each code labels one model rule. Where a rule formalizes an interview mechanism, the two share a code; the eleven infrastructure rules take the remaining codes. The first letter marks a thematic family: A – organizational attributes, B – perception and relocation, C – adaptive traits, D – civilian–military dynamics, E – partnership and trust, F – social capital, G – government, H – trade, I – warfare, J – demographics, K – temporal and support patterns.

The evidence displays three patterns. First, the highest S-code counts belong to empirically discovered mechanisms: planning horizon contraction (C1, 26), voluntary military support (K4, 22), and domain expansion (B7, 16). All three emerged from residual analysis rather than theoretical prediction. Second, the self-organizational pathway receives more empirical support than the organizational pathway. Third, several theory-aligned mechanisms received weak evidence (fewer than four codes). These mechanisms remain in the model. Their parameters are explored through sensitivity analysis rather than treated as empirically anchored.

The Demand column reveals a further pattern. Employee safety is the most heavily addressed demand: 11 of 27 mechanisms respond to it, spanning environmental adaptation, network-based responses, and voluntary expansion of organizational mandate. No organizational-pathway mechanism addresses safety. The state did not provide organizational safety through channels visible to respondents. Military support activates eight mechanisms, heavily concentrated in the self-organizational pathway; the sole organizational-pathway contribution is mobilization (G4), through which the state imposed the demand rather than helping organizations meet it.

3.3. Mechanism Description

Cost-cutting activates six mechanisms spread across environmental and bridging infrastructure. Social responsibility (three mechanisms) is entirely absorbed into broader mechanisms (B7, C2, K3) rather than generating distinct entries. New markets activate only one mechanism (E2, crisis-induced cooperation). Personnel burnout is the only demand class that generates no mechanisms at all; it remains in the X-codes as beyond the model’s current scope.

Environmental mechanisms

Environmental mechanisms describe the conditions, cognitive equipment, and temporal structure within which both pathways operate. They do not produce organizational or self-organizational behavior; they shape the context in which organizations choose between the two.

Local perception anchoring (B1, 12 S-codes) received strong support across the sample. Organizations based their decisions on perceived local safety rather than aggregate threat reports or official assessments. This mechanism underpins most safety-related adaptation: relocation decisions, horizon contraction, and priority shifts all depend on how dangerous organizations perceive their immediate environment to be.

Planning horizon contraction (C1) received the highest S-code count in the inventory (26 S-codes, zero contradictions). Horizon contraction was immediate and universal across the first-wave sample. By the second wave, horizons had partially recovered in some organizations but remained shortened in most. Recovery was triggered not by improved security but by habituation to constant danger. This finding has a direct model implication: the safety threshold should incorporate a habituation component rather than responding only to objective threat levels.

The three-phase temporal pattern (K1, 16 S-codes) structured the entire sample: initial shock (days to two weeks), active crisis management (weeks to months), and gradual normalization under altered conditions. Boundaries varied by organization, region, and sector, but the sequence was stable. Combined with multi-demand behavioral deliberation (B5, 10 S-codes), this temporal pattern describes the cognitive and chronological infrastructure of adaptation. At each phase, organizations weighed competing demands and selected one action. Weights shifted as conditions evolved.

COVID pre-adaptation (J3, 11 S-codes) carried forward prior organizational capacity. Organizations that had built pandemic-era routines reactivated them under invasion conditions. The transfer was effective for coordinating dispersed teams and managing stress, but ineffective for demands specific to warfare. This selective transfer supports modeling pre-adaptation as a conditional advantage rather than a universal buffer.

Risk tolerance (A4) was the only mechanism cleanly contradicted. The original formulation treated it as a fixed organizational trait. Respondents described risk appetite as recalibrating under existential threat, leading to its reclassification as an endogenous (internally driven) adaptive property.

Seven mechanisms received fewer than four codes each (A1, A2, A5, B2, B4, B8, K2). Their definitions, coding criteria, and evidence are documented in the codebook. These mechanisms remain in the model on theoretical grounds. Their parameters are explored through sensitivity analysis rather than treated as empirically anchored.

Organizational pathway mechanisms

Organizational pathway mechanisms operate through formal institutional channels: government regulation, legal mandates, compliance pressure, and hierarchical coordination. Only two mechanisms operate exclusively through this pathway, reflecting the empirical finding that formal institutions played a narrower role in organizational adaptation than self-organizational processes.

Mobilization (G4, 9 S-codes) operated as a discrete workforce shock rather than gradual attrition. Respondents described losing key personnel to military service within days. By the second wave, growing tension between defense contributions and economic viability was a recurring theme.

Government interaction followed a pattern of intermediated compliance (G5, 10 S-codes). Rather than engaging government agencies directly, organizations worked through intermediary bodies: IT companies through IT clusters, manufacturers through industry associations, NGOs through coordination platforms. This buffered pattern is consistent with institutional theory's prediction of isomorphic pressure (organizations converging toward similar structures under regulatory demands), but the intermediation layer had not been anticipated.

Self-organizational pathway mechanisms

Self-organizational pathway mechanisms operate through informal networks, voluntary action, and trust-based cooperation. Organizations act spontaneously, without institutional direction. This pathway received stronger empirical support than the organizational pathway across the combined dataset.

Voluntary military support (K4) received 22 S-codes with zero contradictions and zero nuanced codes, making it the cleanest finding in the dataset. Organizations created internal charity funds, purchased equipment for local military units, organized employee volunteer efforts, and, in some cases, restructured product lines for military needs. In every case, this support preceded government requests or coordination. Formalization was rapid: spontaneous donations evolved into standing organizational roles within two to three months. By the second wave, military support had been routinized as a permanent organizational function.

Domain expansion (B7, 16 S-codes) describes organizations creating functions far outside their original mandate. HR departments took over coordination of military support, evacuation logistics, shelter arrangements, housing for relocated employees, financial support for displaced families, and psychological support, far exceeding their pre-invasion roles. In the model, this is represented as a binary transition triggered by altruism and military friendliness. The interviews revealed that the process was actually gradual, which constitutes a known simplification.

Altruism activation (C2, 12 S-codes, 13 N-codes) showed a complex decay pattern. Initial altruistic responses were strong and universal. By the second wave, several respondents described growing tension between defense contributions and organizational survival. The high N-code count reflects this complexity: the mechanism operates as modeled in the initial phase, but requires a decay component that the current formulation does not capture.

Crisis-induced cooperation (E2) and trust formation (E4) provided evidence for partnership dynamics. Emergency partnerships formed in the first months either solidified into stable relationships or dissolved. Respondents described a shift from proximity-based to value-based partner selection as conditions stabilized. Relocation decisions drew on network ties. Trade-link anchoring (B3, 5 S-codes) kept well-connected organizations in place longer than safety thresholds alone would predict. Destination choice (B9) was guided by partner and workforce location rather than institutional direction.

Bridging mechanisms

Bridging mechanisms describe the interaction between the organizational and self-organizational pathways. They determine which pathway an organization follows, or capture the system-level shift from one regime to the other.

Structural trait homophilic drift (A3, 10 S-codes) received consistent support. It operates through two channels: government compliance pushes hierarchy upward (organizational direction), while trade-partner interaction converges traits between partners (self-organizational direction). The effect was sector-dependent: manufacturers maintained structural continuity more effectively than service firms. By the second wave, organizations that adopted crisis-induced hierarchy reported difficulty returning to pre-invasion governance.

Compliance lock-in (B6) received weak direct evidence (1 S-code) but clearer longitudinal support from cross-wave comparison. Over twenty months, the same respondent moved from articulating compliance as a defining organizational value to describing evasion as a survival necessity, while continuing to experience the deviation as morally uncomfortable. The trajectory from "fundamental point" to "gray area" documents the sorting process through which organizations commit to one pathway or the other.

Civilian-military permeability (D1, 8 S-codes) operates in both directions. Organizations voluntarily crossed into military functions (self-organizational direction), while in the model the government pushes organizations back toward civilian identity (organizational direction). The mechanism sits at the boundary between pathways.

The Jungle-to-Zoo transition (D2, 4 S-codes, 4 N-codes) received partial support. Interview evidence documented a shift from self-organizational dominance in the early crisis phase toward increasing institutional regulation by the second wave. The balanced S/N ratio reflects that the transition was neither complete nor linear; organizations simultaneously experienced regulatory tightening and continued reliance on informal networks.

Several interview findings could not be operationalized within the model's current architecture. Burnout follows a J-curve trajectory that requires an agent-level capacity variable that the model does not have (12 X-codes). Intra-organizational dynamics, social polarization between employees who stayed and those who left, and the international market dimension all exceed the unitary-agent architecture. These findings are documented as candidate extensions for future model iterations.

The five cross-wave respondents provided direct longitudinal evidence. Military support demands had been routinized, moving from the emerging to the established category. Burnout had intensified and was increasingly recognized as a structural problem. Cost-cutting pressures eased in some sectors while deepening in others. Organizations that had adopted experimental approaches showed divergent trajectories: some sustained innovation; others exhausted their capacity and reverted to pre-invasion patterns.

More broadly, organizations had stopped waiting for the war to end and begun building processes that assumed ongoing instability. One respondent captured the paradox as “business as usual” coexisting with “waiting for blackouts.” This endpoint represents neither resilience (returning to a prior equilibrium) nor transformation (a complete break with the past). It is a routinized adaptation to sustained disruption. The finding extends Quarantelli’s (1997) framework, which assumes disasters have a temporal boundary after which organizations either recover or fail. By late 2023, Ukrainian organizations had done neither.

3.4. Translating Mechanisms into Model Rules

An agent-based model represents each organization as an autonomous software agent that perceives its local environment, deliberates over competing needs, and acts according to behavioral rules. Macro-level patterns emerge from the interaction of hundreds of such agents without being programmed directly. This bottom-up architecture matches the research problem: organizational adaptation to warfare is produced by individual decisions, not by central coordination. The method, its historical development, and the rationale for choosing it over alternatives are described in the following chapter.

The interview study produced 27 mechanisms at the resolution of organizational experience: what leaders described doing, deciding, and observing during each phase of the war. Before these mechanisms can be calibrated with survey data, they must be translated into a form that the computational model can implement. This translation is the final step in the instrument-development design: the empirical findings become a model specification that the survey then calibrates with distributional data.

The translation is not one-to-one. Several patterns are consolidated into larger causal chains: perception, intention scoring, compliance, and hierarchy drift are each documented separately in the interviews but jointly constitute a single compliance lock-in mechanism in the model. Other patterns become environmental infrastructure: the spatial landscape, the warfare scenario schedule, and the disaster system are conditions within which mechanisms operate. Still others become architectural components: the perceive-decide-act cycle and tick-based scheduling are the computational infrastructure through which mechanisms are realized.

This consolidation is a deliberate methodological choice. The cost is that some qualitative richness is lost in formalization. Five empirical findings exceed the model's scope: burnout (which follows a J-curve trajectory), intra-organizational dynamics, social polarization between stayers and leavers, the international market dimension, and mobilization as a social capital destroyer. The benefit is that each resulting rule has a complete causal chain from environmental conditions through agent response to aggregate consequence, and can be individually toggled, varied, or stressed in computational experiments.

Table 3.3 shows how each of the 27 mechanisms from Table 3.2 entered the model. All 27 are implemented. Some map one-to-one to a single model rule. Others were consolidated into broader causal chains where the interview data described parts of a process that operates as a single mechanism in the model.

Table 3.3. Translation of Empirical Mechanisms into Model Rules

Code	Mechanism	Translation	Model rule(s)
A1	Resource-exhaustion mortality	One-to-one	Organizational death conditions
A2	Cultural in-group favoritism	One-to-one	Cultural tag and group identity
A3	Structural trait homophilic drift	One-to-one	Organizational structure traits (continuous drift)
A4	Endogenous risk-tolerance shift	One-to-one	Risk tolerance (endogenous adaptive trait)
A5	Size-dependent vision range	One-to-one	Size-dependent vision range
B1	Local perception anchoring	Consolidated	Perceive-decide-act cycle (with B5, B8)
B2	Network information diffusion	One-to-one	Network information diffusion
B3	Trade-link relocation anchoring	One-to-one	Relocation threshold with trade-link anchoring
B4	Return-home intention	One-to-one	Return-home intention

B5	Multi-demand behavioral deliberation	Consolidated	Seven civilian behavioral intentions (with B1, B8)
B6	Compliance lock-in	Consolidated	Comply vs. evade decision (with A3 drift)
B7	Domain expansion	One-to-one	Domain expansion
B8	Horizon-dependent decision weighting	Consolidated	Planning horizon modulation (with B1, B5)
B9	Selective relocation destination	One-to-one	Destination choice for relocation
C1	Planning horizon contraction	One-to-one	Planning horizon as an endogenous adaptive trait
C2	Altruism activation	One-to-one	Altruism increase under crisis
D1	Civilian-military permeability	One-to-one	Dynamic civilian-military boundary
D2	Jungle-to-Zoo transition	One-to-one	Jungle-to-Zoo regime transition
E2	Crisis-induced cooperation	One-to-one	Crisis-induced cooperation
E4	Three-route trust formation	One-to-one	Three-route trust (swift, earned, habitual)
G4	Mobilization workforce shock	One-to-one	Mobilization impact
G5	Intermediated government interaction	One-to-one	Government interaction through intermediaries
J3	COVID pre-adaptation	One-to-one	COVID pre-adaptation
K1	Three-phase temporal pattern	One-to-one	Three-phase temporal pattern
K2	Structural inertia protection	One-to-one	Structural Inertia as a protective factor
K3	HR repurposing	One-to-one	HR repurposing
K4	Voluntary military support	One-to-one	Voluntary military support

Four mechanisms (B1, B5, B8, and the compliance component of B6) were consolidated into larger causal chains. B1 (local perception anchoring), B5 (multi-demand deliberation), and B8 (horizon-dependent weighting) jointly constitute the perceive-decide-act cognitive cycle: the agent observes local conditions (B1), scores competing intentions using horizon-dependent weights (B8), and selects one action from seven behavioral options (B5). B6 (compliance lock-in) integrates with A3 (structural drift) because compliance and evasion choices drive the same hierarchy parameter that structural drift modifies through trade-partner interaction. The remaining 23 mechanisms map one-to-one to model rules.

Formalization also revealed gaps that the interview data alone could not fill. A computational model requires trade mechanics (how agents exchange resources), demographic processes (how organizations are born and die), a cognitive architecture (how agents perceive, deliberate, and act), warfare dynamics (how the warfare environment evolves), and institutional processes (how government taxation and subsidies work). These are not empirical findings; they are computational infrastructure without which the empirical mechanisms cannot operate.

Source computational frameworks

Six established agent-based models informed the design.

- ASSOCC (Dignum et al., 2020) simulates how agents balance competing needs during the COVID-19 pandemic; it contributes the principle that crisis agents must score multiple objectives simultaneously rather than optimize a single utility function.
- Epstein's (2003) model represents organizational hierarchies that form and dissolve endogenously from local rules; it contributes the treatment of flexibility and hierarchy as continuous traits that drift through interaction.
- SugarScape (Epstein & Axtell, 1996) generates markets, cultural groups, and demographic cycles from bilateral exchange on a spatial landscape; it contributes trade pricing, the cultural tag system, and demographic rules.
- Ethnocentrism model shows that ethnocentric cooperation dominates without reciprocity or strategic calculation, contributing in-group favoritism in partner selection (Hammond & Axelrod, 2006).
- SKIN (Gilbert et al., 2001) models innovation networks in which firms form partnerships based on complementary capabilities; it contributes partner memory and the reputation-referral chain.
- WorkSim (Goudet et al., 2017) models institutional labor market constraints with full accounting of employment flows; it contributes the principle that government fiscal rules are binding constraints, not optional features.

Detailed descriptions of each framework's limitations are provided in Appendix C.

No single model provides the combination of deliberative multi-goal agents, endogenous structural change, spatial trade with cultural dynamics, complementary-capability partnerships, and binding institutional constraints that the organizational adaptation context requires. The present model synthesizes specific rules from each source while adding the mechanisms that no existing model contains: safety-driven relocation with network anchoring, domain expansion, planning horizon contraction, altruism activation, the Jungle-to-Zoo regime dynamic, and the three-route trust model. Figure 3.2 shows how each source framework maps onto the model's subsystems.

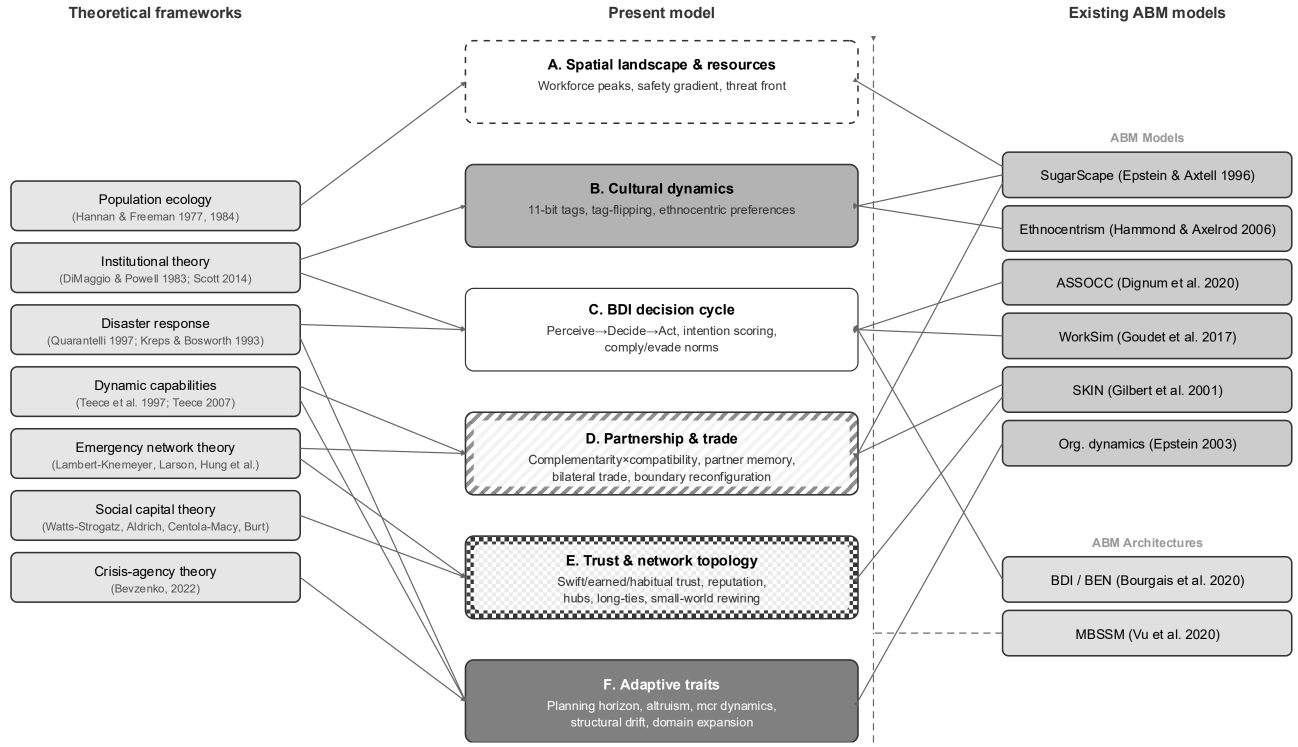

Figure 3.2. Theoretical sources and model subsystem mapping

The model's source frameworks (established models, architectures, and theories), together with interview-derived rules not captured by the 27 mechanisms, contributed additional rules that operate below the resolution of the interview data. Table 3.4 lists each one with its source and what gap it fills. These rules provide the computational infrastructure without which the 27 empirical mechanisms cannot operate: agents need to trade, form and dissolve partnerships, be born and die, pay taxes, receive subsidies, and exist in a spatial environment affected by warfare.

Table 3.4. Computational Infrastructure Rules Added During Formalization

Code	Pathway	Rule	Source framework	Gap filled
E1	SO	Multiplicative partnership scoring	Lambert & Knemeyer (2004)	Partner fit assessment
E3	SO	Phase-sensitive strategy	Larson (2012)	Crisis vs. recovery partner selection

E5	SO	Reputation diffusion	SKIN	Partner referral through networks
E6	SO	Hub coordination	Burt (2005)	Structural brokerage in relief networks
F1	SO	Social capital destruction	Aldrich (2012)	Network disruption through displacement
F2	SO	Long-tie preservation	Centola & Macy (2007)	Displaced agents retain the best partners
F3	SO	Recovery asymmetry	Aldrich (2012)	Rebuilding is slower than destruction
G1	O	Progressive taxation	WorkSim	Binding fiscal constraint
G2	O	Biased subsidies	WorkSim	Culturally weighted resource allocation
G3	O	Military funding allocation	Interviews; Ukrainian data	Echelon-weighted defense spending
H1–H4	E	Bilateral trade mechanics	SugarScape; SKIN	Resource exchange and partner memory
I1–I5	E	Warfare and infrastructure	Ukrainian wartime data: Institute for the Study of War (2026); International Organization for Migration (2022, 2024, 2025, 2026); World Bank Group, European Commission, & United Nations (2026)	Conflict scenario and damage
J1	E	Organizational splitting	SugarScape	Demographic entry by splitting
J2	SO	Spontaneous founding	Interviews	Post-invasion organizational entry

Together with the 27 empirical mechanisms, these rules complete the model rule set. Appendix D, Table D.2 lists all 38 rules together, with each rule's empirical-support assessment.

Mechanism classification

The 38 model rules jointly produce 28 Coleman-Boat causal pathways. These pathways, together with the 27 interview-coded mechanisms and the 38 rules, form three levels of formalization. Mechanisms record what was observed. Rules specify what the agent executes. Pathways reconstruct the causal chains that one or more rules jointly produce and that ground the model's causal claims.

Not every rule produces its own pathway. Perception, intention scoring, compliance action, and hierarchy drift together constitute the compliance lock-in pathway. The remaining rules map one-to-one.

These 28 pathways can be classified by their position in the micro-macro causal chain known as the Coleman Boat (Hedström & Swedberg, 1998, pp. 21–23), which has been operationalized for computational modeling (Vu et al., 2020). This classification locates each pathway at the level where it does its causal work and provides a completeness check. A generative model must contain pathways at every level of the boat to produce a full micro-macro explanation.

Applied to the model, this classification produces a 28-mechanism Coleman-Boat decomposition: 4 situational mechanisms (macro-to-micro), 13 action mechanisms (micro-to-micro), 6 transformational mechanisms (micro-to-macro), 4 feedback mechanisms, and 1 systemic mechanism (network percolation threshold). This decomposition is distinct from the 27 interview-testable mechanism inventory because it operates at the level of causal pathways rather than at the level of individual model rules: a single rule may contribute to multiple causal pathways, and a single causal pathway may aggregate the effects of several rules. The complete mapping is documented in Appendix C, Section C.4.1.

Situational mechanisms (macro-to-micro) are institutional or environmental processes through which macro-level structures constrain or enable individual agent states. The model contains four: the fiscal cycle (taxation, subsidies, and their cultural selection effects), the military mobilization pipeline (recruitment, replenishment, and unit creation), echelon rotation (the doctrinal force-structure cycle), and disaster cascading (the propagation of localized destruction through economic and network linkages).

Action mechanisms (micro-to-micro) are complete causal chains through which individual agents transform beliefs into behavior. The model contains 13. These include economic production and exchange, displacement and return migration, network-anchored resistance to displacement, compliance lock-in and evasion divergence, voluntary defense mobilization, and partnership formation.

Transformational mechanisms (micro-to-macro) are processes through which individual-level interactions aggregate into new macro-level structures. The model contains six. Cultural convergence operates through trade-partner tag-flipping. Trust dynamics follow the swift-earned-habitual trajectory. Reputation-driven network growth, hub-brokering amplification, and displacement-bridge formation through long-tie preservation complete the set, alongside structural homogenization through institutional drift.

Feedback mechanisms span multiple levels, modifying the parameters of other mechanisms over time. The model contains four: planning horizon contraction and recovery, altruism activation and decay, crisis militarization and the peace dividend (Jungle/Zoo dynamics), and domain expansion.

One systemic mechanism spans all three levels: network fragmentation, the process by which cumulative partner loss disconnects the trade network into isolated components. Whether fragmentation occurs depends on the memory-decay rate, which controls partner retention.

The Coleman Boat classification and the crisis-agency pathway classification (E/O/SO/B) cross-cut each other. Situational mechanisms can be organizational (the fiscal cycle operates through formal state institutions) or self-organizational (disaster cascading disrupts informal networks). Transformational mechanisms can be self-organizational (cultural convergence) or bridging (structural homogenization). Pathway classification identifies which adaptation mode each mechanism serves; the Coleman Boat locates it in the micro-macro causal chain. Together, they specify both the functional role and the causal level of each mechanism.

This translation produces the rule set that the survey calibrates. The full computational specification, including spatial implementation, runtime mechanics, and initialization procedures, is described in the following chapter and documented in the ODD protocol (Appendix C).

3.5. Parameter Calibration

The model specification (presented in the next section) identifies 38 rules, each carrying parameters that must be initialized from empirical distributions. Risk tolerance, organizational hierarchy, planning horizon, relocation threshold, compliance orientation, and military friendliness all require population-level values that macro statistics cannot provide and interview accounts cannot quantify. A dedicated CAWI (Computer-Assisted Web Interviewing) survey was designed to fill this gap, with questions targeting parameters identified during model construction.

The survey serves two functions. At the micro level, individual responses provide empirical distributions for agent-level parameters. Aggregate response distributions serve a second function: validation targets against which model outputs can be compared. The survey was not designed for standalone hypothesis testing. It serves the model.

Sample and data collection

The target population comprises Ukrainian organizations that operated during the full-scale russian invasion from February 2022 onward. No restriction was placed on sector, size, or ownership type. The defining criterion was direct organizational experience of adaptation under sustained warfare.

Probability sampling was infeasible. No accessible sampling frame of wartime-active organizations exists, and security conditions ruled out systematic regional outreach. Recruitment proceeded through two channels: direct messenger contact with five of the thirty-two interview respondents, and open distribution through Ukrainian professional networks and business associations. The resulting sample of 35 completed responses is a convenience sample. The five-respondent overlap with the interview sample weakens the independence of the cross-validation but does not invalidate it, and leaves parameter calibration unaffected. Results provide empirical grounding for model parameters without claiming statistical representativeness of the Ukrainian organizational population.

The survey was administered in Ukrainian via Microsoft Forms. Data collection took place from February 14 to February 27, 2026, spanning twelve days. Informed consent was obtained through the first screen. The instrument collected no names, organizational identifiers, email addresses, or IP addresses. All 35 respondents completed the full instrument with no partial abandonments. Median completion time was 8.5 minutes.

The service sector predominates, accounting for 29 respondents (82.9%), with goods and manufacturing contributing 5 (14.3%), and 1 organization operating in both sectors. Geographically, 23 organizations (65.7%) were headquartered in Northern Ukraine (Kyiv, Zhytomyr, Chernihiv oblasts), five (14.3%) in Eastern Ukraine, four (11.4%) in the South, and three (8.6%) in the West. By size, the sample spans micro-enterprises with fewer than 10 employees (six, 17.1%) to large firms with more than 250 (seven, 20.0%), with the modal category being 51 to 250 employees (twelve, 34.3%). Most respondents (27, 77.1%) held owner, top management, or senior management positions. By tenure, 80.0% had worked in their organization for more than four years.

The survey contains 38 questions organized into seven thematic sections plus two open-ended concluding questions. Each section targets a cluster of model parameters identified during the qualitative phase. Questions Q2–Q5 establish organizational profile and initial conditions. Crisis response items (Q6–Q13) capture how organizations shifted priorities between safety, business, and defense. Internal structure items (Q14–Q16) target organizational hierarchy, flexibility, and planning horizon (C1). Relocation items (Q17–Q25) target spatial dynamics (B3, B9). Partnership items (Q26–Q29) target network formation and partner selection criteria (E2, E4). Government relations items (Q30–Q33) target the compliance-evasion spectrum and mobilization impact (B6, G4, G5). Military relations items (Q34–Q36) target military cooperation patterns (K4, D1). The full questionnaire text is reproduced in Appendix B.

The mechanism inventory from the interview study defined the thematic scope. Behavioral patterns described by respondents became response alternatives. A “Difficult to say” option is available for every question. The two open-ended questions (Q37–Q38) serve qualitative face validation.

Survey results

Table 3.5 presents the parameter values derived from survey distributions. Where a parameter maps to a mechanism from the interview codebook, the corresponding code from Table 3.2 is shown; other parameters belong to mechanisms that operate below the resolution of the interview data or to computational scaffolding inherited from earlier agent-based frameworks (further documented in Appendix B, Table B.4). Items that establish organizational profile (Q2–Q5), provide contextual distributions without setting parameters (Q8–Q11, Q17), or are open-ended (Q37–38) are documented in full in Appendix B. Interview-survey cross-validation across fifteen mechanism-level comparisons is reported in the section below.

Table 3.5. Survey-Based Parameter Calibration (n = 35)

Code	Host mechanism	Survey Q	What the survey found	Committed value
–	Computational scaffolding (Lambert–Knemeyer partnership scoring)	Q28	Shared war values: 8.6%; could not single out: 34.3%; not applicable: 25.7%	Cultural similarity weight = 0.35
A3	Structural trait homophilic drift	Q14, Q15	Unchanged: 54.3%; more centralized: 14.3%; more decentralized: 17.2%	Initial hierarchy = Normal(0.63, 0.20)
A4	Endogenous risk-tolerance shift	Q13	Mean: 3.4/5 (SD = 1.19); mode: 4; skewed toward risk-seeking	Initial risk tolerance = Normal(0.60, 0.30)
–	Adaptive trait (below codebook)	Q12, Q18	Adapted to constant danger: 51.4%; improved security: 14.3%. Mean perceived safety: 2.5/5	Safety threshold = 0.35
B6	Compliance lock-in	Q31	Compliance only: 57.1%; active cooperation: 28.6%; avoidance: 8.6%; no interaction: 5.7%	Comply-evade ratio = 86/14
C1	Planning horizon contraction	Q16	Much shorter: 17.1%; somewhat shorter: 34.3%; longer: 5.7%; no change: 40.0%	Initial horizon = 0.38; three-bin agent mixture
–	Partnership memory (below codebook); computational scaffolding (SKIN partnership)	Q27	Never recovered: 14.3%; >6 months: 22.9%; 3–6 months: 17.1%; <3 months: 11.4%	Memory decay = 35 ticks; permanent loss = 14.3%
K4	Voluntary military support	Q35	Active on own initiative: 48.6%; on request: 22.9%; avoidance: 11.4%	Military friendliness = Beta(4.0, 2.1)

The calibrated values describe a population that adapted to danger rather than being overwhelmed by it. Risk tolerance skews toward risk-seeking (mean 0.60 on a 0–1 scale). Planning horizons are shortened but not collapsed (mean 0.38). Compliance dominates over evasion at roughly 86/14, though interview evidence suggests the effective ratio is closer to 80/20 once ceremonial conformity is accounted for. Military friendliness is high, with nearly half of respondents reporting active support on their own initiative. These initial conditions are consistent with Quarantelli's (2006) classification of the invasion as a disaster rather than a catastrophe.

Several survey findings that do not set parameters directly still have implications for model design. Revenue collapse (Q8) was severe: 48.6% of respondents reported drops exceeding 25%, and only 8.6% reported no change. This provides context for the financial pressure under which the calibrated parameters operate.

Workforce change (Q9) produced a sharp divergence between the two data sources. Interviews documented loss almost exclusively. By 2026, 34.3% of survey respondents reported workforce growth. A three-year gap between the invasion and the survey explains the discrepancy: organizations in safe zones that survived the initial shock had time to recover and hire. This led to bifurcating the model's attrition mechanism to allow growth in safe zones.

Priority shift data (Q10–12) are consistent with the three-phase temporal pattern (K1). Most respondents attributed the shift to habituation to constant danger (51.4%), not to improved security (14.3%). This habituation finding contributed to the safety threshold in the table: the value was adjusted downward from the model's default to reflect organizations that adapted to danger without relocating. Relocation patterns (Q17–25) show that most respondents did not relocate (57.1%), partial relocation was far more common than full (28.6% vs. 5.7%), and early movers acted within the first two weeks.

Two areas remain unresolved. Partner selection criteria (Q28) were ambiguous: most respondents could not isolate a single criterion, leaving the cultural similarity weight (0.35 in the table) weakly grounded. Survey data also cannot distinguish ritual compliance from substantive compliance. The raw 86/14 split includes respondents who reported formal adherence while privately practicing evasion, which is why the cross-validation-adjusted 80/20 ratio is tested as a robustness check.

The convenience sample of 35 organizations overrepresents the services sector (particularly IT), Kyiv-based organizations, and medium-sized firms. A cross-sectional design captures respondents' current states and retrospective reports over a three-year interval, introducing recall bias. Several model parameters remain uncalibrated by the survey. Tax rates, revenue coefficients, structural trait drift rates, and metabolism parameters are explored through sensitivity analysis instead. Survival bias is inherent: only organizations that survived to 2026 could respond. How these survey distributions relate to the interview findings is assessed in the following section.

3.6. Interview-Survey Cross-Validation

Fifteen mechanism-level comparisons are possible where both the interviews and the survey provide evidence for the same mechanism. Following cross-validation logic in mixed-methods instrument development (Creswell & Plano Clark, 2018), convergence between sources strengthens confidence in a finding, divergence signals either a genuine difference or a methodological artifact, and complementarity shows that one source provides evidence the other cannot. This section synthesizes all three. The full cross-validation with interview code counts, survey distributions, and verdicts is documented in Appendix B, Table B.3.

Nine of the fifteen comparisons showed convergence across the two sources. Planning horizon contraction (C1), voluntary military support (K4), the three-phase temporal pattern (K1), and mobilization (G4) received strong convergence: large S-code counts in the interviews and consistent population distributions in the survey. Domain expansion (B7) converged indirectly through open-ended survey responses rather than closed items. Compliance lock-in (B6) converged with a qualification: the survey captured the overall comply-evade split, but only the interviews revealed the ceremonial conformity layer beneath it. Structural trait drift (A3) converged at a weaker magnitude than interviews suggested: most survey respondents reported unchanged decision-making. COVID pre-adaptation (J3) converged, with open-ended responses adding qualitative depth beyond what the closed items captured. Partnership disruption and recovery (E2, E4) converged on the centrality of partner loss in wartime adaptation, with the survey adding a permanent-loss component (14.3% of organizations reported partnerships that never recovered) that was incorporated into the model.

Three comparisons showed mechanism-level divergence. Risk tolerance (A4) was divergent by design rather than by contradiction: interviews captured how risk appetite changed during the war (leading to its reclassification as an endogenous trait), while the survey, administered at a single point in time, captured where organizations ended up after the shift. Both sources are consistent with the reclassification. Cultural similarity in partner selection (A2) was divergent in interpretation: the interviews implied a threshold filter shaped by the wartime pro-Ukrainian split, while only 8.6% of survey respondents named shared values as the primary partnership criterion and 34.3% reported no single dominant criterion, indicating a weight rather than a dominant rule. Workforce attrition (A1, I4) was divergent in temporal scope: interviews documented loss almost exclusively, while 34.3% of survey respondents reported growth by 2026. The three-year gap between data collection points explains this discrepancy, and it led to bifurcating the model's attrition mechanism.

Three findings were complementary, with each source providing evidence that the other could not. Habituation to danger was a survey-dominant finding: the forced-choice format isolated it as the most common transition trigger (51.4%), which interviews had described but could not quantify. Burnout was an interview-dominant finding: cumulative exhaustion appeared across 12 X-coded passages, but the survey lacked a burnout-specific item and could not measure it. International market buffer was a survey-dominant finding emerging in 2026: several respondents reported that 100% external clients had been the primary survival factor, a pattern that was not salient in the 2022–2023 interviews and that motivated explicit treatment of cross-border revenue in the model.

The convergence of interview and survey evidence supports six revisions to the model design. First, the safety threshold incorporates a habituation component rather than responding only to objective threat levels. Second, the hierarchy drift rate is reduced to match the survey finding that most respondents reported unchanged governance. Third, risk tolerance is reclassified as an endogenous adaptive property. Fourth, the attrition mechanism is bifurcated to allow workforce growth in safe zones. Fifth, a permanent partnership loss fraction (14.3%) is added alongside memory decay. Sixth, the comply-evade initialization is set at 86/14 from Q31, with the cross-validation-adjusted 80/20 ratio tested as a robustness check. All six revisions have been incorporated into the model.

Chapter 3 Conclusions

This chapter produced four outputs for model construction. First, the interview study established an inventory of 27 mechanisms of organizational adaptation (Table 3.2), classified by their role in the crisis-agency framework: 11 environmental, 2 organizational, 10 self-organizational, and 4 bridging. Second, the formalization step translated these mechanisms into model rules (Table 3.3), adding computational infrastructure from six established agent-based frameworks (Table 3.4). Third, the survey calibrated eight parameter sets from population distributions (Table 3.5). Fourth, the demand classification (Table 3.1; building on Serdyuk, 2023) identified six classes of organizational demands generated by the invasion and mapped each mechanism to the demands it addresses.

The demand-pathway mapping reveals a central empirical pattern. Employee safety is addressed by 11 of 27 mechanisms, spanning environmental adaptation, network-based responses, and voluntary expansion of organizational mandate. No organizational-pathway mechanism addresses safety. Military support activates eight mechanisms, heavily concentrated in the self-organizational pathway; the sole organizational-pathway contribution is mobilization (G4), through which the state imposed the demand rather than helping organizations meet it. Both adaptation pathways are simultaneously active across the sampled population, but self-organization carried the heavier empirical load. This addresses the empirical precondition of the dissertation's scientific problem: the interaction between organizational and self-organizational adaptation is not hypothetical but empirically documented.

Three categories of questions exceed the reach of the empirical methods used in this chapter, regardless of sample size. First, relative influence: the interviews identify 27 mechanisms but cannot determine which contribute most to producing observed macro-level patterns. This is the equifinality problem (Grimm & Railsback, 2012): multiple distinct mechanisms can generate the same aggregate outcome, and resolving it requires systematically toggling mechanisms while observing whether target patterns persist. Second, counterfactual comparison: the data document what happened under one configuration but cannot show what would have happened under different initial conditions. Third, system-level dynamics: the data cannot identify population-level tipping points, test whether the wartime transformation is reversible, or determine whether early-warning signals precede organizational collapse.

Limitations of both the empirical design and the model scope are documented in Sections 3.1 and 3.3. Both convenience samples (32 interview respondents, 35 survey respondents) overrepresent the services sector, Kyiv-based organizations, and medium-sized firms. Results provide empirical grounding for model construction without claiming statistical representativeness.

The following chapter describes the computational architecture that implements the rules specified here: the spatial environment, the agent cognitive cycle, the runtime mechanics, and the validation protocol.

CHAPTER 4

FROM MECHANISMS TO MODEL: AGENT-BASED FORMALIZATION

The preceding chapter produced the empirical inputs for model construction. Twenty-seven mechanisms of organizational adaptation were identified through interviews, translated into thirty-eight computational rules with the help of six source frameworks, and classified by their position on the Coleman Boat. A dedicated survey then calibrated the distributional parameters. Together, these outputs define what the model must implement.

This chapter builds that model. It proceeds from method justification (why agent-based modeling is the appropriate approach), through a review of simulation and agent architectures (what design options are available), to the choices that translate the empirical rules into model form. The resulting model is validated in the following chapter and used as a computational laboratory in the chapter after that.

4.1. Agent-Based Modeling as a Sociological Method

The system under investigation exhibits general complexity (Byrne, 1998): its outcomes are emergent, non-reducible, and path-dependent, arising not from simple rules producing orderly patterns (rigid complexity) but from interactions whose consequences cannot be derived from the components without running them. Sociology has increasingly recognized that social systems are inherently non-equilibrium: they pass through phase transitions, lock into path-dependent trajectories, and produce emergent structures that resist analytical decomposition (Anzola et al., 2017). Agent-based modeling is the natural computational tool for studying such systems because it preserves the heterogeneity and interaction structure that generate the non-equilibrium dynamics.

Definition and sociological positioning

Agent-based modeling (ABM) is a computational approach in which autonomous, heterogeneous agents follow behavioral rules and interact within an explicit environment

(Epstein & Axtell, 1996). Rather than fitting aggregate equations to observed patterns, ABM specifies micro-level rules and lets macro-patterns emerge from the bottom up. Epstein and Axtell called this the generative standard of explanation: a social regularity is considered explained only when one can show that it arises from plausible individual-level mechanisms. The central question shifts from "can you explain it statistically?" to "can you grow it?" (Epstein & Axtell, 1996, p. 14).

The generative stance carries a sociological commitment that positions ABM within a specific tradition of social explanation. Sociology, on the analytical-mechanistic view, should identify the mechanisms through which social phenomena are generated rather than merely demonstrate statistical associations between variables (Hedström & Swedberg, 1998). ABM operationalizes this commitment: it requires the researcher to specify what actors do, how they interact, and what aggregate outcomes these interactions produce. The resulting explanation is mechanistic in the analytical-sociological sense, identifying recurrent causal sequences (Hedström & Bearman, 2009) rather than estimating regression coefficients. Two decades of sociological applications across cooperation, social norms, cultural dynamics, segregation, and collective behavior have confirmed that this capacity to connect micro-behavior to macro-structure through explicit mechanisms is what makes ABM a sociological method rather than merely a technical tool (Bianchi & Squazzoni, 2015).

Following Edmonds et al.'s (2019) purpose taxonomy, the present model is built for two purposes: explanation (identifying which mechanisms produce the observed adaptation patterns and how they interact) and exploration (revealing thresholds, regime shifts, and irreversible changes that no theory predicted and no fieldwork could observe). The model does not predict specific future outcomes. It operates at the restricted end of Byrne's (1998) complexity spectrum, generating population-level patterns from individual-level rules without claiming that these patterns are irreducible to those rules (Bedau, 2003).

Historical development

ABM's development spans five decades, from foundational demonstrations of emergence through empirical engagement to contemporary methodological rigor. Schelling's (1971) checkerboard model showed that mild preferences for same-group neighbors could produce stark residential segregation, establishing that aggregate patterns need not reflect the intensity of individual preferences. Epstein and Axtell's (1996) Sugarscape generated trade, wealth inequality, cultural groups, and combat from a single landscape of foraging agents, establishing ABM's three cornerstones: explicit agents, space, and time. The Anasazi project (Dean et al., 2000) demonstrated that ABM could engage with specific empirical systems by simulating 700 years of settlement dynamics using archaeological evidence. Grimm and colleagues developed the ODD protocol (Grimm et al., 2006), which became the standard for documenting and comparing ABMs across research groups. The COVID-19 pandemic demonstrated ABM's policy relevance at scale, with agent-based models informing public health interventions worldwide (Squazzoni et al., 2020; Lorig et al., 2021). The current frontier is shaped by inverse generative social science, which starts with observed macro-patterns and searches backward for micro-rules that can produce them (Epstein, 2023).

Agent-based modeling arrived in Ukrainian social science in the early 2010s, roughly two decades after its consolidation in Western research communities. Each application addressed a problem of immediate societal relevance. Paniotto and Hrushetskyi (2013) reviewed methods for modeling language dynamics, arguing that ABM's value lies in understanding processes and exploring scenarios rather than producing point forecasts. Venhrina (2012) modeled language stability and shift, showing how individual choices aggregate into emergent structures, while Hrushetskyi (2013) simulated Ukraine's linguistic landscape under alternative scenarios. Moskotina (2019, 2021) demonstrated how verbal theories can be translated into executable code, testing Granovetter's weak-ties hypothesis in the context of protest mobilization. Beyond language, Pugachova's income-redistribution model (2019) examined how tax regimes and rent-seeking influence class structure, her electoral model with Solovienko (2010) explored how propaganda and voter intolerance shape outcomes, and her epidemic-economy model (2021) coupled disease spread with socio-economic feedback.

The author applied ABM to wartime university adaptation in two related studies, testing relocation, merger, and online transition as adaptation strategies (Serdyuk, 2025a) and examining the policy dimension of these responses (Serdyuk, 2025c).

The present dissertation applies ABM to the organizational consequences of the full-scale russian invasion, extending the Ukrainian ABM tradition to the central problem in Ukrainian social science at the time of this research.

Method selection

The epistemological case for ABM, established above, must be operationalized for this specific research context. Roughly four out of five published ABM studies have been found to rely on ad hoc behavioral assumptions rather than theory-driven mechanisms, with a substantial share applying ABM to deterministic systems for which established analytical solutions already exist (Conte & Paolucci, 2014). To guard against selecting ABM on the basis of technical appeal rather than analytical appropriateness, the author developed an eight-criterion ABM Applicability Assessment Framework (Serdyuk, 2026). The framework comprises seven positive criteria scored 0 to 2 (discrete autonomous entities, meaningful heterogeneity, local or network interactions, feedback mechanisms, path dependence, emergent properties, and research question type), minus a penalty for the existence of analytical solutions. The total score classifies ABM fitness as high (11–14), moderate (7–10), or low (below 7). The criteria are ordered by assessment difficulty, reflecting an inherent paradox: the properties that most strongly warrant ABM (emergence, path dependence) are precisely those that cannot be fully verified without building a model. The framework manages this by requiring conservative scoring on the difficult criteria. Validation across 18 Ukrainian ABM studies showed that path dependence and emergence are the criteria most strongly correlated with appropriate ABM use (Serdyuk, 2026).

Table 4.1 presents the ex-ante application to the present research context.

Table 4.1. Ex-ante ABM applicability assessment

Criterion	**Score**	**Justification**
C1: Discrete autonomous entities	2	Three agent types with independent decision logic
C2: Meaningful heterogeneity	2	Distinct sectors, sizes, cultural profiles, structural orientations
C3: Local/network interactions	2	Proximity-based trade; network-mediated information diffusion
C4: Feedback mechanisms	2	Relocation changes local conditions; government responds to aggregate behavior
C5: Path dependence	2	Different initial configurations expected to produce divergent trajectories
C6: Emergent properties	1	Migration waves, network restructuring expected but unconfirmed ex ante
C7: Research question type	2	Mechanistic and exploratory, not optimization or prediction
C8: Analytical solution exists	0	No established solution for simultaneous spatial, network, cultural, and institutional dynamics under warfare
Total	12	High fitness (11-14 range)

Note. Developed by the author (Serdyuk, 2026). Subsequent modeling confirmed emergence (C6 would revise to 2, raising the total to 13); the ex-ante score is retained as the honest pre-modeling assessment.

The score of 12 places this research in the high-fitness category. The research questions confirm the assessment independently: each asks “how does X arise from Y?” rather than “what predicts X?” The generative form of the questions requires a generative method.

Limitations

Despite its capacity to model emergent phenomena, ABM faces epistemological and practical limitations. The most consequential is equifinality (multiple distinct mechanisms producing the same macro-level outcome): successfully reproducing an observed pattern does not prove that the modeled mechanisms actually operate (Grimm & Railsback, 2012; Serdyuk, 2025b). Stochasticity compounds this problem, as each run produces different trajectories even with identical parameters, making ABM better suited to bounding outcomes than to forecasting exact magnitudes (Lee et al., 2015; Epstein, 2008). The formalization problem adds another layer: Muelder and Filatova (2018) showed that different algorithmic translations of the same theory can produce substantially different outcomes, meaning that coding choices carry as much explanatory weight as the theory itself. System observability constrains validation directly, since the micro-interactions that constitute the model's explanatory contribution are precisely those hardest to observe empirically (Serdyuk, 2025b). Computational complexity creates practical barriers, as global sensitivity analysis may require thousands of parameter combinations (Lee et al., 2015).

This dissertation addresses each limitation through specific design choices reported in subsequent chapters. Equifinality is addressed through pattern-oriented validation against 43 empirical patterns across eight domains, so that reproducing any single pattern is insufficient. Stochasticity is addressed through Monte Carlo ensembles of 30 to 200 replications per experimental condition. The formalization problem is mitigated by the KIDS orientation (described in the architectures section below), which grounds every model rule in documented empirical evidence rather than ad hoc assumptions. Observability is addressed through the author's validation method selection framework (Serdyuk, 2025b), which maps twelve validation methods to combinations of model purpose, system observability, and development stage. Computational complexity is managed through Morris elementary effects screening, which identified influential parameters before the full experimental program.

4.2. Simulation and Agent Architectures

Architectural decisions in agent-based modeling operate at two levels: the simulation system (how agents, environments, and schedules are organized) and the individual agent (how each entity perceives, reasons, and acts).

Simulation-level architectures

The most basic architectural choice is how much descriptive detail a model should contain. The dominant tradition follows the KISS principle (Keep It Simple, Stupid): start simple, add complexity only when needed. Edmonds and Moss (2004, p. 133) challenged this position, arguing that simplifying before you know what matters is unjustified. Their analogy: a naturalist sketching a newly discovered species should not draw stick figures "for the sake of simplicity," because the distinguishing details might not be apparent until many specimens have been examined. Their alternative, KIDS (Keep It Descriptive, Stupid), starts with a model as descriptively rich as the evidence allows, then simplifies only where justified. A key advantage is that richer models can be validated against qualitative evidence, such as expert accounts and case studies, that abstract models have no contact with. The trade-off is real: KISS models are easier to analyze and replicate, but may discard the very mechanisms that produce the target phenomenon. KIDS models are empirically richer but harder to diagnose. Most working models fall somewhere between the two poles (Edmonds & Moss, 2004).

Vu et al. (2020) developed the MBSSM architecture (Mechanism-Based Social Systems Modeling), which organizes agent-based models around explicit social mechanisms, drawing on the Coleman Boat from analytical sociology. It decomposes social explanation into three mechanism types: situational (macro shapes micro), action (micro produces micro), and transformational (micro aggregates into macro). Each mechanism is implemented as a distinct component with defined inputs and outputs, making the model's explanatory claims auditable. A key design choice in MBSSM is its adoption of the general micro-macro scheme rather than strict methodological individualism. This allows macro-to-micro mechanisms, such as government policy constraining organizational behavior, without forcing them through implausible individual-to-individual chains (Vu et al., 2020). The trade-off is that the mechanism decomposition requires strong theoretical commitments about which mechanisms are at work, which may be premature for poorly understood systems.

As models grow in scope, monolithic designs become hard to validate. Cottineau et al. (2015) demonstrated a modular approach in which competing hypotheses are formalized as interchangeable components, assembled into configurations, and calibrated using evolutionary algorithms. This converts equifinality (the problem of multiple mechanisms producing the same outcome) from an obstacle into a research design: configurations that fail to reproduce target patterns are systematically eliminated. This approach responds to Muelder and Filatova's (2018) finding that different algorithmic translations of the same theory can produce substantially different outcomes. The cost of modularity is integration complexity: ensuring independently developed components interact correctly requires careful interface design.

Pattern-Oriented Modeling (POM; Grimm & Railsback, 2005, 2012) uses the simultaneous reproduction of multiple empirical patterns as the criterion for accepting or rejecting model structures. Requiring a model to match patterns at multiple scales constrains the space of possible mechanisms far more tightly than fitting a single aggregate outcome. Grimm and Railsback (2012) distinguish strong patterns (spatial structures, cycles) from weak patterns (directional trends, qualitative regularities), and argue that multiple weak patterns at different levels can achieve higher structural realism than a single strong one. The strongest evidence that a model captures real mechanisms is when it reproduces patterns that were not considered during calibration. POM is one of the most principled responses to equifinality currently available, though it depends on the modeler's judgment in selecting which patterns to target (Grimm & Railsback, 2012).

Agent-level architectures

Reactive agents map perceptions directly to actions through condition-action rules, without internal beliefs, goals, or plans. SugarScape and the Hammond and Axelrod ethnocentrism model exemplify this approach: agents use a cultural tag to cooperate with in-group members and defect against out-group members, producing complex population dynamics from simple rules (Hammond & Axelrod, 2006, pp. 928-929). Reactive architectures are computationally cheap and analytically transparent: the causal chain from rules to outcomes is unambiguous. They fail, however, when agents must balance conflicting demands. Since reactive rules cannot represent multi-goal trade-offs, the modeler must pre-resolve conflicts in the rule design, potentially predetermining the dynamics the simulation was meant to investigate.

The Belief-Desire-Intention (BDI) architecture, rooted in Bratman's (1987) theory of practical reasoning, is the dominant framework for deliberative agents. An agent updates its beliefs from percepts, selects plans whose starting conditions match current beliefs and goals, commits to one as an intention, and executes it. De Silva, Meneguzzi, and Logan (2020) survey the key dimensions along which implementations vary: belief representation, goal structure, plan composition, and failure handling. Full BDI provides the richest representation for agents weighing competing goals. The cost is computational: maintaining plan libraries at each cycle scales poorly with population size, and specifying plans requires detailed empirical data on agents' internal organization, which is rarely available in social science. Taillandier et al. (2017) addressed this by developing a simplified BDI for the GAMA platform, replacing plan-library search with rule-based scoring while preserving the perceive-deliberate-act cycle.

Bourgais, Taillandier, and Vercouter (2020) extended BDI into the BEN architecture, adding four optional components on an OCEAN personality foundation: cognitive deliberation, emotional appraisal, normative compliance, and social relations (liking, dominance, trust). Each component can be activated or deactivated independently, so modelers use only what their simulation needs. BEN's modularity is its main strength: selective activation avoids unnecessary overhead. The full architecture, however, demands extensive parameterization across modules. When empirical data about agents' internal profiles are unavailable, additional parameters may reduce rather than increase credibility.

Hybrid designs combine a reactive layer for urgent responses with a deliberative layer for longer-term planning. ASSOCC (Dignum et al., 2020), reviewed in the preceding chapter, demonstrated that scoring competing needs using weighted formulas can capture essential crisis decision-making at a computational cost compatible with large populations. The key design decision in hybrid architectures is where to draw the boundary between reactive and deliberative processing. This boundary embeds assumptions about which behaviors are automatic and which require deliberation, and should ideally be grounded in empirical evidence about real decision-making patterns.

4.3. Model Design Choices

The mechanism specification established in the preceding chapter defines what the model must implement. This section explains the design choices that determine how:

which entities populate the model and why, how space and time are represented, and which cognitive architecture governs agent behavior.

Entities, space, and time

The theoretical framework and the empirical evidence established organizations as heterogeneous, spatially situated, boundedly rational collective actors that pursue goals, maintain workforces, adapt their internal structures, form networks, and operate under governmental constraints. Ukraine had approximately 308,000 active enterprises in 2023 (State Statistics Service of Ukraine, 2024). The model represents them through 800 civilian agents at an approximate 1:400 scale. The mapping ratio reflects the computational cost of the experimental design: 160 structural configurations, each requiring 30 replications over 500 ticks, make it impractical to use larger agent populations within available resources.

The government and the military are the two external forces most consequential in shaping the organizational environment during the invasion. Both were identified as primary agents of the emergency state in the theoretical analysis (Makeiev, 2022; Bevzenko, 2022), and both recurred consistently in the interviews, where government interaction and voluntary military support were among the most frequently coded patterns. These become the model's other two agent types: 120–140 military organizations, each representing one brigade-equivalent formation (a unit of several thousand soldiers) matching Ukraine's approximately 130 brigades, and a single government super-agent. The military population changes through mobilization (the government creates new units from the recruit pool) and combat attrition (units die when resources are exhausted).

Enemy forces are deliberately omitted. The model studies Ukrainian organizations' adaptation mechanisms, not the adversary's behavior. The enemy is represented through the exogenous environment: the advancing threat front, the rear-area strike system, and the nine-phase scenario schedule. This follows the distinction between agent-generated demands (threats and disruptions caused directly by the invasion) and response-generated demands (new pressures created by Ukraine's own organizational responses): the adversary generates the demands, but the organizational response is what the model investigates.

The temporal scale is set at 1 tick = 3 days. The nine-phase scenario schedule maps onto the six-phase crisis periodization developed in the wartime environment analysis, covering the period from the February 2022 invasion through late 2024. A default run of 300 ticks covers approximately 900 days, or roughly 2.5 years from the invasion date. The 3-day resolution balances the need to capture rapid early-phase dynamics against computational feasibility. The fastest organizational responses documented in the interviews (initial relocation decisions, emergency military support) occurred over periods of days, not hours, making a 3-day time step consistent with the temporal grain of the empirical evidence.

The spatial dimension is represented by a 51 × 51 non-wrapping patch grid with an east-to-west safety gradient. The frontline sits at the eastern edge; safety increases toward the west. Eight urban workforce centers are distributed asymmetrically, with higher capacity peaks in the west and lower peaks in the east, mirroring Ukraine’s population distribution. This is explicitly not a geographic map: the model does not attempt to reproduce exact spatial distributions of agents, workforce, or migration routes. The spatial abstraction is sufficient for the mechanisms under investigation (safety-driven relocation, network anchoring, cultural clustering, compliance/evasion trajectories) because they depend on relative safety gradients and proximity-based interactions rather than on the specific geometry of the frontline.

Economic activity is represented through bilateral trade using SugarScape’s geometric-mean pricing mechanism, a two-sector goods/services structure, workforce as a depletable resource tied to spatial availability, and government taxation/subsidies as the fiscal channel. This captures the essential dynamics documented in the wartime environment analysis (revenue collapse, fiscal recovery, workforce depletion) without modeling specific industries or supply chains. The government’s effective tax rate of 0.27 represents the aggregate tax-to-GDP ratio rather than any single statutory rate, since the model consolidates the simplified regime and the general tax system into a single fiscal channel (Ministry of Finance of Ukraine, 2024; Kyiv School of Economics, 2024;

Bogdan, 2024). A spending floor decouples fiscal expenditure from institutional capacity during crisis phases, reproducing the Ukrainian fiscal collapse-and-recovery trajectory, in which the government maintained essential expenditure through international borrowing even as domestic tax collection collapsed in early 2022.

Agent architecture

The entities, spatial structure, and temporal scale define the world the agents inhabit. How those agents perceive, reason, and act within it depends on the cognitive architecture. The mechanisms classified in the preceding chapter place specific demands on this architecture: some mechanisms require agents that weigh competing goals, others require agents that can obey or resist institutional rules, and others require traits that change endogenously over time. The architectural options reviewed in the preceding section define the design space; this subsection explains which options were selected and why.

The first choice concerns the level of descriptive detail. The preceding section introduced the KISS and KIDS approaches. Because the empirical work produced a large set of empirically grounded mechanisms whose relative importance is unknown in advance, and because the experimental program is designed to determine which mechanisms matter through systematic toggling, the KIDS orientation is adopted here. The model begins with all documented mechanisms represented and uses experiments to determine which can be simplified or removed.

The interviews documented that the same organization shifted priorities across war phases, weighing safety against profit, compliance against evasion, and defense contribution against operational continuity. Reactive condition-action rules cannot represent these trade-offs. Worse, reactive rules would require the researcher to hard-code goal priorities, predetermining the very dynamics of structural drift that the model investigates.

Full BDI was rejected for two reasons. First, maintaining plan libraries across approximately 1,000 agents, 300+ ticks, and 160 configurations in NetLogo is computationally prohibitive. Second, the interview data reveal which goals organizations pursued and what actions they took, but not their internal plan structures. Specifying detailed plans would require unsupported assumptions, violating the KIDS principle.

The chosen architecture keeps the core BDI insight: agents maintain beliefs, pursue multiple goals, and commit to intentions. Implementation uses a scoring mechanism inspired by ASSOCC, with a three-phase cognitive cycle from BEN: perceive (update safety, financial trend, partner reliability), decide (score intentions, pick the highest), act (execute). Scoring formulas incorporate beliefs, structural traits, risk tolerance, and two adaptive traits (planning horizon, altruism) as weights. This produces heterogeneous behavior without plan libraries, and because all weights are documented, alternative operationalizations can be compared directly (Muelder & Filatova, 2018).

From BEN's normative engine, the model borrows the concept that agents can obey or violate rules, represented as comply/evade intention pairs. Interview evidence supports this binary framing: organizations described their government stance as cooperation versus resistance, not in terms of differentiated norm types. The full normative engine is not needed here.

Two adaptive traits replace BEN's OCEAN personality model, which is designed for individual humans and lacks meaning at the organizational level. The planning horizon captures a crisis-induced temporal reorientation, documented across 26 interview passages with no contradictions: organizations under sustained threat shift from reactive to strategic thinking. Altruism captures volunteer mobilization documented across 22 interview passages with no contradictions: in the face of institutional failure and visible peer distress, organizations spontaneously redirect resources to defense and mutual aid. Both represent behavioral consequences of organizational crisis responses without modeling internal psychological states (Bevzenko, 2022).

BEN's five-dimensional social relations module assumes a psychological approach to interpersonal relations. The model replaces it with two organizational-level mechanisms: cultural similarity using 11-bit tags from Epstein and Axtell (1996, p. 73) combined with the in-group favoritism mechanism from Hammond and Axelrod (2006, pp. 928–929), and the three-route trust model from Hung et al. (2004, p. 4), which tracks swift, earned, and habitual trust through transaction history.

Two reactive overrides fire before the deliberative scoring process. A relocation override triggers when an organization's safety perception, blended with information from its trade partners, drops below a threshold modulated by risk tolerance and trade-link count. A return-home override fires when the origin has recovered sufficient safety. These reflect the empirical observation that relocation decisions are triggered by immediate danger, not strategic calculation, while return decisions involve assessing both current and origin conditions.

This hybrid structure produces emergent spatial differentiation. Organizations in safe areas operate through stable deliberative cycles; those near the front alternate between reactive relocation and deliberative recovery. Well-connected organizations relocate later because network information dampens local volatility, creating a network-modulated migration wave that could not arise in either a purely reactive or purely deliberative model.

Five requirements shaped the overall design. Testing mechanisms across causal levels (macro-to-micro taxation, micro-to-micro trade, micro-to-macro migration) required explicit mechanism decomposition (Vu et al., 2020). Grounding the model in interview data required a KIDS orientation (Edmonds & Moss, 2004). Comparing 160 configurations required a modular toggle-based design (Cottineau et al., 2015). Representing competing organizational goals required deliberative agents, but computational and empirical constraints mandated scoring rather than plan-library search. Validation follows the pattern-oriented modeling approach (Grimm & Railsback, 2005, 2012): the model is tested against multiple empirical patterns simultaneously, spanning fiscal indicators, displacement flows, survival rates, and structural change rates, so that reproducing any single pattern is insufficient to pass.

4.4. Model Description

The description follows the ODD protocol (Grimm et al., 2006, 2020), proceeding from entities and scales through initialization and scheduling to the key submodels. A complete ODD specification, including full parameter tables and submodel equations, is provided in Appendix C.

The model is implemented in NetLogo 7.0.3, chosen for rapid prototyping and visual debugging during the KIDS development cycle, where direct observation of agent behavior was essential for model rule verification, and for BehaviorSpace integration enabling systematic parameter sweeps across 160 configurations. Table 4.2 summarizes the model's principal attributes.

Table 4.2. Model summary

Attribute	Value
Spatial scale	51 × 51 patch grid (abstract landscape)
Temporal scale	1 tick = 3 days; 300 ticks ≈ 2.5 years
Agent population	800 civilians, 120–140 military, 1 government
Network layers	5 link breeds (trade, supply, requisition, coordination, long-tie-viz)
Model rules	38 (27 interview-testable, 11 computational scaffolding)
Structural toggles	cultural-transmission?, trust-enabled?, reputation-enabled?, hub-brokering-enabled?, long-ties-enabled?
Scenario	9 war phases
Society presets	5 (baseline, total-defense, decentralized, centralized, dual-economy)
Total configurations	5 presets × 2^5 toggles = 160
Stochasticity	random agent initialization and placement, front-line jitter, random disaster occurrence and placement, stochastic recruitment and splitting, stochastic decisions inputs

The model contains four entity types and five breeds of network links. A typical simulation includes 2,601 patches (a 51 × 51 grid), 800 civilian organizations, 120–140 military organizations, and a single government super-agent.

Figure 4.1 summarizes the four entity types, their principal state variables, the five link breeds that connect them, and the directional relationships through which entities interact.

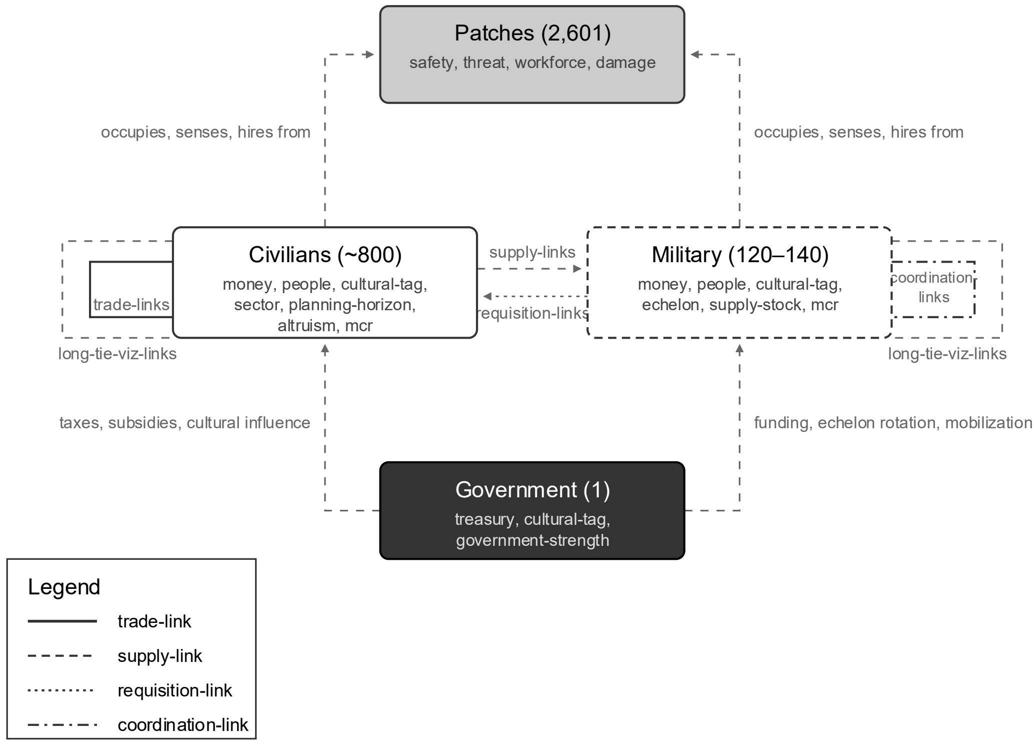

Figure 4.1. Entity types and link breeds

Patches represent spatial units holding state for safety, threat level, workforce, cumulative infrastructure damage, and disaster effects. Eight asymmetrically distributed urban-center workforce peaks (higher density in the west) loosely correspond to Ukraine’s population distribution.

Civilian organizations are the primary agents. Each represents a commercial entity (enterprise, firm, or NGO) that produces goods or services, trades with partners, pays taxes, may relocate under threat, and can develop military support functions through domain expansion. Civilians carry approximately 35 state variables spanning financial reserves, workforce, sector, an 11-bit cultural tag, structural and adaptive traits, partner memory with trust values, and a simplified BDI cognitive state. Full state-variable tables are in Appendix C.

Military organizations represent brigade-level formations that project safety through presence, share situational awareness, requisition supplies, and rotate through three echelons (front, operational, reserve). They share most state variables with civilians, adding echelon assignment, cooperativeness toward civilians, and long-tie partner lists for cross-front information exchange. Military units are initialized at 120–140 and change through mobilization and attrition.

Government is a single super-agent that collects taxes, distributes subsidies and military funding, manages the personnel pipeline (recruitment, replenishment, unit creation, echelon rotation), and broadcasts cultural influence. Its institutional capacity varies by war phase, rising from near zero during the initial chaos to moderate levels as the state reconstitutes.

Five breeds of undirected links connect organizations: trade-links (civilian-civilian exchange), supply-links (civilian-military voluntary provision), requisition-links (forced extraction), coordination-links (military-military), and long-tie links (preserved long-distance partnerships, operationalizing Watts-Strogatz small-world rewiring through displacement). All links carry weight, recency, and frequency.

At model scale, one model person corresponds to approximately 189 real people (derived from the military-people-cap of 4,800 representing approximately 907,000 total military headcount). The 800 civilian organizations represent Ukraine's commercial sector at approximately 1:400 scale; the 120–140 military organizations represent Ukraine's approximately 130 brigade-equivalent formations. Approximately 200 global parameters govern scoring weights, thresholds, rates, and calibration constants.

Five society presets define structural configurations for counterfactual experiments, each operationalizing a distinct theoretical proposition from the wartime environment analysis by modifying agent properties at initialization without altering the landscape or scenario schedule. Centralized and decentralized test institutional theory's predictions about hierarchy and government control. Dual-economy tests what happens when all organizations are internal civilian-military hybrids from the start, approximating a total-war mobilization economy. Total-defense represents the Ukrainian model of high civilian-military cooperation while remaining inherently civilian. Baseline applies no modifications, reproducing the pre-invasion Ukrainian configuration. Exact parameter modifications for each preset are documented in Appendix E.

In terms of the crisis-agency framework, the centralized preset maximizes the organizational mechanism and suppresses self-organizational capacity. The decentralized preset structurally favors the self-organizational mechanism. The total-defense preset front-loads self-organizational capacity while retaining civilian identity. The dual-economy preset dissolves the organizational / self-organizational boundary by making all organizations internal hybrids. The baseline reproduces the empirical Ukrainian configuration. Crossed with five transformational-mechanism toggles (cultural-transmission?, trust-enabled?, reputation-enabled?, hub-brokering-enabled?, long-ties-enabled?), with mobilization always active as a situational precondition, the presets produce $5 \times 2^5 = 160$ experimental configurations. Exact parameter values for each preset are provided in the supplementary ODD (Appendix C).

Initialization establishes the model state at tick 0. 800 civilian organizations are placed near workforce peaks, each assigned to a size class drawn from the national enterprise size distribution, with resources scaled by tier. Sectors are randomly assigned (50% goods, 50% services). Cultural tags are random 11-bit strings with west-biased probability, generating maximum initial diversity. Structural traits start at moderate levels with a slight skew toward hierarchy, reflecting pre-invasion Ukrainian organizational norms. The 120–140 military units use a 73/27 frontline-to-rear distribution, high hierarchy, low flexibility, and cultural tags inherited from the government with a 10% per-locus mutation rate. The government starts with a treasury representing approximately five days of wartime expenditure at institutional capacity 0.10 and tax rate 0.27 (the Ukrainian mean corporate income tax rate). Full initialization parameter ranges are in Appendix C.

The warfare scenario is divided into nine phases, each specifying a front movement direction, intensity, and government institutional capacity. Table 4.3 specifies the phases that drive the threat front, intensity, and government strength over time.

Table 4.3. Scenario schedule (nine war phases)

Phase	Ticks	Direction	Intensity	Government strength	Description
0	0–30	advance	0.50	0.10	Rapid invasion; government near-collapse
1	30–50	hold	0.00	0.20	Stabilization; minimal recovery
2	50–80	retreat	0.30	0.30	Counteroffensive; growing capacity
3	80–110	hold	0.00	0.40	Consolidation; institutional rebuilding
4	110–160	advance	0.15	0.50	Grinding war; government at half capacity
5	160–200	retreat	0.10	0.55	Attrition-phase pushback
6	200–250	advance	0.08	0.50	Stalemate oscillation
7	250–300	retreat	0.08	0.50	Stalemate oscillation
8	300+	hold	0.00	0.50	Frozen conflict; no front movement

During advance phases, the front drifts westward at a rate proportional to intensity; during retreat phases, it drifts eastward. Hold phases produce no directional drift; the front evolves only through stochastic jitter and neighbor smoothing. Government strength at tick 0 is 0.10, representing near-total institutional paralysis in the first days of the full-scale invasion.

Each tick proceeds through twelve phases. Figure 4.2 shows the main execution sequence within each tick, grouped by functional role: perception, decision and action, and state update.

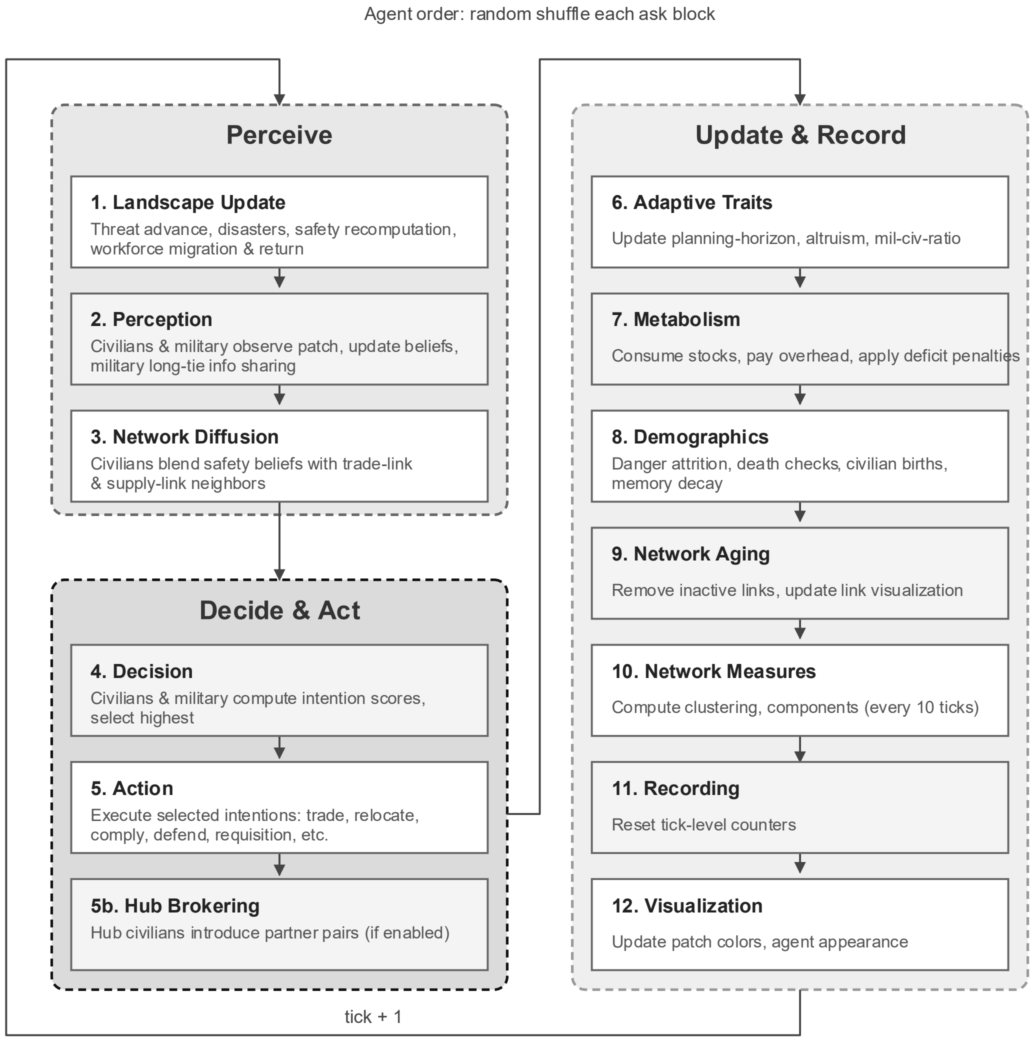

Figure 4.2. Twelve-phase tick execution sequence

The first three phases establish the state each agent perceives: landscape update (Phase 1) handles war-phase transitions, threat propagation, safety computation, rear-area strikes, and workforce updates; perception (Phase 2) updates each agent's beliefs; network information diffusion (Phase 3) blends each civilian's own-patch safety with information from trade and supply partners. Phase 4 runs the BDI intention-selection procedure: civilians evaluate two priority overrides (relocate and re-enter-market) before scoring seven competing intentions, while military units score echelon-gated intentions. Phase 5 carries out each agent's selected intention, followed by government fiscal and mobilization actions and hub brokering. Detailed per-phase logic is in Appendix C.

The remaining phases handle adaptive trait updates (Phase 6), metabolism and fixed costs (Phase 7), demographics including attrition, death, birth by splitting, and partner memory decay (Phase 8), network link aging and pruning (Phase 9), periodic network measurement (Phase 10), counter resets (Phase 11), and visualization updates (Phase 12).

4.5. Key Submodels

The submodels are presented from agent decision-making through environmental dynamics to interaction and adaptation processes. The descriptions below cover the mechanisms most central to the dissertation's research questions. Complete descriptions for all submodels are provided in the supplementary ODD in Appendix C.

Civilian decision-making

Civilian decision-making follows a perceive-decide-act cycle (Bourgais et al., 2020). Two priority overrides are tested before competitive scoring. The relocate override fires when network-blended safety falls below a personalized threshold modulated by risk tolerance and stabilized by a network anchor term, reproducing the finding that organizations with stronger social capital resist displacement longer (Aldrich, 2012). The re-enter-market override fires when a displaced organization's origin has recovered sufficient safety. If neither override fires, seven intentions compete on numerical scores combining beliefs, structural traits, and adaptive traits. The operating score is dominated by perceived safety modulated by risk tolerance, with smaller contributions from financial trend and flexibility. Compliance reflects cultural similarity to the government and hierarchy; evasion weights cultural distance, risk tolerance, and autonomy; support-defense is proportional to altruism and local danger. The planning horizon trait modulates scores: medium-horizon agents incorporate trend data, while long-horizon agents additionally assess global conditions. Exact formulas and weights are provided in Appendix C.

Figure 4.3 traces the civilian decision cycle from the two pre-emptive override checks (relocation and return-home) through the seven scored intentions and planning-horizon modulation to the final intention selection.

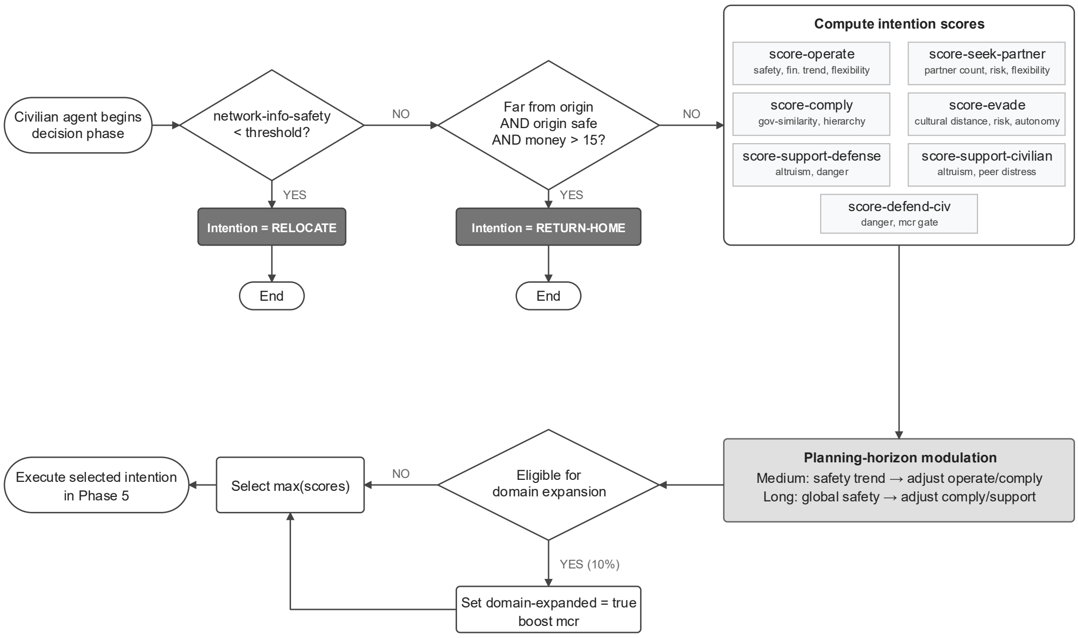

Figure 4.3. Civilian intention selection cycle

Military behavior and echelon system

Military organizations cycle through three echelons (front, operational, reserve) based on local threat and doctrinal rotation rules. Each echelon gives access to distinct intentions: front units defend, advance, withdraw, coordinate, and requisition; operational units stage; reserve units garrison and recruit. Promotions and demotions are governed by depletion thresholds and government decisions. The system produces emergent force-structure dynamics: under sustained attrition, unit counts decline gradually, matching observed Ukrainian force-sustainability trajectories. Figure 4.4 shows the four-stage government-controlled personnel pipeline from workforce recruitment through reserve replenishment and forward rotation to front-line deployment, including the depletion-driven feedback that returns depleted units to reserve.

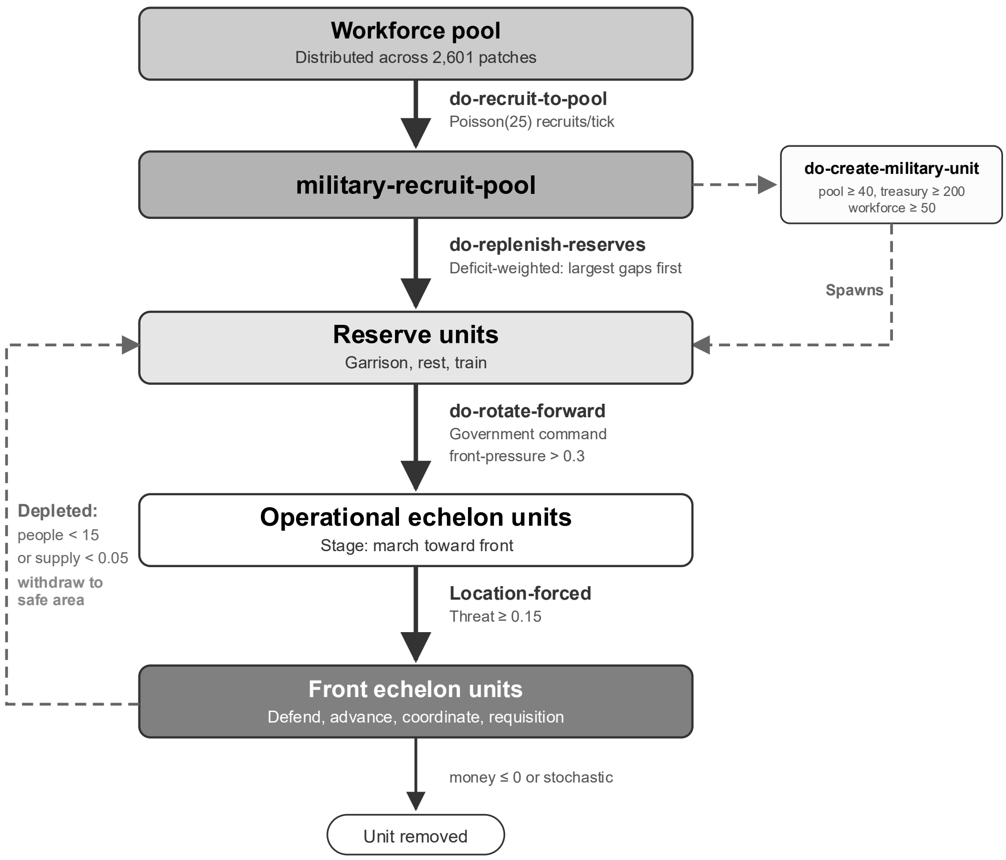

Figure 4.4. Centralized military personnel pipeline

Military units also participate in a small-world network paralleling the civilian social capital story: when reserve units are promoted, they retain their garrison coordination partners as long-ties, which carry simple contagions only (belief-safety averaging) but reduce variance across distant front sectors.

Government

The government executes fiscal and mobilization policies each tick, parameterized by institutional capacity (government-strength), which varies across war phases from near-zero to moderate levels. Taxation extracts revenue at the Ukrainian wartime corporate income tax rate, scaled by local safety and capacity; evading civilians pay reduced tax. Subsidies are weighted by cultural similarity to create a fiscal incentive for cultural alignment. Military funding is front-weighted and deficit-allocated.

A spending floor decouples fiscal expenditure from institutional capacity during crisis phases, reproducing the Ukrainian fiscal trajectory in which spending continued through reserves and international support even as tax revenue collapsed. Mobilization uses stochastic recruitment and deficit-weighted replenishment. New units are created only when the recruit pool is sufficient and no existing unit is critically under-strength, matching the Ukrainian General Staff's policy of prioritizing replenishment over new brigade formation.

Patch safety

Patch safety is the primary environmental signal in the model, recomputed each tick from five layers: a fixed east-to-west base gradient, the diffused threat level around the front, a military bonus from co-located units (with cultural-coordination amplification), a disaster boost from acute strikes, and slowly decaying cumulative damage. Strikes occur stochastically each tick, with 30% targeting deep-rear urban centers, reproducing the documented long-range strike pattern. Layered composition means that military presence can partially offset proximity to the front but cannot compensate for sustained bombardment, and that rear areas can lose safety abruptly from deep strikes while recovering only gradually. Exact decay rates and weights are provided in Appendix C.

Figure 4.5 depicts the model's spatial architecture: the 51×51 patch grid with eight urban workforce peaks, the east-west safety gradient modified by military presence and disaster events, the three echelon zones defined by threat thresholds, and the threat front whose position fluctuates according to the nine-phase scenario schedule.

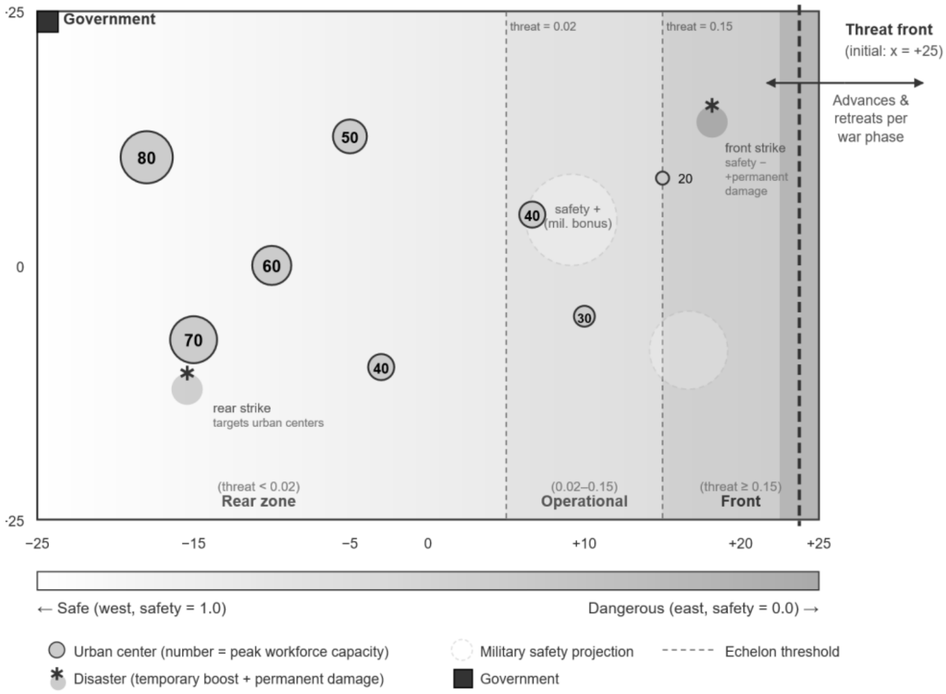

Figure 4.5. Spatial landscape structure and safety computation

Workforce dynamics

Workforce is a spatial resource represented as anonymous patch-level pools from which organizations hire. The submodel produces three dynamics documented in Ukrainian displacement data: rapid outflow when local threat exceeds a threshold, calibrated so that patches under sustained threat empty within 15–20 ticks (matching February-to-May 2022 mass displacement, IOM 2022); permanent diaspora loss accumulating toward the documented 15–25% settlement rate (IOM, 2025; UNHCR, 2026); and slow gravity-based return distributed across patches meeting a minimum safety threshold. The combination produces the asymmetric pattern matching the Ukrainian data: depopulation concentrates in the first weeks, while recovery takes years and remains incomplete in heavily damaged areas.

Bilateral trade

Bilateral trade simultaneously drives economic exchange, network formation, trust accumulation, cultural convergence, and structural homogenization. Each trade event sets price as the geometric mean of the two parties' valuations (Epstein & Axtell, 1996); volume is constrained by capacity and ability and scaled by trust. Cross-sector trades create mutual material dependency. Both parties update partner memory, increment trust, share referrals, exchange cultural tags through Axelrod's tag-flipping (Axelrod, 1997), and slowly blend structural traits, intentionally slower than cultural tag-flipping to reproduce the empirical pattern of rapid value alignment with persisting structural diversity.

Long-tie trade extends this to displaced partners. When organizations relocate, they preserve their highest-trust partner as a long-tie. Long-tie trades transfer money, trust, and referrals (simple contagions) but not cultural tags or structural traits (complex contagions), following Centola and Macy (2007, p. 706). As organizations relocate and maintain high-trust bonds across the landscape, the network transitions from purely local clustering to local density with long-range bridges, matching the small-world signature (Watts & Strogatz, 1998).

Partnership formation and the three-route trust model

Partnership formation follows three routes (Hung et al., 2004, p. 4). In the habitual route, organizations whose trust in an existing partner exceeds a high threshold trade directly. In the active search route, they scan their vicinity and score candidates on a multiplicative composite of compatibility (cultural similarity, hierarchy match, flexibility match) and complementarity (cross-sector bonus, civilian-military differences, resource imbalance), following Lambert and Knemeyer (2004). The multiplicative form means both dimensions must contribute. A crisis cooperation mechanism allows same-sector partners to receive a bonus under acute threat. Phase-sensitive scoring modulates which dimension dominates: short-horizon agents boost complementarity, long-horizon agents boost compatibility, testing Larson's (2012) prediction computationally. A residual route falls back to the most trusted remembered partner.

Trust follows a lifecycle from swift initialization (categorical cues including cultural similarity and sector match), through earned accumulation per successful trade, to habitual automaticity above a threshold. Trust decays during inactivity and modulates trade volume through a scaling factor; entries expire without interaction. Reputation diffusion extends awareness: each successful trade transfers up to two novel partner referrals, added to the receiving partner's memory at a discounted swift trust. Reputation diffusion is controlled by the reputation-enabled toggle.

Network dynamics

Displacement simultaneously destroys local ties and may create long-distance bridges. The asymmetry between destruction and recovery is the central dynamic. When an organization relocates, all local trade-links are severed in a single tick; partner memory entries age and decay until permanently lost. Rebuilding requires finding new partners, accumulating trust, and reaching the habitual threshold.

Long-tie preservation partially offsets this destruction: the highest-trust partner is preserved as a long-distance link, and the referrals it transmits catalyze new local partnerships at the destination. Permanent partner loss models irreversible damage from wartime attrition: when a partner organization dies, 14.3% of the survivor's partner-memory slots are permanently destroyed (calibrated from CAWI Q27).

Hub brokering emerges endogenously. Organizations whose total connections exceed a threshold (default 5) receive enhanced vision range and can introduce pairs of their trade partners to each other, facilitating new connections through structural hole brokerage (Burt, 2005, p. 18). The role emerges from differential network success, producing preferential attachment (Kovács & Spens, 2012).

Adaptive traits and behavioral permeability

Three endogenously adaptive traits modulate behavior over time. Figure 4.6 depicts the mechanisms that drive civilian organizations along the military–civilian ratio continuum, the institutional cap that separates bottom-up militarization from government-created military units, and the resulting Jungle–Zoo regime classification.

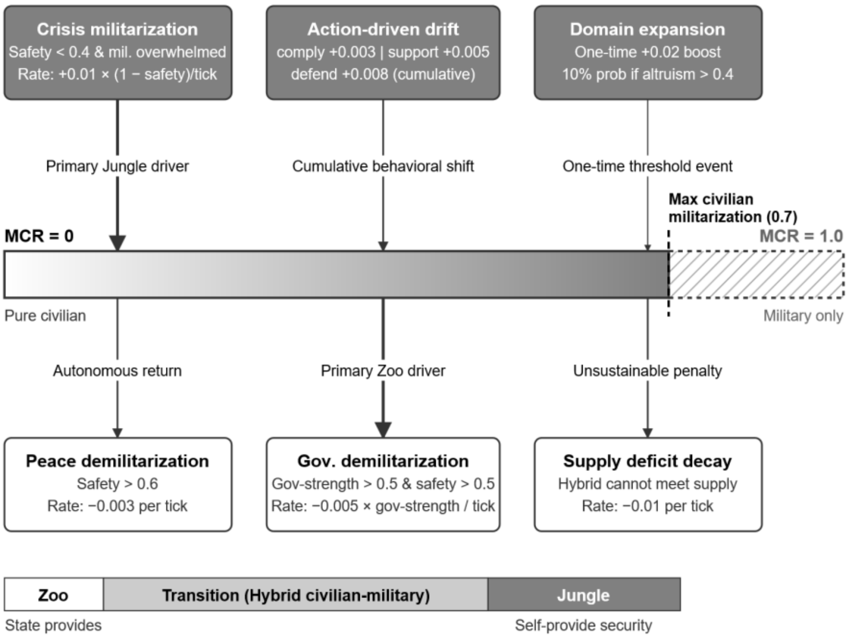

Figure 4.6. Military-civilian ratio drift mechanisms and the Jungle–Zoo spectrum

Planning horizon contracts under sustained dual crisis (both safety trend and financial trend simultaneously negative), with contraction faster (0.015/tick) than recovery (0.004/tick). Recovery is gated by a population-level soft ceiling (~0.70), reproducing the CAWI finding that roughly 40% of organizations never recovered their pre-invasion planning horizons. Altruism increases when three conditions co-occur (non-positive financial trend, low local safety, visible peer distress) and decays slowly otherwise. The asymmetry between contraction and recovery produces persistent population-level shifts, representing partially irreversible organizational learning consistent with crisis-agency theory (Bevzenko, 2018).

The mil-civ-ratio governs behavioral permeability between civilian and military functions and is shaped by four mechanisms: crisis militarization (low safety + understrength military), action-driven drift (military actions raise the ratio, civilian actions lower it), supply-deficit decay, and a peace dividend triggered by improving safety. These feedback loops produce the emergent Jungle/Zoo dynamics: during rapid advance, crisis militarization creates decentralized volunteer defense (the Jungle); as conditions improve and the government strengthens, the peace dividend restores centralized coordination (the Zoo).

Chapter 4 Conclusions

This chapter built the computational model that implements the rules from the empirical chapter. Agent-based modeling was selected through a systematic applicability assessment. The method fits because the empirical findings require heterogeneous agents with adaptive behavior, emergent macro-patterns from micro-level interaction, and the capacity for controlled counterfactual experimentation. Architectural choices were mapped onto the requirements of the thirty-eight rules and twenty-eight causal mechanisms.

The model addresses each of the three methodological gaps identified in the preceding conclusions. Structural toggles address equifinality by activating or removing specific micro-to-macro aggregation pathways, allowing systematic isolation of individual mechanisms. Five society presets address the counterfactual gap by configuring the balance between organizational and self-organizational pathways under different initial conditions, from fully centralized to fully decentralized. Running hundreds of heterogeneous agents over extended time horizons addresses the system-dynamics gap, generating emergent trajectories, tipping points, and feedback effects that fieldwork cannot observe.

Several empirical findings exceed the model's scope: burnout, intra-organizational dynamics, social polarization between stayers and leavers, the international market dimension, and mobilization as a network destroyer. These acknowledged gaps, documented in the empirical chapter, bound the model's empirical precision. The model formalizes the mechanisms that the empirical investigation identified as most prevalent and most consequential.

Executable code is not yet a credible scientific instrument. Without evidence that the model reproduces known empirical patterns under calibrated Ukrainian conditions, computational experiments would carry no evidential weight. The following chapter subjects the model to a progressive validation procedure: sensitivity analysis, empirical calibration against Ukrainian macro-data, and pattern-oriented validation across eight empirical domains. With that credibility established, the model is used as a computational laboratory to answer the questions that motivated its construction.

CHAPTER 5

MODEL CREDIBILITY: CALIBRATION AND VALIDATION

The preceding chapter described the organizational adaptation model's architecture: its BDI-based agent decision cycle, four typed network layers, adaptive trait dynamics, government policy apparatus, and the nine-phase warfare scenario calibrated to the documented timeline of the 2022 russian invasion of Ukraine. Before this computational model can be used to investigate how micro-level organizational mechanisms generate macro-level adaptation patterns, its empirical credibility must be established. This chapter reports the systematic validation process, applying the validation method selection framework developed by the author (Serdyuk, 2025b) to derive a validation plan tailored to the model's specific context, and then executing that plan through five progressively demanding phases.

The validation process is itself a step in the theory-driven sequential design: it establishes whether the computational instrument, constructed from qualitative and quantitative inputs, faithfully represents the empirical system it was built to investigate, before the instrument is used to answer questions that the empirical phases could not address.

5.1. Validation Strategy and Method Selection

Validation practices in agent-based modeling remain diverse and inconsistent, with most researchers selecting methods ad hoc rather than systematically assessing what their research context permits and requires (Grimm & Railsback, 2012; Lee et al., 2015). To address this gap, the author developed a practical framework grounded in computational analysis of 76 research scenarios (Serdyuk, 2025b). The framework maps twelve validation methods against combinations of model purpose, system observability, and development stage. Euclidean distances between scenario profiles showed that no single validation protocol fits all ABM applications (maximum distance 8.5), confirming the need for context-specific method selection. The framework identifies two principal constraints: observability (a hard limit on available methods) and development stage (which determines when methods become feasible). These are operationalized as a five-step procedure: (1) assess context along three dimensions, (2) apply universal methods as a baseline, (3) filter by development stage, (4) select strategy-specific methods based on the observability–purpose interaction, and (5) document the trade-offs inherent in the chosen plan. The framework was earlier applied to validate an agent-based model of wartime migration (Serdyuk, 2025d). Table 5.1 presents the complete mapping of the framework to the present model.

Table 5.1. Validation method selection framework applied to the organizational adaptation model

Framework Step	Recommended Actions	Application to This Model
Step 1: Context Assessment	Evaluate observability, development stage, and primary purpose	Partial observability (IOM, SSS, MoF macro; 37 interviews + 35 surveys micro). Refinement stage (all mechanisms operational, iterative revision). Explanatory purpose with secondary hypothesis generation.
Step 2: Universal Methods	**Visualization:** apply in all contexts **Expert review:** involve domain experts **Structural checks:** verify theory-to-code mapping	**Visualization:** spatial dynamics inspection, trajectory plots, network rendering (ongoing throughout) **Face validation** of 38-rule inventory against 37 interview transcripts and 35 survey responses **Structural checks:** BDI/BEN, cultural tags, SKIN trade, adaptive traits
Step 3: Stage Constraints	Refinement stage enables all advanced methods. **Filter out:** none **Keep:** sensitivity analysis, empirical validation, sampling, bootstrapping, causal analysis, data analytics, IGSS, docking	All twelve methods pass the stage gate. Practical constraints further narrow the set in Step 4.
Step 4: Strategy-Specific Methods	Partial observability × explanatory purpose: prioritize sensitivity analysis, empirical validation with available data, and pattern-oriented multi-criteria testing. Consider causal analysis and data analytics. Deprioritize IGSS, docking, bootstrapping, and role-playing where practical constraints apply.	**Selected:** sensitivity analysis (Morris + OFAT), empirical calibration (macro anchors + survey + LHS + BehaviorSearch), pattern-oriented validation (43 criteria, 8 experiments) **Deferred:** docking (empirical data more demanding), IGSS (38-param space infeasible), role-playing (dispersed respondents), bootstrapping (subsumed by replication design)

Step 5: Trade-Offs	Acknowledge what the chosen plan cannot do. Record gaps and their rationale	No full docking against parent models (BEN, SugarScape, SKIN). No participatory role-playing. No inverse generative search. Trust parameters lack direct empirical proxy; calibrated jointly with network targets as a partial substitute. MCR-gated behaviors remain structurally undertested.

Applied to the present model, the framework places it in the hybrid validation zone: partial observability (macro data from IOM, State Statistics Service, Ministry of Finance, and CSIS and OSW military analyses, plus 37 interview transcripts and a survey of 35 respondents), refinement stage (all mechanisms operational), and explanatory purpose with secondary hypothesis generation. This configuration makes 6–8 methods feasible (Serdyuk, 2025b).

Three universal methods were applied: visualization (ongoing throughout), face validation against the 38-rule inventory using interview and survey evidence (replacing expert review, since no accessible community combines ABM expertise with Ukrainian wartime experience), and structural checks against the source frameworks.

The framework recommends sensitivity analysis, empirical validation, and pattern-oriented testing for this configuration. Four eligible methods are deferred: docking (empirical data provide a more demanding target), IGSS (constructing and comparing alternative model variants across 38 parameters produces a combinatorial space too large to explore systematically), role-playing (respondents geographically dispersed), and bootstrapping (subsumed by the 30-replication design).

The chosen plan cannot do three things. Discrepancies between the model and its parent frameworks are identified through structural checks, not quantitative output comparison. The subjective plausibility of the decision cycle is tested through retrospective interview coding rather than real-time participatory experience. The parameter space is explored through targeted sampling rather than exhaustively, and structurally different parameterizations producing indistinguishable outputs may go undetected. A more specific limitation is that the model’s nine trust parameters have no direct real-world data to anchor them; they are instead constrained by their observable consequences in network structure.

Validation plan

The five-step framework application produces a validation plan with six consecutive phases. Each phase answers a question that depends on the answer produced by the preceding phase, and no phase can be executed before its predecessor is complete. The validation flow is shown in Figure 5.1.

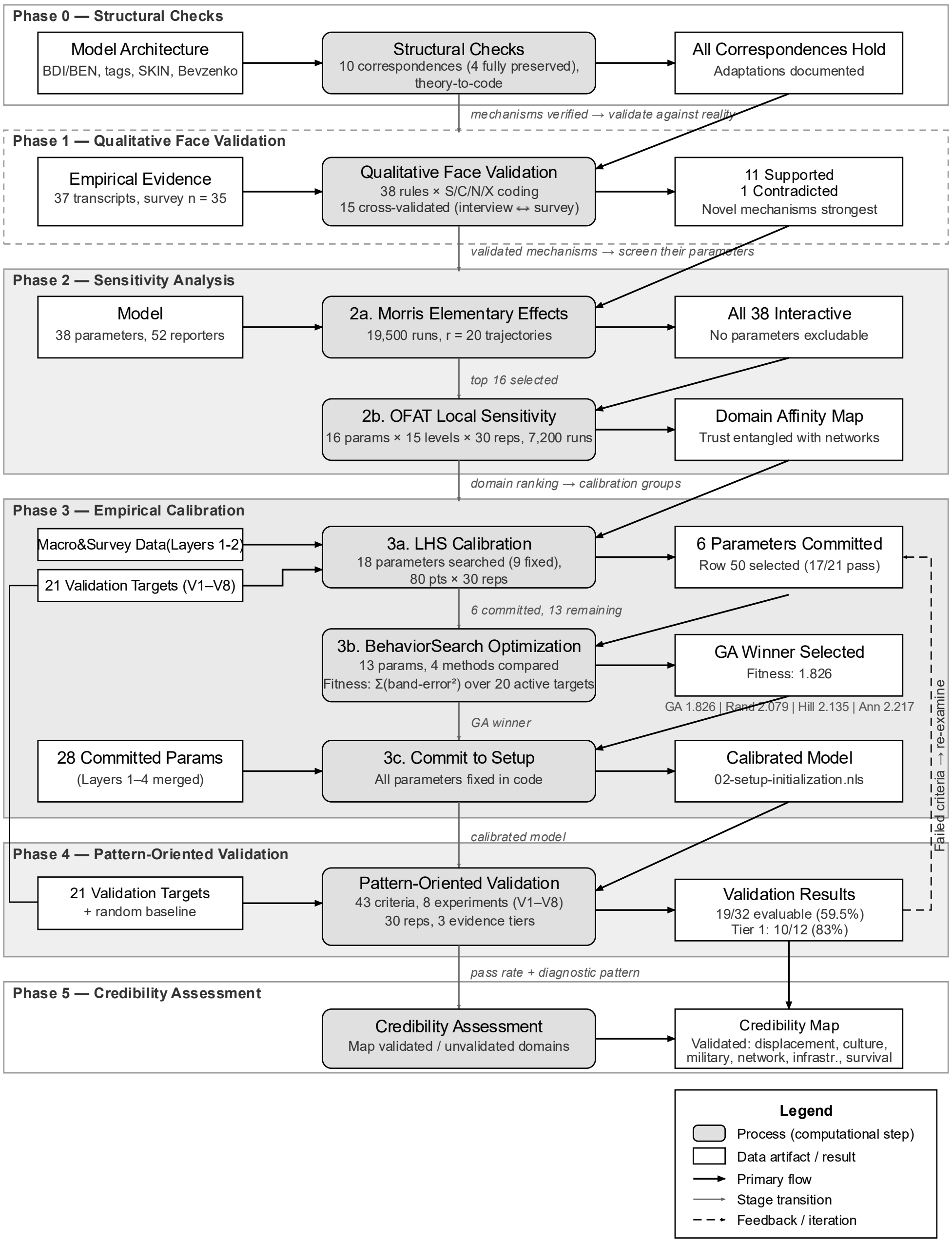

Figure 5.1. Calibration and validation flow

Phase 0 (structural checks) verifies that the code correctly implements each parent framework's architecture.

Phase 1 (face validation) tests whether those correctly implemented mechanisms correspond to what real actors describe; if a mechanism were contradicted, screening its parameters would mean optimizing something wrong.

Phase 2 (sensitivity analysis) identifies which parameters of the validated mechanisms matter most, how strongly they interact, and which output domains they affect.

Phase 3 (empirical calibration) uses the sensitivity results to set parameter values from four layers of evidence, from macro data down to metaheuristic optimization.

Phase 4 (pattern-oriented validation) tests whether the calibrated model can simultaneously reproduce 43 empirical patterns from eight experiments, each run with 30 replications; a pass rate of 70% on evaluable criteria is adopted as the credibility benchmark.

Phase 5 (credibility assessment) synthesizes the cumulative evidence to map where the model is credible and where it is not.

Each step narrows the space of credible models; the final credibility assessment documents the boundaries of what survives. The rest of this chapter reports the execution and results of each phase.

5.2. Structural Checks

This model draws on fifteen sources: six established agent-based models, two modeling architectures, and seven theoretical frameworks. Ten of them are implemented closely enough to trace a theory-to-code correspondence, where the code must preserve the source's essential structure. The other five shape the design conceptually, with no single procedure to trace. Table 5.2 reports the ten correspondences and the adaptation each one required.

Table 5.2. Structural checks: theory-to-code correspondence for source frameworks

Subsystem (source)	Specification	Code Implementation	Documented Adaptation
Spatial landscape and resources (SugarScape;	Grid with resource peaks; agents harvest, metabolize, and	51×51 grid with 8 workforce peaks. Safety from five layers (base gradient, threat, military	Single resource replaced by workforce pools. Safety is multi-layered rather than a

Subsystem (source)	Specification	Code Implementation	Documented Adaptation
Epstein & Axtell, 1996)	trade; geometric-mean pricing; reproduction by splitting above a threshold	projection, disaster, cumulative damage). Geometric-mean pricing preserved. Birth-by-splitting with money, safety, and workforce preconditions	regrowth rule. Birth requires environmental preconditions beyond size
Structural trait drift (Epstein, 2003)	Local rules cause spontaneous hierarchy formation/dissolution; "traveling wave" between flat and tall structures	Trade partners blend org-hierarchy and org-flexibility at a configurable rate. Compliance drifts hierarchy up; evasion drifts it down	Drift is compliance-driven rather than environment-driven. No traveling-wave oscillation. Blend rate reduced after survey finding that 54% reported no structural change
Multi-need scoring (ASSOCC; Dignum et al., 2020)	Maslow hierarchy of needs; context determines which need dominates; health, social, and economic layers interact	Seven competing intentions (operate, seek, comply, evade, support, defend, mutual-aid) scored simultaneously using weighted formulas over beliefs, traits, and adaptive parameters	Maslow hierarchy replaced by flat scoring of empirically grounded organizational intentions. Individual-level needs omitted. Core principle of competing-need scoring preserved
BDI cognitive cycle (BEN; Bourgais et al., 2020)	Three-phase perceive–deliberate–act; emotional appraisal; separate normative reasoning module	Perceive: updates safety, financial, and partner beliefs each tick. Decide: scores seven intentions; highest wins. Act: dispatches to selected intention with trait drift	Emotional layer omitted (no organizational equivalent). Normative reasoning integrated into scoring formula as competing intentions
Cultural tag dynamics (Epstein & Axtell, 1996)	11-bit binary tag; Hamming similarity; rule K flips one differing bit per interaction; convergence within clusters	11-bit list; normalized Hamming distance; rule K preserved in trade. With evasion disabled, original convergence pattern reproduced	Evasion adds a government-opposition channel: evading agents flip one bit toward the government tag's complement
Partnership and trade (SKIN; Gilbert et al., 2007)	Complementary-capability matching; partner memory prioritizes proven relationships; geometric-mean pricing	Complementarity from sector, resource gap, and MCR. Habitual partners tried before search. Geometric-mean pricing preserved	Extended with dual-dimension scoring (Lambert & Knemeyer, 2004), phase-sensitive weighting (Larson, 2012), and three trust routes (Hung et al., 2004)
Government fiscal cycle (WorkSim; Goudet et al., 2017)	Binding institutional constraints; government as fiscal regulator with taxation and redistribution	Tax collection scales with government-strength and patch safety; evaders pay half. Subsidies weighted by cultural similarity and compliance. Spending floor decouples	Labor market replaced by organizational economics. Tax rate is aggregate (0.27) rather than statutory. Subsidies are culture-biased, extending WorkSim's neutral redistribution. Spending floor

Subsystem (source)	Specification	Code Implementation	Documented Adaptation
		expenditure from institutional capacity	added for Ukrainian fiscal trajectory
Partnership scoring and trust (Lambert & Knemeyer, 2004; Larson, 2012; Hung et al., 2004)	Multiplicative complementarity × compatibility scoring. Phase-sensitive strategy. Three trust routes: swift, category-based, earned	Scoring multiplies complementarity by compatibility. Habitual partners tried first. Trust accumulates through swift (cultural similarity), earned (per-trade increment), and habitual (threshold-gated) routes	Three contributions combined into a single subsystem. Trust routes operate simultaneously rather than sequentially
Network topology and social capital (Aldrich, 2012; Centola & Macy, 2007; Burt, 2005)	Social capital destruction faster than recovery. Weak ties bridge clusters. Complex contagion requires co-location. Structural hole brokerage by intermediaries	Memory decay removes stale partners; permanent loss fraction on relocation. Long-tie preservation saves highest-trust partner. Hub agents broker introductions. Tag/trait exchange restricted to co-located trade; referrals propagate over long ties	Recovery asymmetry is parametric rather than structural. Hub threshold is degree-based (Burt uses betweenness; Burt, 2005, p. 27). Contagion boundary implemented as a feature toggle
Adaptive crisis-agency dynamics (Bevzenko, 2018, 2020)	Planning contraction: dual precondition (safety crisis + financial decline). Altruism activation: triple precondition (institutional failure + peer distress + capacity)	Contraction: safety trend < threshold AND financial trend < 0. Recovery: stochastic with population-level ceiling. Altruism: financial distress AND low safety AND nearby distressed ≥ threshold	Altruism decline uses a single uniform rate; real trajectories are qualitatively diverse (wave-like, sudden collapse, deliberate sustenance)

All ten correspondences preserve the structural commitments of their sources. Four frameworks (BEN, Hammond-Axelrod, SKIN, and SugarScape trade and splitting) are fully preserved: the core mechanism operates exactly as specified in the original framework, and this model's extensions are layered on top without altering the base logic. The other six of these correspondences contribute architectural principles rather than complete procedural specifications, so the correspondences are partial by design. Adaptations in these six cases reflect one of three reasons: the parent framework targets individuals rather than organizations (BEN's emotional layer, ASSOCC's individual needs), empirical data constrain the implementation differently than the original specification (Epstein's blend rate, crisis-agency uniform decline), or interview findings motivated a design departure (WorkSim's culture-biased subsidies, SugarScape's environmental birth preconditions).

5.3. Qualitative Mechanism Validation

Structural checks verified that the code correctly implements each parent framework's architecture. The next question is whether those correctly implemented mechanisms correspond to what real actors describe. This is the equivalent of verifying that the telescope is pointed at the right part of the sky before adjusting the focus. If a mechanism is contradicted by empirical evidence, screening and calibrating its parameters would mean optimizing something wrong. Face validation compares the model's rule inventory against the interview and survey evidence, requiring zero model runs. It was the first validation step performed and is logically prior to all computational validation.

Face validation against interviews

All 37 interview transcripts were coded against the model's 38-rule inventory using the S/C/N/X scheme developed in the empirical chapter, where S indicates support, C indicates contradiction, N indicates nuance, and X indicates an unmatched pattern. Table 5.3 summarizes the results by strength of empirical support. The complete rule-by-rule coding is reported in Appendix D, Table D.2.

Table 5.3. Face validation summary (38 model rules against 37 interview transcripts)

Support category	**Rules**	**Key mechanisms**
Strong support (≥6S, ≤1C)	11	Planning horizon contraction (26S), voluntary military support (22S), domain expansion (16S, 1C), three-phase temporal pattern (16S), perception and priority shift (12S), COVID pre-adaptation (11S)
Partial support (1–5S)	10	Relocation threshold (5S, 3N), crisis cooperation (4S), three-route trust (3S, 4N), comply/evade decision (1S, 1N)
Heavily nuanced	2	Altruism dynamics (12S, 13N), organizational structure drift (10S, 5N)
Contradicted	1	Risk tolerance as fixed trait (0S, 2C)

Below interview resolution	14	Partnership scoring, network topology, government budget, trade mechanics, warfare/infrastructure

The model's core theoretical contributions (planning horizon contraction, voluntary military support, domain expansion, and the three-phase temporal pattern) all received strong support with minimal or no contradiction. These mechanisms anchor the experimental program in the subsequent chapter: their parameters can be calibrated with confidence that the underlying behavioral logic is empirically sound.

Two mechanisms require specific comment because they affect how subsequent results should be interpreted. Altruism dynamics (C2) received strong support for the activation logic (12S) but substantial nuance for the decline trajectory (13N). Respondents described wave-like resurgences, sudden collapses from institutional disillusionment, and deliberate organizational efforts to sustain engagement. The model compresses these qualitatively distinct trajectories into a single uniform decay rate. It captures the aggregate pattern but not the diversity, which means that experimental findings about altruism dynamics should be interpreted as population-level tendencies rather than organizational-level predictions.

Risk tolerance (A4) was the only contradicted mechanism: two respondents described endogenous shifts in organizational risk appetite. It is retained as a fixed parameter because the evidence identifies that change occurred but does not specify the change mechanism. The survey provides a post-crisis distribution usable as a calibration value, but not a change trajectory.

The coding also identified 19 behavioral patterns with no model counterpart (X-codes). These fall into two categories, documented in detail in Appendix D. Patterns at the model's level of abstraction (client compliance blocking employment, mobilization destroying inter-organizational trust) represent architectural gaps. Patterns below the unitary-agent abstraction (burnout, fled-stayed polarization, work as psychological shelter) represent scope boundaries. The distinction matters: gaps could be addressed within the current architecture; scope boundaries would require a different kind of model.

Fourteen mechanisms received zero codes because they operate below the resolution of qualitative data: partnership scoring formulas, network topology dynamics, government budget algorithms. Their absence is not evidence against them. They require computational validation in the subsequent phases.

Cross-validation: Survey against interviews

The face validation established which mechanisms are empirically grounded in the qualitative evidence. The cross-validation extends this by comparing the quantitative survey findings (n = 35) against interview coding across 15 mechanism-level comparisons. When two independently collected sources agree, confidence increases. When they disagree, the divergence identifies either a real population difference or a methodological artifact. The full comparison is reported in Appendix D, Table D.3.

Nine comparisons showed convergence. Planning horizon contraction showed strong agreement across methods (26 interview S-codes; 51.4% shortened in survey). Voluntary military support likewise converged (22S; 48.6% active support). Mobilization as workforce disruptor was consistent across sources (multiple interview passages; 74.3% affected in survey). The compliance distribution converged with nuance (interview: compliance dominant with ritual compliance; survey: 86/14 comply/evade split). This convergent evidence covers the mechanisms that drive the model's main experimental variables.

Three comparisons showed divergence, each with an identifiable explanation. Risk tolerance diverged because interviews captured change over time while the survey captured a cross-sectional 2026 snapshot. Cultural similarity diverged because cultural compatibility likely operates as a threshold filter (determining who enters the candidate pool) rather than a selection weight (determining who is chosen from it). Only 8.6% of survey respondents ranked shared values as their top partner criterion, yet interviews documented that cultural identity shapes group membership. Workforce dynamics diverged because the three-year gap between data collections captured different moments in the same trajectory.

Three findings were complementary: each method revealed something the other could not. The survey added a prevalence estimate (51.4%) to the habituation-to-danger process documented in interviews. Burnout was visible only in interviews (approximately

12 passages), a survey design gap. The international market buffer became prominent only in the 2026 survey.

Implications for calibration

The cross-validation identified six areas where convergent evidence from both sources warranted structural changes to the model before calibration. One compliance precondition was removed. Persistence mechanisms were added for government support and partnership loss. The planning horizon recovery logic was revised to accommodate the 40% of organizations that showed stability rather than universal contraction. The organizational structure drift rate was reduced. Workforce dynamics were differentiated by threat zone. All six corrections were implemented before the calibration pipeline, ensuring that the calibration optimizes the corrected mechanisms. The specific changes are documented in Appendix D, Table D.4.

Three simplifications are consequential but outside the model's architectural scope: the unitary-agent assumption (no intra-organizational dynamics), the domestic-only landscape (no international market buffer), and the absence of a psychological dimension (no burnout or work-as-shelter). These are carried forward as documented boundaries on the model's credibility rather than as mechanisms to be added.

Two gaps have been partially addressed through the calibration pipeline. Trust parameters lack direct interview evidence and are instead constrained by their observable consequences in network structure. The Jungle-to-Zoo regime dynamics, which received mixed interview support (4S, 4N), are included in the sensitivity screening, though the MCR-gated behaviors they depend on show near-zero sensitivity. This structural issue is carried forward to the pattern-oriented validation.

5.4. Sensitivity Analysis

Before calibrating the instrument, sensitivity analysis determines how it responds to adjustments: which knobs matter most, whether turning one knob shifts readings on unrelated dials, and whether any component fails to respond at all. Two complementary methods were applied: Morris elementary effects screening for global parameter ranking, and one-factor-at-a-time (OFAT) analysis for local response characterization and domain mapping.

Morris elementary effects screening

The Morris method (Morris, 1991) estimates each parameter's global influence by constructing randomized trajectories through the parameter space. Each trajectory starts from a random point, then changes one parameter at a time by a fixed step, recording how the model output changes with each step. The ratio of output change to parameter change is the elementary effect for that parameter at that point. Because the trajectory visits a different region of the parameter space for each step, the elementary effects capture how the parameter behaves across diverse contexts rather than at a single operating point. The method repeats this with multiple trajectories from different starting points, then summarizes each parameter by two statistics: the mean absolute elementary effect (μ^*), which indicates average influence, and its standard deviation (σ), which indicates how much the parameter's effect depends on the values of other parameters. When σ exceeds μ^*, the parameter is interactive: its effect cannot be understood in isolation. The screening used the enhanced trajectory selection of Campolongo, Cariboni, and Saltelli (2007), which optimizes the starting points to maximize coverage of the parameter space, with companion R scripts from Thiele, Kurth, and Grimm (2014). The detailed method specification, including the trajectory construction procedure, the Campolongo optimization, and the μ^*/σ calculation, is documented in Appendix D, Section D.10.

All 38 model parameters were included in the screening because the purpose was to determine which parameters matter, and excluding any in advance would presuppose the answer. The design used $r = 20$ trajectories, $p = 4$ levels, and 25 replicates per design point, producing 19,500 model runs measured on 52 reporters at four ticks (80, 160, 300, 400) for a total of 208 output measures. The full parameter rankings are reported in Appendix D, Table D.8.

The screening produced three findings.

The first is pervasive interaction. A Spearman rank-correlation check compared the top-10 parameter ranking from the first three trajectories against the full 20 for each output measure. Only 1 of 208 measures was stable (ρ≥0.8); the remaining 207 were unstable, with many correlation coefficients near zero or negative. This means the effect of any single parameter depends strongly on the values of others. The model is a complex adaptive system in the technical sense: its behavior cannot be decomposed into independent parameter contributions. Figure 5.2 illustrates this for aggregate economic output at tick 300 – all 38 parameters fall above the σ = μ* diagonal.

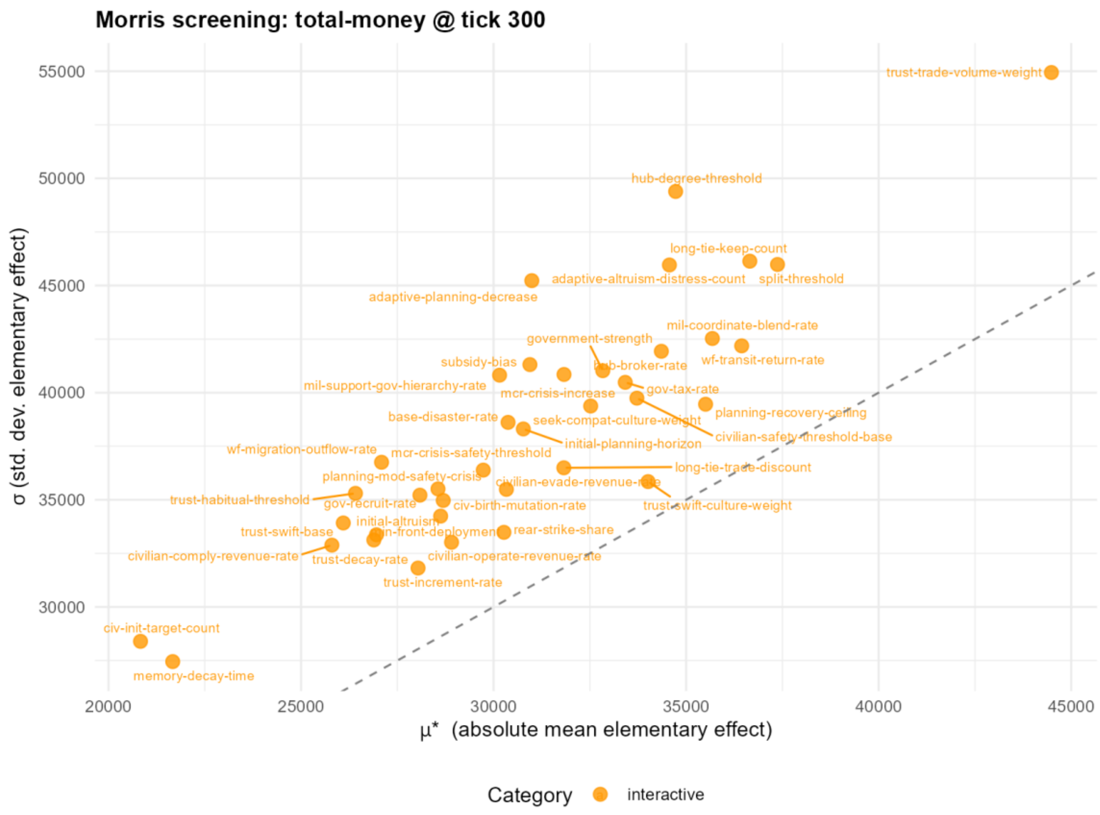

Figure 5.2. Morris elementary effects screening for total-money at tick 300 (38 parameters, 19,500 runs)

The second finding is a flat influence distribution. The aggregate μ* ranges from 659 (trust-trade-volume-weight) to 391 (trust-increment-rate) – less than a factor of two. There is no clear cutoff between influential and negligible parameters. No parameter can be safely fixed at its default value.

The third finding is a structural diagnostic. Two output reporters (pct-civilians-defending and pct-civilians-mutual-aid) returned μ*=0 for all parameters at all ticks, meaning that defending and mutual-aid intentions are never activated under any parameter combination in the screening space. The activation chain for these intentions involves multiple mechanisms: the altruism threshold (adaptive-altruism-distress-count, itself ranked 8th in the Morris screening), the MCR gating condition (which requires a specific military-civilian ratio), low government strength, high peer distress among nearby organizations, and sufficient individual capacity. All of these conditions must be met simultaneously. Morris trajectories, which change one parameter at a time, are unlikely to produce this specific conjunction because each condition depends on a different parameter. The consequence is the entire activation chain, from altruism through MCR gating to defending and mutual-aid behavior, is invisible to the sensitivity screening. This affects not only the Jungle-to-Zoo dynamics but also the altruism mechanism's downstream effects on these specific outputs. Neither can be calibrated through parameter adjustment alone.

OFAT domain mapping

The OFAT (one-factor-at-a-time) analysis complements the Morris screening by revealing what the global screening cannot: the direction, shape, and domain specificity of each parameter's effects. While Morris asks "how influential is this parameter overall?", OFAT asks "what exactly happens when this parameter changes, and which output domains are affected?" For each parameter, OFAT holds all others at their baseline values and sweeps the focal parameter across its range. The response is measured in every output domain, revealing whether the effect is linear or threshold-like, monotonic or non-monotonic, and whether it spills across domain boundaries.

Sixteen parameters were selected for OFAT analysis: the eight most influential from the Morris screening and eight additional parameters from the upper half of the Morris ranking. The lower-ranked parameters were excluded because their aggregate μ* values were within the flat distribution range, meaning that OFAT analysis of any one of them would be unlikely to reveal qualitatively different behavior than the Morris screening already showed. Each selected parameter varied across 15 levels with 30 replications, producing 7,200 runs. The full domain affinity mapping is reported in Appendix D, Table D.10.

The central finding is trust-network-economy entanglement. Trust-trade-volume-weight, the Morris screening's top-ranked parameter, primarily affects behavioral outputs but has substantial secondary effects on both economic and network outputs. Trust-decay-rate and trust-swift-culture-weight cross spatial and behavioral domains. The network topology parameters (hub-degree-threshold, long-tie-keep-count) likewise show cross-domain effects. This entanglement means that trust parameters cannot be calibrated independently: changing a trust parameter to improve a behavioral outcome simultaneously shifts network structure and economic aggregates.

The remaining parameters show more contained effects. Government-strength and split-threshold affect behavior and economy but not network structure. Workforce parameters (wf-transit-return-rate, wf-migration-outflow-rate) primarily affect spatial and economic outputs. Only mcr-crisis-safety-threshold shows low cross-domain influence, consistent with the structural isolation identified in the dead-reporter diagnostic.

Consequences for the remaining calibration steps

The screening results confirm that the four-layer calibration architecture adopted for this model is appropriate. The flat influence distribution and pervasive interactions mean that no parameter can be excluded from calibration. The layered strategy of committing empirically anchored parameters first is the correct way to reduce the search space. More importantly, the results identify three specific adjustments for the remaining calibration steps.

The most consequential adjustment concerns the three trust parameters (trust-trade-volume-weight, trust-decay-rate, trust-swift-culture-weight). They must move from Layer 3, where they would be searched against economic targets alone, to Layer 4, where they can be optimized jointly against behavioral, economic, and network targets. Without this adjustment, calibrating trust against one domain would degrade the others because of the entanglement the OFAT analysis revealed.

A second adjustment is to expect the dead-reporter outputs (defending and mutual-aid intentions) to fail in the pattern-oriented validation. No parameter search in any layer can activate these outputs because the failure is structural: it traces to the joint activation chain, not to parameter values. Attempting to fix these failures parametrically would distort the calibration of other mechanisms without resolving the underlying issue. These outputs are excluded from the calibration fitness function and carried forward as a known limitation.

A third adjustment, conditioned by the flat influence distribution, is that the Layer 3 search (Latin Hypercube Sampling) must cover the full range of all remaining parameters rather than concentrating on a subset. No parameter can be narrowed based on the screening results because all contribute comparably to model behavior.

5.5. Empirical Calibration

The preceding phases established that the instrument is assembled correctly and detects what it should. Calibration adjusts its settings until it reproduces known reference points, the equivalent of pointing a telescope at stars whose positions are known and turning the focusing knobs until the image is sharp. In agent-based modeling, calibration means anchoring each parameter to empirical evidence so that the model's outputs match observed reality before the model is used to investigate questions that observation alone cannot answer.

The calibration uses a four-layer architecture. Each layer anchors a group of parameters to the best available evidence for that group, proceeding from the most constrained (macro statistics) to the least (computational search). This layered approach addresses the finding from the sensitivity analysis that all 38 parameters interact: searching all of them simultaneously would produce an unmanageably large space, while fixing most and searching a few would ignore the interactions. The architecture resolves this by committing parameters from strong evidence first, then searching the remainder within progressively narrower bounds.

Layer 1 committed four parameters derived from Ukrainian aggregate statistics. Each required a derivation step rather than a direct lookup. The effective tax rate (0.27) was calculated from multiple statutory tax regimes weighted by the proportions of enterprises in each ownership form and size category. The mobilization rate was rescaled from General Staff reports to the model's population ratio. The infrastructure strike frequency was converted from World Bank damage assessments to a per-tick probability. The initial organizational population was set from State Statistics Service registry data at the model's scale. The derivation methodology for each parameter is documented in Appendix D, Section D.6.

Layer 2 committed five parameters from survey response distributions (n = 35). The survey items that anchored each parameter, the distributional assumptions used to convert ordinal responses into continuous parameter values, and the sensitivity of each derivation to alternative assumptions are documented in Appendix B (Survey Instrument, Results, and Mechanism Mapping). The survey also provided initial distributions for four agent-level properties (risk tolerance, organizational hierarchy, military friendliness, and planning horizon mixture) and the initial comply/evade behavioral split. These are the eight survey-calibrated parameter sets reported in Table 3.5.

Layer 3 addressed the six operational parameters that have no direct empirical anchor but whose values shape model dynamics. These were searched using Latin Hypercube Sampling, a method that divides each parameter's range into equal intervals and samples one value from each interval, ensuring even coverage of the parameter space without requiring an exhaustive grid (McKay, Beckman, & Conover, 1979). The design used 80 sample points with 30 replications each, producing 2,400 runs evaluated against 21 validation targets. The best-performing point committed six parameters: a cultural tag mutation rate, three revenue coefficients, and two workforce migration rates. Three trust parameters were carried forward to Layer 4 because the sensitivity analysis had identified them as entangled with both economic and network outputs, requiring joint optimization.

Layer 4 optimized the remaining thirteen parameters, including the three trust parameters. This layer used BehaviorSearch (Stonedahl & Wilensky, 2010), a software tool bundled with NetLogo that automates nonlinear numerical optimization in a model's parameter space. The user defines a fitness measure (here: the sum of squared deviations from the 21 validation targets), and BehaviorSearch searches the parameter space to minimize it. The tool offers several search algorithms, since different strategies may be more efficient for different fitness landscapes. Four were run independently: a genetic algorithm (which maintains a population of candidate solutions and recombines the best performers across generations), simulated annealing (which accepts worse solutions with decreasing probability to escape local optima), stochastic hill climbing (which accepts only improvements), and random search as a baseline. Each used approximately 2,500 evaluations with 3 replications per evaluation. Running multiple algorithms from different starting points tests whether the search converges on a single solution or reveals equifinality. The algorithms, their settings, and the convergence diagnostics are documented in Appendix D, Section D.7.

Equifinality: Two calibration regimes

The four search methods found structurally different solutions that achieve similar fitness. The genetic algorithm's rechecked fitness (1.826) is only 22% better than the worst performer, simulated annealing (2.217). This is equifinality in the technical sense: multiple distinct parameterizations produce comparably acceptable macro-level behavior. The full cross-method comparison is reported in Appendix D, Table D.5.

The comparison reveals not random scatter but two distinct regimes of model behavior.

In the first regime (genetic algorithm and hill climbing), organizations build durable partnerships based on cultural affinity. Trust decays very slowly (0.002 per tick), so once a partnership forms, it persists. Government support is minimal (spending floor 0.15–0.20). The wartime economy is sustained by a stable network of culturally similar, long-term partners.

In the second regime (random search and simulated annealing), partnerships form and dissolve rapidly (trust decay 0.024–0.044). Each trade carries greater economic weight, compensating for network instability. Government subsidies are higher (spending floor 0.40–0.45), providing a fiscal buffer that the first regime does not need. The wartime economy is sustained by high-throughput exchange backed by state spending rather than by durable relational infrastructure.

Both regimes reproduce the same macro-level patterns. They differ in what sustains the wartime economy at the micro level. Three parameters are tightly constrained across both regimes: bankruptcy death probability (0.07–0.10), cultural weight in compliance (1.00–1.40), and operating cost rates (0.08–0.13). These can be interpreted with greater confidence than the trust parameters and government spending floor, which are the primary sources of equifinality.

This finding has a direct consequence for the experiments in the subsequent chapter. Findings about trust dynamics, partnership duration, and trade network density should be interpreted as regime-level tendencies rather than precise parameter estimates. Findings about population survival, cultural convergence, and compliance dynamics rest on parameters constrained across both regimes and can be interpreted with greater confidence. Resolving the equifinality would require longitudinal network data on partnership formation, duration, and dissolution, which are not available for Ukrainian organizations during the full-scale invasion.

The genetic algorithm winner was selected as the committed parameterization because it achieved the best rechecked fitness among the alternatives explored. The complete committed parameter set across all four layers is documented in Appendix D, Table D.6. The committed set satisfies 17 of 21 validation targets.

5.6. Pattern-Oriented Validation

The instrument has been assembled, inspected, and calibrated. What remains is its most demanding test: pointing it at known constellations and checking whether it resolves them. Pattern-oriented modeling (POM) does exactly this, using multiple empirical patterns as simultaneous filters on model output and requiring that a single parameterization reproduce diverse observations from independent domains (Grimm & Railsback, 2012; Grimm et al., 2005). The calibrated model was evaluated against 43 criteria derived from eight experiments, each run with 30 replications over 500 ticks. The question is not whether the model is "correct" but where it succeeds, where it fails, and what the failures reveal about its architecture. Table 5.4 reports the validation results aggregated by experimental domain.

Table 5.4. Pattern-oriented validation results by domain (GA winner, 30 replications)

Experiment	Total	Pass	Fail	Excluded	Noted	Key Discrepancies
V1 Displacement	6	2	3	1	-	V1.1 relocation peak, V1.5 workforce ratio, V1.6 outflow/return
V2 Business Survival	5	2	2	1	-	V2.3 output drop, V2.5 death ratio
V3 Military Structure	5	3	1	1	-	V3.3 front/reserve ratio
V4 Government Fiscal	6	2	3	1	-	V4.1 treasury drop, V4.4 comply/evade, V4.5 recovery
V5 Infrastructure	5	3	-	-	2	-
V6 Jungle-Zoo	5	1	4	-	-	V6.1–V6.5: MCR gating structural limitation
V7 Culture / Planning	5	4	1	-	-	V7.2 short-horizon dominance
V8 Network Structure	6	3	3	-	-	N2 link density, N3 giant component, N4 deficit
Total	43	20	17	4	2	-

Reproduced patterns

The model reproduces empirical patterns most closely in the domains nearest its core architecture. Military structure passes 3 of 4 evaluable criteria; infrastructure damage passes all three. Cultural convergence and planning horizon dynamics pass 4 of 5: cultural diversity declines to the expected range, long-horizon agents reach the survey-predicted share, and the altruism peak-and-decline pattern emerges without calibration targeting. These are the domains where the model's distinctive theoretical contributions received the strongest face validation support, and the pattern-oriented results indicate that the mechanisms practitioners described in interviews also generate the correct macro-level patterns in simulation.

Displacement and business survival each pass two of their evaluable criteria. The model reproduces the front-zone collapse (the civilian count drops to about 10% of the initial level in the front zone), the persistent displaced workforce pool, and the front/rear financial disparity. These passes indicate that the relocation decision logic, the safety threshold mechanism, and the zone-partitioned landscape work together to produce the documented pattern of rapid westward movement followed by gradual stabilization.

Figure 5.3 presents selected POM validation trajectories. Blue lines show the model mean across 30 replications with 95% confidence intervals (shaded). Red bands show empirical acceptance intervals at target ticks.

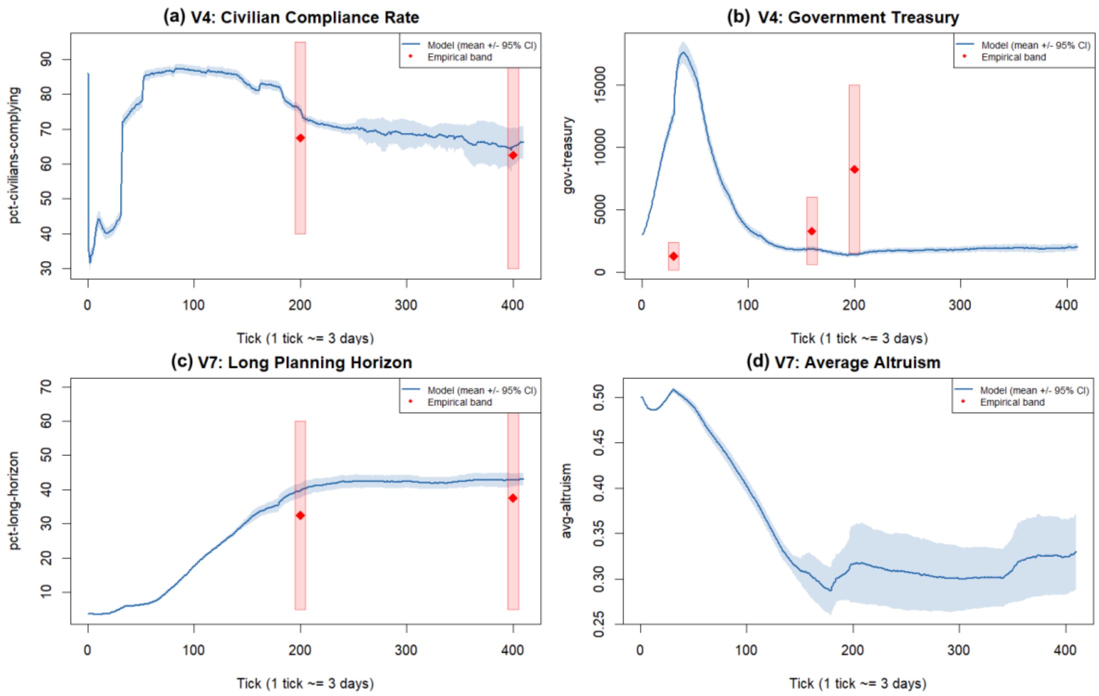

Figure 5.3. Selected POM validation trajectories

The pattern-oriented validation tested the calibrated model against 43 empirical criteria across eight domains. Of the 37 evaluable criteria, 20 pass and 17 fail (54%); excluding the five Jungle-Zoo criteria, all of which trace to a single structural limitation, raises the pass rate to 59% (19 of 32). The failures concentrate in three identifiable areas: fiscal coupling, MCR gating, and trade-network density. The credibility assessment that follows interprets these results and maps the domains where the model can and cannot support credible experimental claims.

5.7. Credibility Assessment

The validation pipeline has progressively narrowed the space of credible claims the model can support. The pass rate of 59% (after excluding the structurally limited Jungle-Zoo domain) falls below the 70% benchmark adopted in the validation plan. This section diagnoses the failures, evaluates whether they undermine the model's intended use, and maps the domains where the model can and cannot support credible claims.

Failure diagnostics

The failures cluster into three structurally identifiable categories rather than scattering across all eight domains.

The fiscal domain shows the largest discrepancies (2 of 5 criteria pass). The treasury does not collapse in the first month as Ministry of Finance data shows; instead, it grows. The spending floor mechanism was intended to decouple tax collection from institutional strength, but tax revenue still exceeds spending during the acute crisis because the model does not represent payment system disruptions, currency instability, or supply-chain interruptions. This is structural: no combination of the 13 search parameters produces a matching fiscal trajectory.

The Jungle-Zoo transition domain passes only 1 of 5 criteria, consistent with the dead-reporter diagnostic from the Morris screening. The jungle index never reaches the expected crisis peak, and the MCR front/rear gradient reverses. All four failures trace to the same MCR gating limitation.

The network domain reveals a calibration trade-off rather than a structural gap. The GA winner's low trust-trade-volume-weight (0.25) reproduces supply-link growth, hub emergence, and crisis fragmentation, but produces trade networks that are too sparse (17.5 links at tick 80 versus a target of 100–500). A higher value, such as the random search winner's 0.85, would produce denser networks but degrade economic calibration. The trust-network-economy entanglement identified in the OFAT analysis means that no single parameterization satisfies both domains.

The remaining seven failures are spread across displacement, business survival, military structure, and planning dynamics, where most criteria pass. A model whose failures cluster in identifiable structural areas is more credible for its intended use than one whose failures are diffuse, because clustering tells the experimenter which output domains to trust and which to treat with caution (Grimm & Railsback, 2012).

Interpreting the pass rate

Three considerations address whether the result supports the model's intended use.

The highest-quality empirical criteria show a substantially better pass rate. Of the twelve Tier 1 criteria, where acceptance bands derive directly from time-series macro data and the model reporter measures the same quantity as the empirical source, ten pass (83%). Most failures occur at Tier 2 (requiring proportional scaling or measurement-unit mapping) and Tier 3 (derived from qualitative impressions or model output statistics). When evaluated against the criteria where disagreement is most informative about mechanism accuracy, the model exceeds the 70% benchmark.

The shortfall is robust rather than an artifact of a single search trajectory. The four BehaviorSearch methods, starting from different parameter regions, all converge on the same narrow band: the GA winner passes 19 of 32, the random search winner 18 of 32. The GA performs better in the cultural and network domains; the random search performs better in the fiscal domain. Neither resolves all failures. If the failures were caused by suboptimal parameter values, at least one of the four methods would have found a parameterization that resolves them. The consistency indicates that the pass rate ceiling is architectural rather than parametric: improving beyond 56–59% requires structural model changes, not better parameter tuning.

The failures are therefore informative rather than disqualifying. They identify three specific architectural limitations (fiscal loop completeness, MCR gating conditions, and the trust-density trade-off) while leaving the model's core explanatory domains intact.

Domain credibility map

Figure 5.4 summarizes the per-domain validation results. Three domains pass the 70% benchmark unconditionally: military structure, infrastructure, and culture and planning. Two fall below the benchmark because of structural model limitations: fiscal coupling and Jungle-Zoo dynamics. Three more pass with qualifications: displacement, business survival, and network structure.

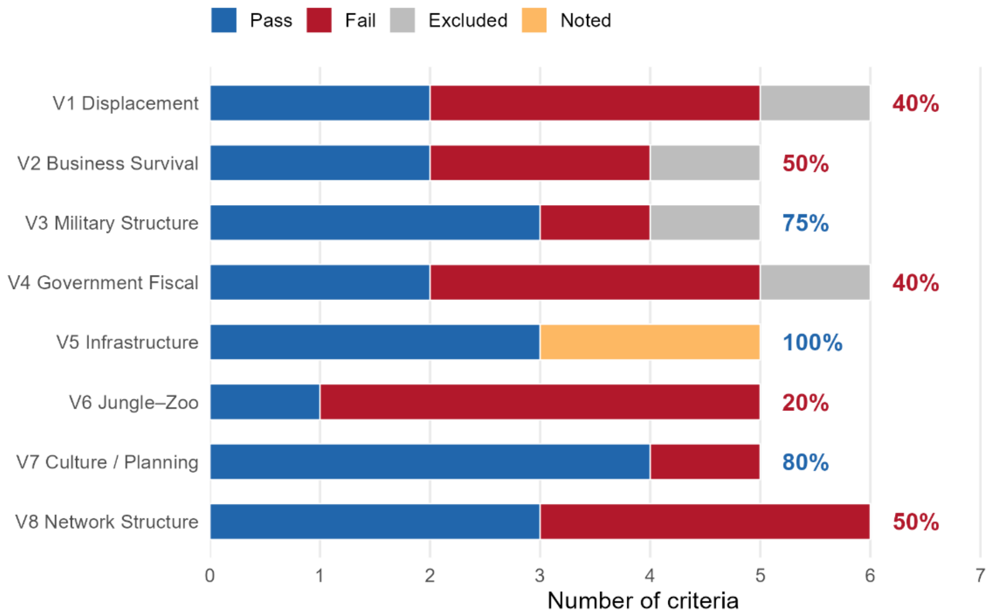

Figure 5.4. Pattern-oriented validation results by domain (GA winner, 30 replications)

The three domains that pass unconditionally and the three that pass with qualifications support two uses in the subsequent chapter: mechanism exploration (which mechanisms operating through the organizational and self-organizational pathways are necessary for adaptation) and counterfactual comparison (how different configurations of the organizational / self-organizational balance shape resilience).

Two domains fall outside the model's validated scope. The government fiscal domain shows structural discrepancies, so fiscal outcomes should not serve as the primary criterion for discriminating between societal configurations. Conclusions about the Jungle-to-Zoo transition should be treated as theoretical explorations; the computational experiments chapter includes a dedicated experiment (B10) that directly varies the MCR parameters.

The trade network domain passes with qualifications: the supply-link layer and hub dynamics are validated, but trade-link density falls below acceptance bands due to the trust-density trade-off described above. Experiments that depend on trade-link topology should acknowledge this limitation, while supply-chain and hub-mediated experiments can proceed with confidence.

The trust mechanism warrants a separate note. The three trust parameters are constrained by their observable consequences in network structure rather than by direct measurement, and the equifinality analysis showed that a structurally different trust configuration produces comparable overall fitness. The calibrated trust values are instrumentally useful but should not be interpreted as empirical estimates of how organizational trust actually accumulates and decays.

Chapter 5 Conclusions

This chapter established the model's empirical credibility. Three of eight validation domains pass the 70% benchmark unconditionally (military structure, infrastructure, culture and planning), two fail because of structural model limitations (fiscal coupling, Jungle-Zoo dynamics), and three pass with qualifications (displacement, business survival, network structure). This credibility profile supports two uses in the subsequent chapter.

First, mechanism analysis: by toggling structural features on and off under the calibrated parameters, the mechanism exploration can determine whether specific mechanisms operating through the organizational and self-organizational pathways contribute distinctive explanatory value or are redundant. The model's credibility for this purpose rests on the validation evidence that the integrated mechanism set reproduces reality in the validated domains.

Second, counterfactual analysis: the six society presets, each representing a different configuration of the organizational/self-organizational balance, can be subjected to identical warfare conditions. Because the model has been validated against Ukrainian reality under the baseline preset, differences in outcomes across presets can be attributed to structural differences rather than unvalidated mechanics. Conclusions should be restricted to the validated domains and should not extend to fiscal trajectories, MCR-dependent dynamics, or trade-network density.

Model validation is not a binary judgment but a process of building confidence in the model's usefulness for its intended purpose (Sargent, 2013, p. 12). The model is not universally correct, and this chapter has documented precisely where and why it fails. Within these boundaries, the model provides a credible computational instrument for investigating the questions that motivated its construction: under what conditions the organizational mechanism enhances or suppresses self-organizational adaptation (RQ3), how different pre-invasion configurations of the organizational/self-organizational balance shape resilience trajectories (RQ3), and where the viability boundaries of the system lie and whether the wartime shift is reversible (RQ4). The following chapter addresses these through four batteries of computational experiments.

CHAPTER 6

COMPUTATIONAL EXPERIMENTS: MECHANISMS, CONFIGURATIONS, AND SYSTEM BOUNDARIES

The wartime context analysis documented two adaptive pathways operating simultaneously under sustained warfare and produced a 27-mechanism inventory; the computational formalization and credibility assessment demonstrated empirical fit across six of eight validation domains (three unconditionally and three with qualifications), while two domains (fiscal coupling and Jungle-Zoo dynamics) fall outside the model's validated scope. Together they resolved several theoretical predictions directly: DRC organizational types, coercive isomorphism, r-strategy founding, but left open the questions of thresholds between the two pathways, the comparative advantage of self-organization at different institutional capacities, the reversibility of wartime solidarity activation, and the equifinality, counterfactual, and tipping-point questions that the fieldwork sharpened into computationally testable form.

This chapter uses the validated model as a computational laboratory to address these questions across four experimental batteries. The mechanism exploration battery tests which mechanisms are necessary, which are redundant, and whether their effects are conditional on one another. The counterfactual battery compares societal configurations that differ in institutional capacity, solidarity, and network structure. The complex-systems battery examines path dependence, tipping points, and the reversibility of pathway transitions. A final robustness battery tests whether the findings from the preceding three reflect structural properties of the modeled system or artifacts of specific parameter values.

6.1. Predictions and the Counterfactual Program

A calibrated agent-based model can generate evidence that observation alone cannot produce. The same simulated population is run under a baseline condition and then re-run with one structural feature altered. The difference between the two trajectories is interpretable as a causal effect in the potential-outcomes sense (Marshall & Galea, 2015; Rubin, 1974). Read sociologically, what such a comparison reveals is the operation of a social mechanism, a recurrent causal sequence linking micro-level actions to macro-level outcomes (Hedström & Swedberg, 1998).

The validity of model-generated counterfactuals depends on three conditions (Casini & Manzo, 2016). **Theoretical realism** requires that the mechanisms in the model be those identified through fieldwork, not mathematical constructs. **Empirical calibration** requires that the parameters come from the target population. **Empirical validation** requires that the model reproduce known patterns before generating unknown ones. The preceding empirical and computational work satisfied each condition. The mechanisms were identified through interviews with Ukrainian organizations. The parameters were calibrated using exclusively Ukrainian sources through a four-layer procedure. Because all calibration inputs come from this population, the counterfactuals explore what could happen in this system, not what would happen in another country (Murray et al., 2017). The outputs were validated against 43 empirical criteria across eight domains.

A model that generates its own quantitative data creates a temptation to treat standard statistical tests as the primary measure of evidential force. In conventional inference, a p-value measures the probability of observing data at least as extreme under a null hypothesis, given sampling variation from a real population. In a simulation, the data do not come from a population. They come from a model. Statistical tests remain useful for a narrower purpose: distinguishing genuine effects from replication noise (the variation across runs produced by different random seeds). A Kruskal-Wallis test can establish that two configurations produce reliably different outputs. It cannot establish that either output corresponds to reality. A finding can be statistically significant and still wrong if the model's mechanisms are misspecified. The evidential force of ABM counterfactuals therefore comes not from statistical significance but from the chain of empirical grounding described above. Statistical tests support the analysis but do not carry the argument.

The experimental program reports results primarily as patterns with effect sizes. Effect sizes are measured by Cliff's delta, a statistic describing how consistently values in one condition exceed values in another. A delta of 1.0 means complete separation between conditions; 0.0 means no difference. Pattern filters describe whether the model reproduces what was observed in reality. Where appropriate, Kruskal-Wallis tests and Kendall's tau trend tests (a measure of monotonic trend strength) identify which comparisons exceed replication noise. Neither effect sizes nor statistical tests substitute for the mechanism-grounding chain. Technical details of all statistical procedures are in Appendix E.

Three broader epistemological challenges also apply to any ABM counterfactual study. The **uniqueness problem** (history happened once, so there is no second observation to compare against) is addressed through large Monte Carlo ensembles. These are many independent simulation runs with different random seeds, evaluated against distributional signatures rather than single trajectories. **Non-ergodicity** (small initial differences can lock the system into qualitatively different states) is addressed through phase diagrams and reversibility tests (tests of whether changes reverse when the cause is removed) that map the full space of possible system configurations. **Over-parameterization** (too many free parameters can fit any pattern) is addressed through the four-layer calibration that restricts the parameter space to empirically grounded zones.

These measures mitigate the challenges but do not eliminate them. Counterfactual results remain theoretical explorations, not claims about alternative empirical realities (Windrum et al., 2007).

The experiments that follow use four concepts from complex systems theory. Each is tested by a specific experiment in this chapter. A **regime** is a kind of system behavior, defined by population size, economic output, and network structure, that persists when conditions change within a range (C5 phase diagram). A **tipping point** is a parameter value beyond which a small change causes the system to switch to a different regime (C1 collapse boundaries, supported by C3 early-warning signals). **Multistability** means the system can settle into two distinct outcomes from identical starting conditions (C2 bimodality test). **Path dependence** means the system's history leaves a mark that removing the cause does not remove. The post-war outcome depends on the wartime trajectory, not only on whether the war is over (C6).

Not every sharp boundary in the model is a tipping point though. A tipping point is where the system as a whole shifts to a different regime. A threshold is where a specific behavior changes sharply, but the system continues in the same regime. Below altruism 0.3, organizations do not volunteer, but they still survive and trade. The system stays in the same regime. The C1 collapse boundaries are tipping points: beyond them, the system reorganizes entirely.

Experimental program

The experiments follow a sequential logic in which each battery depends on the results of the one before. The mechanism exploration battery identifies which mechanisms matter. The counterfactual battery uses those mechanisms to compare alternative societal configurations. The complex-systems battery tests whether the configurations produce tipping points, regime boundaries, and irreversible transitions. The robustness battery tests whether the findings from the preceding three batteries reflect structural properties of the modeled system or artifacts of specific parameter values. Figure 6.1 summarizes the sequence.

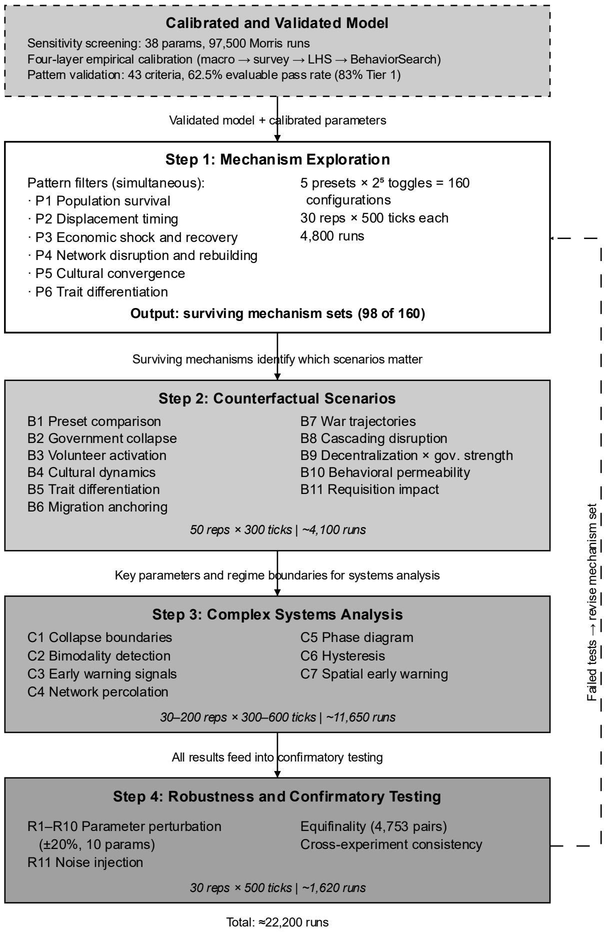

Figure 6.1. Sequential experimental program

Table 6.1 summarizes the experiment batteries, their questions, and their scale.

Table 6.1. Experiment battery summary

Code	**Name**	**Question**	**Configurations**	**Runs**
S1	Mechanism exploration	Which mechanism combinations reproduce the Ukrainian record?	160	4,800
B1	Preset comparison	Which societal configuration adapts best?	5	250
B2	Government collapse	What happens without institutional capacity?	3	150
B3	Volunteer activation	What drives domain expansion: disposition, institutions, or crisis?	32	1,600
B4	Cultural dynamics	Does cultural conformity help or hurt adaptation?	8	400
B5	Trait differentiation	Do front and rear zones diverge in adaptive traits?	1	50
B6	Migration anchoring	Which network mechanisms sustain partnerships under displacement?	8	400

B7	War trajectories	How do different war patterns damage different domains?	5	250
B8	Cascading disruption	Does doubled disaster frequency cascade systemically?	2	100
B9	Decentralization x gov.	Is the decentralization advantage conditional on institutional capacity?	6	300
B10	Behavioral permeability	What determines civilian military participation?	9	450
B11	Requisition impact	Does moderate military requisition damage the economy?	3	150
C1	Collapse boundaries	Where are the extinction thresholds?	99	4,950
C2	Bimodality detection	Does the model have multiple stable states?	5	1,000
C3/C7	Early warning signals	Can collapse be predicted from early indicators?	1	100
C4	Network percolation	Is there a critical connectivity threshold?	49	2,450
C5	Phase diagram	How do government strength and threat interact?	100	3,000
C6	Hysteresis	Is the wartime transformation reversible?	3	150
R1-R11	Robustness	Are findings stable under parameter perturbation and noise?	54	1,620
			Total	~22,200

The mechanism exploration battery (S1) asks which combinations of transformational mechanisms reproduce the Ukrainian empirical record. Five mechanisms (cultural transmission, trust, reputation, hub brokering, and long ties) are crossed with five societal configurations spanning the space from self-organizational dominance through the empirical Ukrainian balance to organizational dominance. Each of the 160 resulting combinations is evaluated against six empirical pattern filters and a continuous fitness score.

The counterfactual scenario battery (B1–B11) asks how specific structural features shape organizational survival. Each experiment varies one feature while holding the rest of the system constant. The features tested include government capacity, volunteer activation, cultural conformity, migration anchoring, war trajectory, and military requisition. Together, these experiments probe the interaction between the organizational and self-organizational pathways under controlled conditions.

The complex-systems battery (C1–C7) asks where the boundaries of viability lie and whether the wartime transformation is reversible. It applies tools from critical transitions theory (Scheffer et al., 2009) and social-ecological resilience research (Walker et al., 2004). These include tipping-point detection, bimodality analysis (testing whether the system has multiple stable states), network percolation thresholds (the minimum connectivity below which the network fragments), phase diagrams mapping institutional strength against external pressure, and a dedicated test of reversibility.

The robustness battery (R1–R11) tests whether the findings survive when inputs are imprecise or decision rules are noisy. Parameter perturbation shifts ten calibrated parameters by up to 20%. Noise injection adds random variation to the decision weights that govern how organizations choose between competing strategies. Findings that survive both tests describe properties of the modeled system. Findings that do not describe properties of a specific parameterization.

Every experiment uses 30 to 200 replications per condition. Full experiment designs, statistical procedures, and per-experiment results tables are in Appendix E. The remaining sections report the results in the order of the four batteries, followed by a synthesis that develops six sociological arguments: the institutional paradox, the structural advantage of self-organization, the four regimes of wartime adaptation, three qualifications to common theoretical assumptions, the asymmetry of recovery, and an integrative reading of what the experiments reveal for social theory.

6.2. Institutional Paradox

Government is necessary for organizational survival under warfare. But beyond a threshold of institutional strength, government suppresses the informal adaptation on which survival also depends. The formal system designed to protect organizations can begin to destroy their capacity to protect themselves. This is the institutional paradox. Three experiments locate the threshold, and a fourth maps the viable band within which both pathways coexist productively.

Government strength in this model bundles four functions that the formal pathway performs simultaneously. Safety provision projects military presence onto the landscape.

Subsidy provision distributes state resources to organizations, reducing their need to self-organize. Resource extraction transfers money and workforce from organizations to the state through taxation and mobilization. Selective subsidization channels more support to organizations whose practices align with state-preferred norms, producing cultural homogenization as a side effect rather than through direct regulatory coercion.

Safety provision is the beneficial side of institutional capacity. Without it, organizations die from direct threat exposure. Reducing government strength is therefore not a solution. The three remaining channels produce the paradox. Subsidy provision crowds out informal adaptation. When the state distributes resources, organizations with moderate solidarity disposition stop activating their own (the substitution effect documented in B3). Resource extraction depletes what organizations need for self-organizational adaptation. Every unit of taxation or mobilized workforce is a unit unavailable for voluntary cooperation (visible in the B2 finding, read in reverse). Selective subsidization narrows the population's adaptive repertoire. Organizations converge on rewarded patterns, and the resulting homogeneity reduces the behavioral variety on which self-organization depends (the conformity cost documented in B4).

Because government strength is a single parameter, the experiments show the joint effect of all three suppression channels but cannot isolate their individual contributions. Decomposing subsidy provision, extraction, and selective subsidization into separate parameters is a recommended extension. Empirical evidence supports each channel separately. Provision substitution appears in the volunteer-displacement patterns documented in interviews. Extraction appears in the taxation and budget redirection documented by Artiukh and Fedirko (2025). Selective subsidization appears in regulatory shifts in NGO reporting during martial law.

The clearest evidence of the paradox comes from the volunteer activation experiment (B3, the largest counterfactual experiment at 1,600 runs). The experiment asks whether strong institutions suppress volunteering, and if so, under what conditions. A factorial design varies initial altruism across four levels, government strength across four levels, and military mobilization as a toggle. Figure 6.2 presents the results.

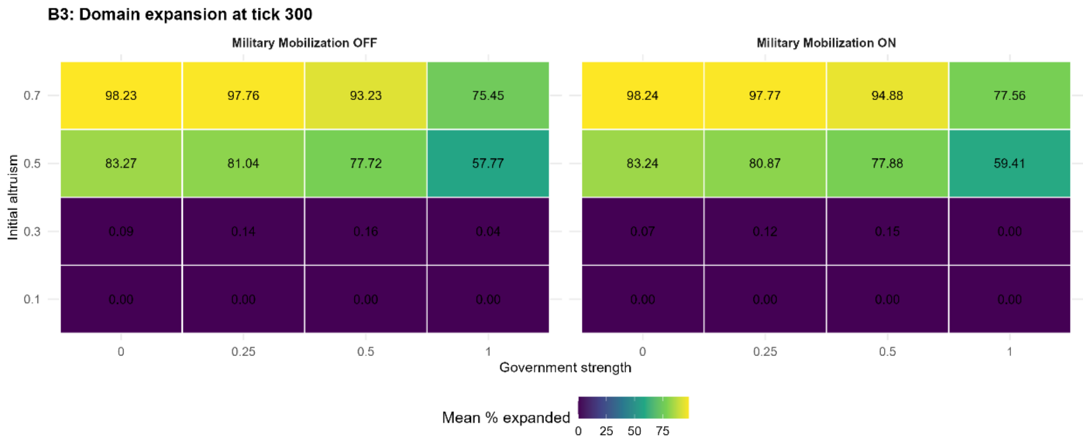

Figure 6.2. Domain expansion by initial altruism and government strength (B3)

The heatmap reveals three findings. First, volunteering is dispositional rather than reactive to crisis pressure. Initial altruism dominates domain expansion (Kruskal-Wallis chi-squared = 1420.98, $p < 10^{-300}$). A sharp nonlinear threshold appears between altruism 0.3 and 0.5. Below the threshold, virtually no domain expansion occurs regardless of conditions. Above it, 58 to 98% of organizations expand into new domains. Crisis pressure does not create volunteers. It removes barriers for organizations that were already disposed to act.

Second, strong institutions suppress volunteering. Under full government strength, domain expansion at altruism 0.5 drops by 25.5 percentage points compared to the no-government condition. State provision substitutes for spontaneous organizational adaptation. When the formal system provides defense services, organizations with moderate altruism no longer activate their own. At high altruism (0.7), the suppression effect weakens. Highly disposed organizations volunteer regardless. But for the population's middle range, the two pathways compete: where institutional provision is present, it leaves less room for voluntary cooperation.

Third, both dispositional readiness and institutional weakness are necessary for maximal volunteer activation. Neither alone is sufficient. This dual-condition finding is the computational signature of the institutional paradox. Beyond a threshold of institutional strength, the system enters a regime where self-organizational channels cease to operate. Below a threshold of dispositional readiness, no amount of institutional weakness activates self-organization. The full factorial design, cell means, and statistical details are in Appendix E.

Government strength and self-organization regime

The government collapse experiment (B2) models three institutional conditions: normal government strength (the calibrated Ukrainian scenario), temporary institutional weakness (government at 10% capacity for the first 50 ticks, then restored), and prolonged institutional weakness (government at 10% capacity throughout). The weakened conditions correspond to the empirical situation documented in the wartime context analysis: the invasion did not destroy the Ukrainian state but deeply disrupted it. Institutional capacity was severely reduced while the state continued to function at a fraction of its pre-invasion effectiveness.

Prolonged institutional weakness produces twice as many surviving organizations as the normal-strength condition, with large effect sizes across population and economic indicators. The reduction in taxation and mobilization costs outweighs the reduction in government protection and subsidies. Organizations that retain their resources survive in greater numbers than organizations from which the state extracts its wartime share. Figure 6.3 shows the altruism trajectories.

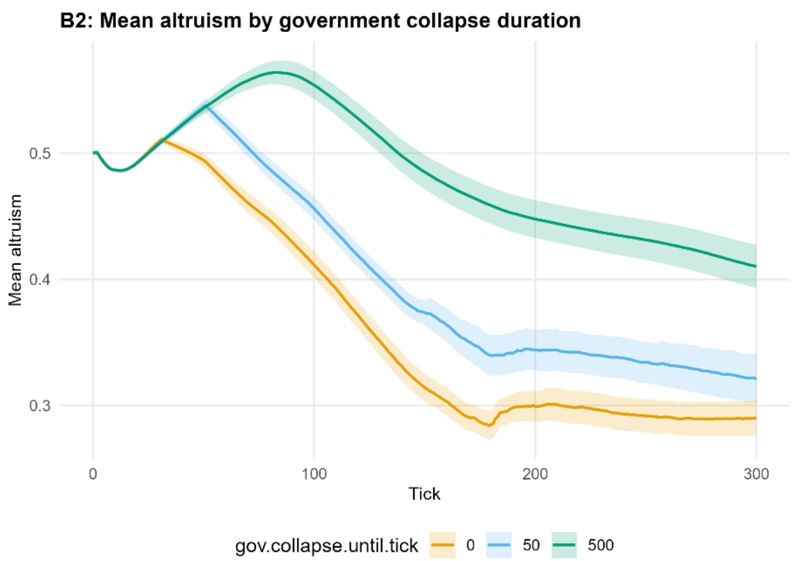

Figure 6.3. Mean altruism under three government conditions (B2)

The altruism trajectories reveal the mechanism. Under prolonged weakness, mean altruism remains at 0.42 by tick 300. Under normal government, it drops to 0.29. The institutional vacuum keeps the self-organizational mechanism active: organizations that would otherwise rely on state provision instead activate voluntary cooperation. This is the B3 substitution effect operating in reverse. When the state does not provide, organizations provide for themselves, and the volunteer activation persists.

Temporary weakness produces the lowest survival of the three conditions. The society absorbs disruption costs during the collapse period, then resumes paying extraction costs when government returns. Altruism rises during the weakness but is suppressed once institutional strength is restored, leaving the population with neither the full benefit of self-organization nor the full benefit of state provision.

The finding does not mean that government is unnecessary. It means that institutional extraction at normal wartime levels carries a cost that the model makes visible: each unit of additional government strength reduces the room for voluntary cooperation. Figure 6.2 heatmap quantifies this trade-off directly.

Cultural conformity as a second face of the paradox

The institutional paradox operates not only through fiscal provision but also through cultural homogenization. Cultural conformity carries a paradoxical cost (B4). The mechanism that strengthens within-group coordination simultaneously weakens the population’s overall adaptive capacity. When cultural transmission is active, organizations converge toward shared norms and practices. This convergence improves short-term displacement coordination (organizations with similar cultural tags cooperate more readily) while reducing long-run population size and economic output, with large effect sizes across all metrics.

Fiscal incentives operate through a separate pathway: they influence population and economy but not cultural diversity or altruism. Cultural conformity operates through the organizational pathway, imposing homogeneity that reduces the diversity on which self-organizational adaptation depends. Diversity, in this finding, is not a normative value but a functional resource. Organizational populations with greater behavioral variety maintain more pathways through which self-organization can operate. The paradox is that the very process that makes organizations more legible to institutions (cultural convergence toward sanctioned forms) simultaneously narrows the repertoire of adaptive responses available to the population as a whole. Short-run coordination stability and long-run adaptive capacity work against each other. The conformity that sustains one depletes the diversity that sustains the other.

This finding provides a computational specification of the tension that Seo and Creed (2002) identified theoretically: institutional contradictions accumulate within and between institutional systems. The contradiction here is precise. The institutional pathway rewards conformity, while the self-organizing one requires behavioral variety. The conditions that support one work against the other. The system performs better in the short run (coordination gains) and worse in the long run (adaptive capacity loss).

Implications of the paradox

The institutional paradox provides a quantified test of the boundary condition where compliance becomes maladaptive. The existing institutional literature recognized the possibility in principle. Oliver (1991) identified conditions under which organizations resist institutional pressures. Seo and Creed (2002) showed how contradictions between institutional logics can transform embedded actors into agents of change. Neither framework specified where the threshold lies or how much adaptive capacity is lost when it is crossed.

The experiments provide three specifications. The B3 substitution effect quantifies the crowd-out: a 25.5 percentage-point reduction in domain expansion at the population's dispositional midpoint. The B4 cultural conformity cost quantifies the diversity loss: large effect sizes on population and economy when conformity is active. The C5 phase diagram (developed in the four-regime analysis below) maps the viable band: only 7 of 100 parameter cells produce conditions where both pathways coexist productively.

Decoupling, in which organizations maintain ceremonial compliance while adapting actual practices, takes on a new role in this light. Decoupling has been described as a structural feature of organizations operating in institutionalized environments (Meyer

& Rowan, 1977). In the model, decoupling operates as an active organizational capability, a mechanism through which organizations preserve adaptive capacity under coercive pressure. The computational evidence reframes it: decoupling is not an imperfection of institutional control but a survival strategy that preserves the behavioral variety voluntary cooperation requires.

Read sociologically, these findings concern the limits of state capacity as a source of social order under sustained warfare. Too little institutional capacity leads to collapse (B2). Too much crowds out the self-organizational mechanism that sustained organizational survival during the acute phase (B3). The viable band between these two failures is narrow (C5). Wartime governance that maximizes institutional extraction (the centralized preset) produces the lowest survival across all tested configurations (B1, B9). Governance that balances provision with permissive space for spontaneous adaptation produces the highest. This is the interaction between the two pathways that the crisis-agency framework (Bevzenko, 2022) predicted but could not test empirically. The B3 substitution effect and the C5 viable band provide the quantitative specification.

6.3. Structural Advantage of Multiple Coordination Channels

Configurations that leave space for informal coordination produce more surviving organizations than configurations that rely primarily on institutional channels. This advantage is not conditional on institutional weakness. It holds at every tested level of institutional capacity. The experiments show why: the system works through redundant coordination channels, so disabling any single mechanism leaves the others intact. What matters is not any specific mechanism but the structural conditions under which multiple channels operate simultaneously.

The preset comparison (B1) explores five societal configurations representing different balances between the organizational and self-organizational pathways, which are subjected to identical warfare conditions. Figure 6.4 shows the results.

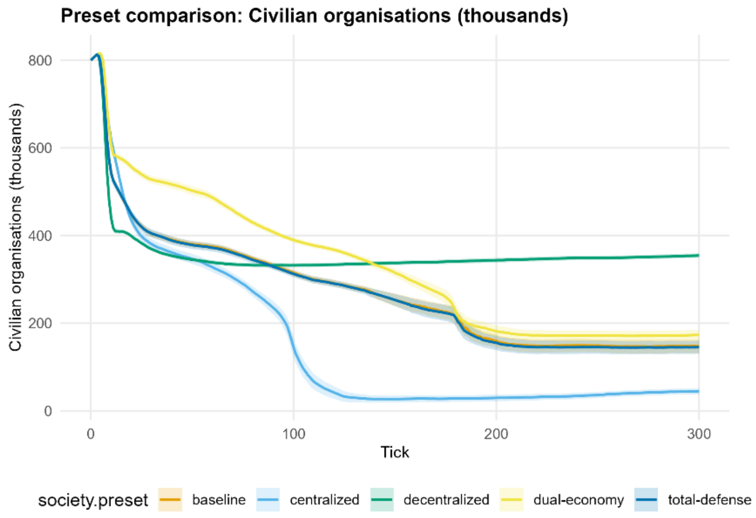

Figure 6.4. Civilian organizations under five societal configurations (B1)

The centralized preset (high hierarchy, low flexibility, elevated taxation) produces the fewest surviving organizations and the lowest economic output, with consistently large effect sizes on population (delta = 0.91–1.00). The decentralized preset (low hierarchy, high flexibility, reduced government fiscal capacity) outperforms all others except total-defense on most indicators. Total-defense performs comparably to baseline, suggesting that high civilian-military cooperation provides no additional survival advantage beyond what the calibrated Ukrainian configuration already achieves. The centralized preset produces the fewest surviving organizations. The decentralized preset produces the most.

Decentralization resists collapse

A follow-up experiment (B9) tests whether the decentralized advantage depends on institutional weakness. The decentralized and centralized presets are combined with three levels of government strength (0.20, 0.50, 0.80). Government strength enters the model as a multiplier on fiscal extraction: higher strength means higher effective taxation, more military funding, and more subsidies. Figure 6.5 shows the results.

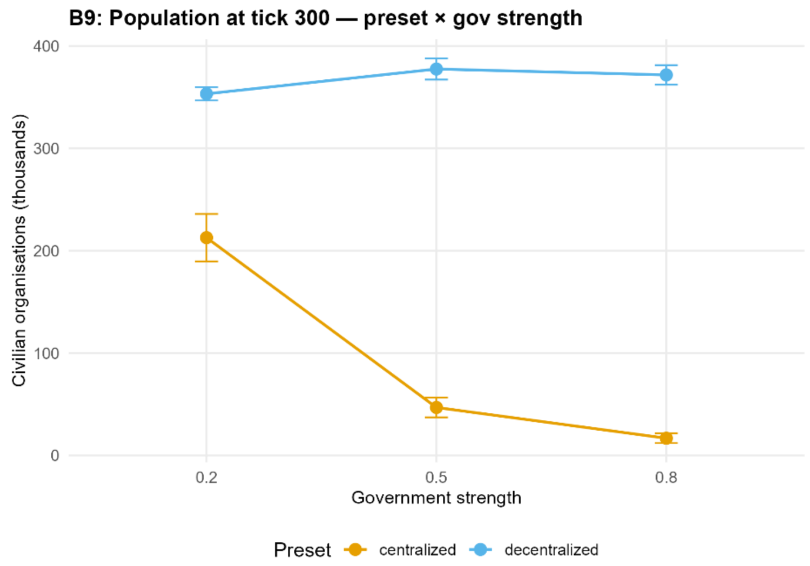

Figure 6.5. Population at tick 300 by preset and government strength (B9)

The decentralized preset survives equally well at all three levels (approximately 360 organizations). The centralized preset collapses from approximately 210 survivors at low government strength to approximately 20 at high government strength. The reason is structural. The decentralized preset combines three properties: low fiscal extraction (tax rate at 30% of baseline), low organizational hierarchy, and high organizational flexibility. Government strength has little to amplify because the fiscal footprint is already minimal, and the organizations can self-organize regardless of state activity. The centralized preset combines the opposite: high extraction (tax rate 0.40), high hierarchy, and low flexibility. Government strength amplifies a heavy extraction burden on organizations that cannot compensate through informal adaptation.

The finding is not about decentralization as a political principle. The specific combination of low extraction, low hierarchy, and high flexibility produces the highest survival rates across all tested conditions in the model.

The B9 result also addresses the question of how the two pathways interact posed in the analytical framework. The answer is configuration-dependent. Increases in government strength push the centralized configuration across the collapse tipping point but have no effect on the decentralized one. The properties that make centralized coordination efficient under stable conditions, tight hierarchy and high extraction capacity, make it fragile under sustained disruption.

No single mechanism is necessary

The mechanism exploration (S1) tested whether specific self-organizational mechanisms drive adaptation outcomes. Five transformational mechanisms (cultural transmission, trust, reputation, hub brokering, and long ties) were toggled on and off across five societal configurations, producing 160 structural combinations. Figure 6.6 presents the pattern filter results.

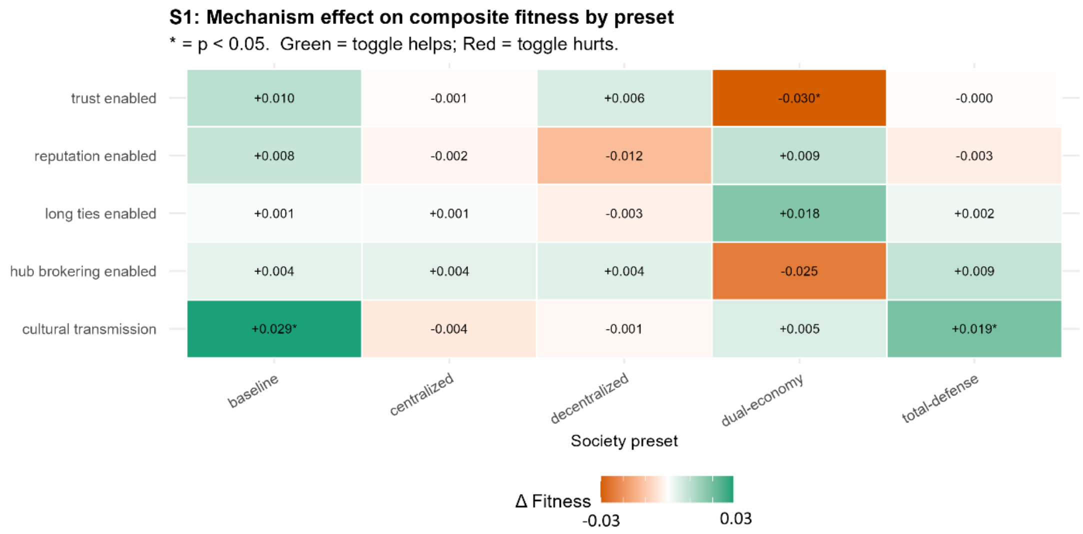

Figure 6.6. Pattern filter pass rates by preset and mechanism combination (S1)

No single mechanism produces a large effect on composite fitness at the pooled level. Cultural transmission shows a marginal positive contribution in the baseline and total-defense presets, but even this effect is context-dependent rather than general. The remaining four mechanisms show negligible effect sizes.

The explanation is functional interchangeability. The five mechanisms operate through overlapping network pathways: trust, reputation, hub brokering, and long ties all facilitate the same underlying process, connecting organizations to partners, resources, and information without institutional mediation. Disabling any one pathway leaves the others intact. The system adapts through whichever self-organizational channels are available. The equifinality analysis supports this reading: 31.3% of structurally different configuration pairs produce indistinguishable outputs, and all 32 possible toggle combinations are represented among surviving configurations.

The finding shifts the question from "which mechanism matters?" to "under what structural conditions does adaptation succeed or fail?"

Network connectivity as the infrastructure of self-organization

If self-organization operates through redundant network pathways, then network connectivity should be the structural precondition for organizational survival. Two experiments support this.

The network anchoring experiment (B6) tests three network mechanisms under displacement pressure: memory decay time, long ties, and hub brokering. Only long ties produce a consistent effect. Preserving long-distance connections during displacement improves trade degree, population survival, and economic output. Memory decay time does not affect network structure at the tested contrast levels. Hub brokering shows no main effect. Long ties function as infrastructure for the self-organizational mechanism: they sustain the relational pathways through which informal coordination operates when displacement disrupts local networks.

The convergence between the population tipping point (C1, at a base vision range of 2.19 patches) and the network percolation threshold (C4, at 2.0 patches) indicates that network connectivity acts as a precondition for survival in the model, not merely a correlate. When organizations cannot perceive potential partners beyond two patches, the trade network fragments into isolated components. Organizations die from economic isolation before direct threat exposure kills them. The threat does not explain collapse here; network fragmentation does.

Implications for social theory

The computational evidence supports Aldrich’s (2012) thesis that the structure of inter-organizational connections determines post-disaster recovery but extends it in two respects. First, the C1/C4 convergence shows that connectivity is not a recovery resource mobilized after the disaster but a real-time survival condition whose loss is immediately lethal. Networks are a survival condition, not only a recovery resource. Second, the B1/B9/S1 findings show that connectivity operates alongside two other structural conditions (the dispositional threshold identified in the institutional paradox analysis and the organizational/ self-organizational balance) rather than as the sole determinant. Organizational resilience under warfare depends on redundancy across parallel adaptive channels, not on the strength of any single network. This extends Aldrich’s network-centered thesis into a multi-dimensional account of adaptive capacity.

Wynnyckyj’s (2020) characterization of post-Maidan Ukrainian society as deliberately heterarchical (peer-to-peer coordination without central command) becomes not merely a historical description but a structural explanation. The B1/B9 finding explains why this society adapted the way it did to the full-scale invasion: the societal configuration that emerged from the Revolution of Dignity combined low hierarchy, high flexibility, and moderate fiscal extraction. These are the properties that the experiments identify as structurally favorable for wartime organizational survival.

6.4. Regime Structure and Tipping Points

When the model sweeps the entire range of institutional strength and external pressure, outcomes group into four regimes rather than the three that the crisis-agency framework describes. The transitions between them are asymmetric: the path into collapse is not the reverse of the path out.

The phase diagram (C5) maps system outcomes across a 10 × 10 grid of government strength (0.0 to 1.0) and threat intensity (0.0 to 2.0). Each of the 100 cells is run for 30 replications and classified by its population, economic, and network outcomes. Figure 6.7 shows the resulting regime map.

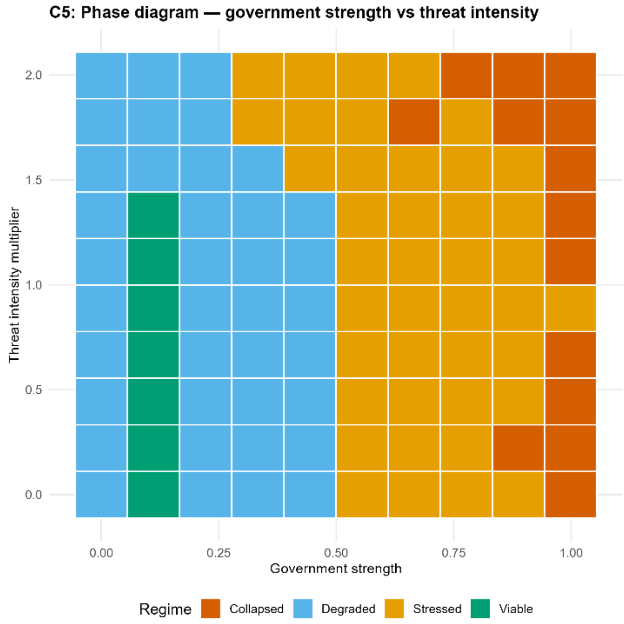

Figure 6.7. Phase diagram: regime classification by government strength and threat intensity (C5)

Viable occupies a narrow band of 7 cells where both pathways operate at intermediate intensity and reinforce each other. Organizations adapt, the economy recovers, and networks remain connected. The Viable cells cluster at low government strength, just above zero, and at low-to-moderate threat. This is the region where the institutional paradox does not bite: institutional capacity is present but minimal, and self-organizational pathways have space to operate.

Stressed is a larger region (41 cells) where the system absorbs pressure at a cost but still recovers. Organizations survive with reduced population and economic output. This corresponds to the constructive-adaptive instability that the crisis-agency framework describes: the system is under strain but its adaptive mechanisms are functioning.

Collapsed (14 cells) is the region where organizations fail outright and the state loses fiscal capacity. Both pathways have broken down.

Degraded is a region as wide as Stressed (38 cells) and more damaging in the long run. Organizations persist at permanently reduced capacity. They neither fully adapt nor fully comply. Informal networks are too thin to sustain full recovery, but enough institutional scaffolding remains to prevent outright collapse. The system continues to function at a level that looks like survival but is not recovery.

Degraded regime adds a category that the crisis-agency framework does not describe. The crisis-agency framework has no place for a population that neither returns to stability nor moves through destructive transformation but persists in functional compromise. Pugachova (2025b) named this condition the survival regime: a system that continues to exist but has lost the capacity to return to a functional state. The phase diagram locates it quantitatively. What distinguishes Degraded from Stressed is not the intensity of external pressure but the erosion of the relational infrastructure that would allow recovery. The self-organizational mechanism's fuel (network connectivity, cultural diversity, solidarity capital) has been depleted below the threshold needed for the system to rebuild itself. The organizational mechanism provides enough structure to prevent collapse but not enough adaptive space for self-organization to restore what was lost.

Regime classification varies primarily along the government-strength axis, not the threat-intensity axis. At zero government strength, most cells are Degraded regardless of how severe the external threat is. Even the minimal institutional scaffolding that the B2 experiment provided (10% capacity) is absent here, and the system lacks the coordination that even weak government supplies. At the other extreme, high government strength pushes the system toward Collapsed through overextraction. Both Collapsed and Degraded are outcomes of the institutional paradox, reached from opposite directions. The viable band between institutional absence and institutional overextraction is narrow and asymmetric.

Tipping points and fragility

Three parameters show clear extinction tipping points (C1). Military attrition rate crosses the tipping point at 0.327. Government strength crosses at 0.830. Base vision range (the distance within which organizations can perceive potential partners) crosses at 2.19 patches. Civilian attrition rate and partner memory decay show no sharp tipping points: the model tolerates wide variation in direct civilian damage and in how long organizations remember former partners. The system's vulnerability is concentrated in military protection and network connectivity, not in the direct exposure of civilian organizations to harm. Figure 6.8 shows the collapse curves.

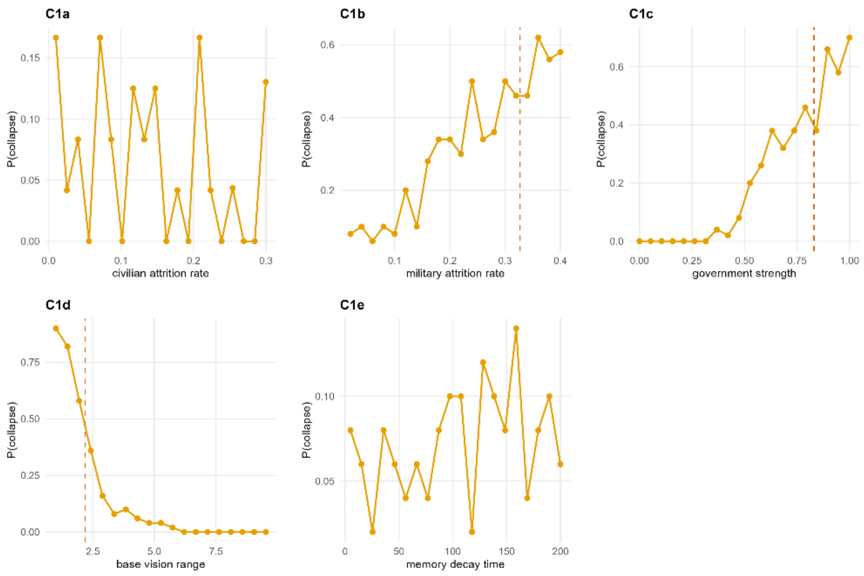

Figure 6.8. Collapse probability by parameter value (C1). Dashed lines mark identified tipping points

At government strength 0.830, the system crosses a tipping point into the collapse regime. This is the maximum institutional capacity the system can sustain: beyond it, extraction exceeds what the organizational population can bear. This converges with the institutional paradox: the B3 substitution effect divides outcomes between the two pathways at levels where the system survives; above 0.830, extraction crosses into outright collapse.

Multiple stable states appear only under the centralized preset (C2). Under this configuration, some replications build enough trade connections to sustain the economy while others fail to reach that threshold and collapse. No other configuration shows this fragility. Outside the centralized preset, the model degrades gradually rather than switching between regimes. Suppressing self-organizational pathways does not merely reduce average performance. It makes the system structurally fragile, capable of catastrophic failure under conditions where other configurations degrade.

Ecological early-warning diagnostics transfer to this social-organizational system (C3/C7). When civilian attrition is gradually increased, four indicators are tracked in rolling windows. All four show stronger upward trends in collapsing replications than in surviving ones. The strongest predictor is spatial autocorrelation of safety (Moran’s I, a measure of how similar neighboring locations are to each other), with the largest gap between collapsing and surviving trajectories. Spatial indicators outperform temporal and economic ones, consistent with Dakos et al. (2010, p. 163).

6.5. Asymmetry of Recovery

The hysteresis experiment (C6) runs the model through three scenarios over 600 ticks. Each scenario specifies the government strength and threat exposure the system faces over the run. The no-war scenario holds government at moderate strength (0.50) with zero threat throughout. The shock-recovery scenario begins with government weakened to 10% capacity (reflecting the institutional disruption of the acute crisis phase), runs through invasion, holding, and retreat over 300 ticks, then allows 300 ticks of peace. The permanent occupation scenario begins with the same institutional weakness and sustains warfare indefinitely.

The scenarios differ not only in threat exposure but also in government strength. The no-war scenario operates at 0.50 throughout. The shock-recovery and occupation scenarios start at 0.10. Population and economic comparisons across scenarios therefore reflect both the effect of war and the effect of different institutional extraction levels. Cultural and behavioral comparisons are less affected, because these dimensions respond to crisis activation and network dynamics rather than to fiscal extraction directly.

If the wartime transformation were fully reversible, the shock-recovery society would return to the no-war baseline during the peace period. Cultural diversity and altruism show that it does not. The system is path-dependent: the war leaves marks that removing the threat does not erase.

Persistent loss

Cultural diversity falls sharply during the war and does not recover during 300 ticks of peace, stabilizing 13.2% below the no-war level ($p = 0.018$). Altruism (the model's measure of solidarity disposition) follows the same direction, falling 11.8% below the no-war level, though this gap does not reach conventional significance thresholds ($p = 0.058$). Population shows the same pattern: a positive gap (+39.1%) that does not reach significance ($p = 0.052$). Planning horizon is the exception: cognitive adaptation reverses fully when the stressor is removed (+3.4%, $p = 0.053$). Economic output is higher in the shock-recovery society than in the no-war society (+125.2%), but this comparison is confounded by the different government-strength settings across scenarios and falls in a domain with known calibration limitations. Figure 6.9 shows the cultural diversity trajectories.

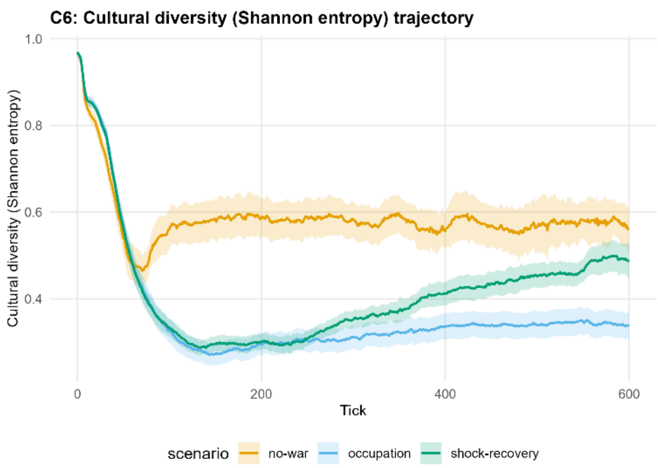

Figure 6.9. Cultural diversity under three scenarios (C6)

The asymmetry has a structural explanation. The organizational mechanism's domain (trade networks, fiscal flows) operates through resources that can be rebuilt: physical capital is destroyed and reconstructed, trade links are severed and reformed. The self-organizational mechanism's fuel (cultural diversity, solidarity capital, the willingness of strangers to coordinate without formal mediation) is consumed when used. Cultural convergence during the acute phase enabled rapid coordination, but it did not replenish during peacetime. The cultural homogeneity that remains after the crisis is the residue of an adaptive process that spent its own preconditions.

Shared threat dissolves social barriers and activates prosocial behavior (Fritz, 1961). The C6 cultural and behavioral trajectories specify what that activation costs. The prosocial response is visible in credible domains, but the activation draws down the diversity and solidarity that made it possible. Fritz treated the consequences as jointly positive. The computational evidence suggests the material and social dimensions move in opposite directions. The economic trajectory in C6 is consistent with this direction, but economic output falls in a domain with known calibration limitations and cannot carry interpretive weight.

Three modes of reversibility

The five tracked metrics fall along a spectrum that maps onto Walker et al.'s (2004, p. 3) resilience framework. Planning horizon demonstrates adaptability: fully reversible response to stress. When the stressor is removed, cognitive adjustment returns to baseline. Cultural diversity demonstrates transformability: the system transitions to a qualitatively different state from which no return occurs within the observation horizon. Altruism occupies an intermediate position, with a gap in the expected direction that does not reach significance. The boundary between adaptability and transformability runs through the social fabric rather than through material resources.

Calamities are expected to simultaneously produce moral degeneration and altruistic self-sacrifice (Sorokin, 1942), but Sorokin treated these as parallel reactions distributed across different parts of the population. The C6 result specifies the structure differently. The polarization operates across dimensions of the same system (material indicators recover, cultural indicators do not) rather than across individuals. What can be stated is that the asymmetry between material and social indicators is a structural property of the model, reproduced across replications, and consistent with the theoretical prediction that the two pathways draw on different kinds of resources.

The institutional paradox and the solidarity asymmetry combine into a single proposition. The formal state that provides institutional capacity beyond the viable threshold does so by consuming the informal solidarity that sustained organizational survival during the acute phase. The material gains are visible: trade networks reform, organizational populations stabilize. The social depletion is invisible and reveals itself only when the next disruption arrives and finds the solidarity pool empty.

The system that emerges from war is not uniformly stronger or uniformly weaker. It is stronger in the organizational mechanism's domain and weaker in the self-organizational mechanism's fuel. This is what Pugachova (2025b, p. 168) calls **resilience without adaptation**. A society that stays resilient on material dimensions while losing its capacity to reorganize on social ones has not survived the disruption. It has postponed its consequences. War consumes solidarity that powered adaptation, and solidarity does not replenish when the threat recedes.

The irreversibility documented here differs from lock-in as defined in path-dependence theory (Page, 2006, pp. 88, 97). Lock-in operates through increasing returns. The current configuration reinforces itself over time, making departure progressively costlier. Selective subsidization does produce an increasing-returns dynamic while the threat persists. Organizations that align with state-preferred norms receive more support, succeed at higher rates, and are imitated by others. Cultural homogeneity grows through a self-reinforcing loop.

That loop, however, is wartime-specific. It ceases when the threat recedes and the wartime incentive structure dissolves. The system still does not return to its pre-invasion configuration. What prevents return is not active reinforcement but substrate depletion. The cultural diversity and solidarity capital that any reversion would draw on have been consumed by the activation process itself. In Page's (2006, p. 97) taxonomy, the finding is path-dependent in the strict sense: different wartime trajectories produce different post-war configurations, and the sequence of wartime states determines the outcome. It is not lock-in. No increasing-returns mechanism sustains the post-war configuration. What sustains it is the absence of the substrate that any alternative would need.

Full experimental design, per-metric results, and time-series trajectories for C6 are in Appendix E.

6.6. Secondary Findings

Four secondary findings qualify, contradict, or fail to support specific assumptions from the analytical framework.

Front-zone depletion under sustained threat

The spatial differentiation hypothesis predicts that sustained threat exposure should produce divergent adaptive profiles between front-zone and rear-zone organizations. Organizations near the front should develop crisis-adapted traits that organizations in the rear do not share. The experiment supports this prediction (B5). Kendall's tau trend tests show strong monotonic divergence on both planning horizon and altruism (tau = -0.944, $p < 0.001$ for both). Front-zone organizations lose planning capacity and solidarity disposition steadily over the wartime period. Rear-zone organizations retain both. The gap between zones starts near zero and widens monotonically. Figure 6.10 shows the trajectories.

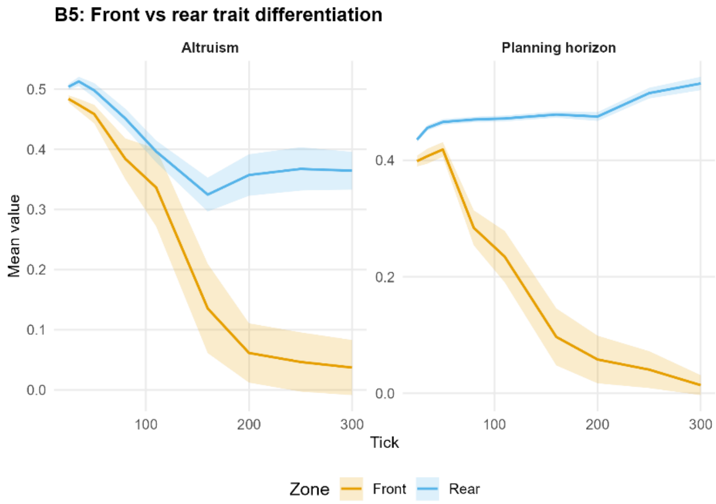

Figure 6.10. Front vs. rear trait trajectories under sustained warfare (B5)

The finding has an implication for post-war recovery. The organizational population that emerges from war is spatially stratified. Front-zone organizations carry depleted adaptive traits. Rear-zone organizations retain pre-invasion levels. Whether displacement mixing redistributes these traits across zones at the individual-organization level is a question the current zone-level analysis cannot answer, because the model tracks zone averages rather than individual organizational trajectories across relocations.

Structural inertia is sometimes protective

The centralized preset preserves organizational form at the cost of adaptive capacity (B1, C2). Read alongside the interview finding that manufacturers with rigid production processes survived the shock phase more effectively than flexible service firms whose employees dispersed, this complicates the managerial assumption that flexibility is always adaptive. The resolution is temporal. Inertia protects during the acute phase by preventing organizational disintegration. Reconfiguration capacity determines medium-term adaptation. Both properties are adaptive under different temporal conditions. The dynamic capabilities literature (Teece, 2007) emphasizes sensing and reconfiguration. The population ecology literature (Hannan & Freeman, 1984) emphasizes structural inertia. Computational evidence suggests that the two perspectives describe different temporal horizons of the same adaptive process rather than competing accounts of organizational survival.

War trajectories damage different domains independently

Five war scenarios produce distinct damage signatures (B7). Frozen conflict produces the highest population and economic outputs among the five scenarios. Among active combat scenarios, rapid collapse kills more organizations during the intense initial phase but concentrates wealth among survivors through a selection effect. Prolonged attrition steadily erodes the population but does not produce additional economic damage beyond the default, because organizations have time to rebuild trade networks and adapt production. Neither pattern is unambiguously worse. Intensity and duration are independently destructive along different dimensions. Figure 6.11 shows the population trajectories.

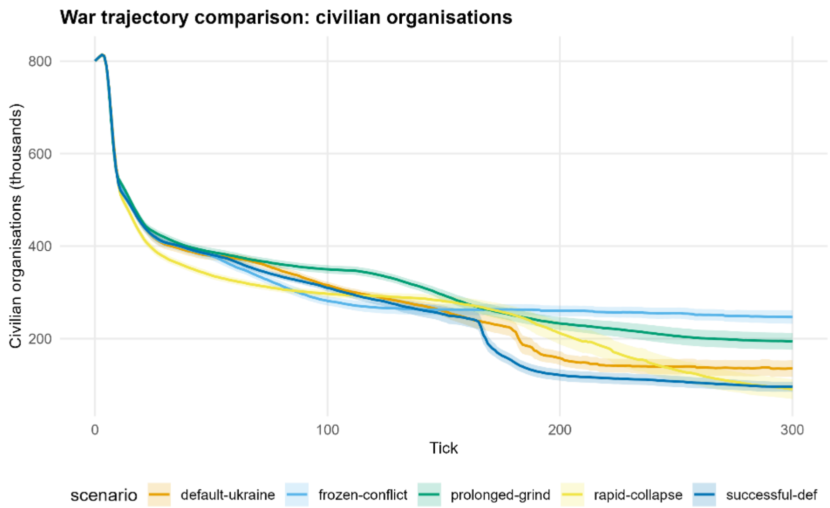

Figure 6.11. Civilian organizations across five war scenarios (B7)

Perturbations the system absorbs

Two expected effects are absent. Doubled disaster frequency does not cascade through the trade network into systemic collapse (B8). The system absorbs localized disruptions without systemic consequences, suggesting that the primary risk to organizational survival is sustained, geographically broad warfare rather than concentrated shocks. The cascading disaster framework (Pescaroli & Alexander, 2016) is not supported at the tested intensity, though this may reflect insufficient network coupling in the model. Military requisition at rates up to 20% produces no detectable economic effect (B11). Civilian adaptation capacity buffers moderate state extraction, consistent with the B3 substitution finding.

Full experimental designs and statistical results for B5, B7, B8, and B11 are in Appendix E.

6.7. Synthesis and Limitations

Under sustained warfare, institutional compliance and informal self-organization do not operate as independent survival strategies. They form a coupled system whose interaction determines whether organizations adapt or fail. The main results sections documented this coupling from different angles. The institutional paradox identified the threshold beyond which conformity works against voluntary cooperation. The self-organizational advantage showed that the coupling is asymmetric. The regime structure mapped where the system breaks. The asymmetry of recovery revealed the long-term cost. This section identifies patterns visible only across experiments, integrates the computational findings with the theoretical framework and the fieldwork, and documents the limitations that bound the results.

Cross-cutting patterns

Three patterns emerge from the experiments taken together rather than individually.

First, the same property appears in multiple experiments with different functional roles. Altruism (the model's measure of solidarity disposition) operates as a dispositional threshold in B3: below 0.3, no volunteering occurs regardless of conditions. It operates as a fuel consumed by wartime adaptation in C6: altruism falls 11.8% and does not recover during peace. It operates as a spatially stratified trait in B5: front-zone altruism depletes while rear-zone altruism holds. These are not three separate findings about three separate variables. They are three views of one resource that the self-organizational pathway depends on. It must exist before the crisis. It is spent during the crisis. It is unevenly distributed across space after the crisis.

Second, the model's structural failures are informative. The three domains that fall outside the validated scope (fiscal coupling, MCR gating, and trade-network density) share a common source: the model's economic and institutional components are simplified relative to its behavioral and network components. Government collects taxes and distributes subsidies through a single agent with no internal budget dynamics. Trade networks rebuild faster than empirical benchmarks because partnership search is unconstrained by institutional friction. The MCR mechanism (military-civilian ratio gating, the mechanism controlling when organizations shift between volunteer-driven and state-coordinated defense) requires a conjunction of conditions that the model rarely produces. These failures do not invalidate the behavioral and network findings, but they define the boundary. The model is credible for questions about organizational behavior and network structure, not for questions about fiscal dynamics or institutional regime transitions.

Third, the robustness results create a hierarchy among findings. Structural findings (which societal configuration produces the highest survival, where the tipping points lie, whether the regime structure has four categories) are robust to parameter perturbation (80.3% within baseline confidence intervals). Behavioral-weight findings (which specific decision rule dominates under which conditions) show moderate sensitivity to noise injection (50%), meaning that adding random variation to the weights that govern how organizations choose between competing strategies changes some outcomes. The qualitative architecture of the results is stable. The quantitative magnitudes are approximate.

Theoretical integration

The six analytical frameworks generated 23 testable predictions (Table 6.2). Thirteen were supported by the computational evidence. Four were qualified. Two were contradicted. Two were not supported at the tested intensity. One was extended beyond its original formulation. One remained inconclusive due to a structural limitation in the model. No framework was wholly wrong. Every framework contributed predictions that the experiments supported. But each framework also reached a boundary where the experiments forced a qualification.

Institutional theory did not anticipate the threshold beyond which compliance works against voluntary cooperation. Network theory underestimated connectivity as a real-time survival condition. The crisis-agency framework was extended by the addition of a fourth regime it did not describe. Disaster response sociology was partially supported: hastily formed networks persisted rather than dissolving. Dynamic capabilities and population ecology were both qualified by findings that complicate their core predictions.

The pattern across these verdicts is consistent. Every framework performed well within its original scope and reached its limit where the two pathways interact. Institutional theory described compliance but not its threshold. Network theory described connectivity but not its coupling to institutional extraction. The crisis-agency framework described the interaction between the two pathways but did not specify its thresholds. The computational experiments address the interaction, which is where the individual frameworks stop.

Fieldwork integration

The mechanism exploration (S1) showed that no single mechanism is necessary for organizational survival. What matters is the structural conditions under which multiple mechanisms operate simultaneously.

The three mechanisms with the strongest empirical support in the interviews (planning horizon contraction with 26 S-codes, voluntary military support with 22, and domain expansion with 16) all draw on the same resource: the altruism and solidarity disposition that the cross-cutting pattern analysis identifies as the central determinant of organizational survival across experiments. The dispositional threshold identified in B3 (altruism between 0.3 and 0.5) determines whether these mechanisms activate. The solidarity depletion identified in C6 determines whether they remain available for the next crisis. The spatial stratification identified in B5 determines where in the territory they persist.

The survey-calibrated initial conditions (compliance-evasion split 86/14, planning-horizon distribution 51% shortened, military-friendliness 49% active support) position the Ukrainian baseline within the Viable-to-Stressed band of the C5 phase diagram: close to the institutional paradox threshold but not beyond it.

Table 6.2 documents the prediction-by-prediction verdicts that underlie the synthesis above. Each row links a theoretical (TP) or empirical (EP) prediction to its source, the experiment that tested it, and the experimental conclusion.

Table 6.2. Theoretical predictions and experimental conclusions

Prediction	Source	Experiment	What the experiment tests	Conclusion
TP1. Mutual suppression between pathways beyond a threshold	Crisis-agency theory	B3, C5	Substitution effect between government strength and volunteering; phase diagram of regime space	Supported and quantified. B3 substitution effect, C5 phase diagram.
TP2. Adaptive traits follow three-phase pattern	Crisis-agency theory	C5, C6	Phase diagram extends to four regimes; hysteresis tests reversibility	Extended. Four regimes identified; Degraded regime added.
TP3. Institutional capacity is necessary for organizational survival	Crisis-agency theory; disaster sociology	B2	Government at 10% capacity vs. temporary weakness vs. normal strength	Qualified. Weakened government activates self-organization and produces higher survival than normal strength. Temporary weakness produces worst outcomes.
TP4. Coercive isomorphism toward war-oriented structures	Institutional theory	C1, C5	Government strength effects on population and regime classification	Supported. C1/C5 government strength effects.

Prediction	**Source**	**Experiment**	**What the experiment tests**	**Conclusion**
TP5. Widespread decoupling between formal compliance and practice	Institutional theory; interviews	B4	Cultural transmission cost on population and diversity	Supported and reframed. Decoupling as active capability, not passive feature.
TP7. Complementarity dominates in crisis; compatibility in recovery	Network theory; interviews	B6	Long ties, hub brokering, memory decay effects on trade network	Partially supported. Long ties significant; hub brokering null.
TP8. All four DRC organizational types activated	Disaster sociology	descriptive	Resolved through descriptive and interview evidence	Supported. Descriptive evidence.
TP9. Hastily formed relief networks dissolve after triggering event	Disaster sociology	B6	Network persistence under displacement; long-tie effects	Contradicted. Networks persisted; B6 long ties sustain them.
TP10. Prior disruption experience accelerates adaptation	Dynamic capabilities; interviews	S1, B3	Mechanism interchangeability; dispositional threshold vs. sensing capacity	Qualified. Mechanism interchangeability; dispositional threshold matters more than sensing.
TP11. Boundary reconfiguration critical under resource depletion	Dynamic capabilities; interviews	B3	Domain expansion rates under factorial conditions	Supported. B3 domain expansion.
TP12. Elevated specialist mortality; generalist advantage	Organizational ecology	B1, C2	Preset comparison; structural inertia effects	Qualified. Structural inertia sometimes protective (temporal resolution).
EP1. Volunteering is dispositional, not reactive to crisis pressure	Interviews	B3	Altruism threshold; crisis pressure effect on domain expansion	Supported. B3 altruism threshold.
TP13. Spatial threat exposure produces divergent front-rear profiles	Interviews; macro data	B5	Trait differentiation vs. displacement mixing	Supported. B5 shows monotonic front-rear divergence (tau = –0.944).
EP2. Cultural convergence during wartime	Survey; macro data	B4, S1	Cultural transmission effect on diversity; cultural pattern filter	Supported. B4 cultural transmission; S1 cultural pattern filter.

Prediction	Source	Experiment	What the experiment tests	Conclusion
EP3. Network connectivity determines organizational survival	Interviews; network theory	C1, C4	Population tipping point and percolation threshold convergence	Supported. C1/C4 threshold convergence.
TP14. War intensity and duration damage different domains independently	Disaster sociology; macro data	B7	Five war scenarios: damage signatures across domains	Supported. Intensity kills organizations; duration erodes culture.
TP15. War-induced changes are selectively irreversible	Complex systems theory	C6	Hysteresis: three scenarios compared on five metrics	Supported. Cultural diversity does not recover (–13.2%). Economic overshoot (+125%) confounded by government-strength settings and in a domain with calibration limitations.
TP16. Cascading disruptions compound systemic damage	Disaster sociology	B8	Doubled disaster frequency on trade network and population	Not supported at tested intensity. May reflect insufficient network coupling in the model.
TP17. Moderate military requisition damages the civilian economy	Wartime governance literature	B11	Requisition at 0%, 10%, 20% of local resources	Not supported. Only 2 of 33 comparisons show any effect; the rest are negligible or inconclusive.
TP18. Decentralization advantage is conditional on institutional weakness	Common expectation from institutional theory	B9	Decentralized vs. centralized at three government strength levels	Contradicted. Advantage holds at every tested level.
EP4. Ecological early-warning signals transfer to social-organizational systems	Critical transitions theory (Scheffer et al., 2009)	C3, C7	Temporal and spatial indicators in gradually stressed system	Supported. Spatial autocorrelation strongest predictor.
TP19. Organizational-mechanism-dominant	Complex systems theory; crisis-agency	C2	Bimodality detection across five presets	Supported. Bimodality only under centralized preset.

Prediction	Source	Experiment	What the experiment tests	Conclusion
configurations can bifurcate				
EP5. Civilian military participation gated by permission, not crisis	Interviews (Jungle/Zoo dynamics)	B10	Civilian cap vs. crisis-increase rate on jungle index	Inconclusive. Null effect of crisis intensity consistent with the MCR gating limitation identified in the credibility assessment.

Limitations

These findings rest on a model with documented limitations. The trade network rebuilds too quickly, likely explaining the failure of the network-structure validation criterion, the predominantly gradual degradation (rather than splitting into two distinct outcomes) outside the centralized preset, and the null cascading disruption result. The mechanism exploration tests only five of the model's mechanisms as binary toggles; others are always active. The counterfactual presets have no direct empirical analogs. The B10 experiment tested civilian military participation by varying MCR parameters. The null effect of crisis intensity is consistent with the MCR gating limitation rather than a substantive finding about the determinants of civilian militarization.

The findings are robust to parameter perturbation but show moderate sensitivity to noise injection, as detailed in the cross-cutting patterns above. Detailed robustness results are in Appendix E.

Chapter 6 Conclusions

This chapter used the validated model as a computational laboratory to test how the organizational and self-organizational pathways interact under sustained warfare. Approximately 22,200 simulation runs across four experimental batteries addressed the dissertation's third and fourth research questions.

Configurations with multiple open coordination channels produce higher organizational survival than configurations that concentrate coordination in one pathway. No single mechanism is necessary. The system adapts through whichever informal channels are available, and the advantage holds at every level of institutional capacity.

The institutional paradox specifies the boundary: institutional compliance supports organizational survival up to a threshold, beyond which the system shifts toward state-organized coordination at the expense of voluntary cooperation on which survival depends. The substitution effect quantifies the crowd-out at the population's dispositional midpoint. Configurations that combine low fiscal extraction, low organizational hierarchy, and high flexibility produce the highest survival rates across all tested conditions. Configurations that maximize institutional control produce the lowest survival.

The system's viability boundaries are defined by three tipping points in military protection, government strength, and network connectivity. The full parameter space produces four regimes: Viable, Stressed, Collapsed, and Degraded. The Degraded regime, in which organizations persist at permanently reduced capacity without the relational infrastructure to recover, is a conceptual contribution not described by existing frameworks. The wartime transformation is selectively irreversible. Cultural diversity and solidarity disposition are consumed during adaptation and do not recover when the threat recedes. Planning horizons reverse fully. The boundary between adaptability and transformability runs through the social fabric rather than through material resources.

These findings are bounded by the model's documented limitations. The dissertation conclusions that follow synthesize these findings with the theoretical framework and the fieldwork evidence.

CONCLUSIONS

This dissertation asked how institutional and self-organizational pathways of adaptation interact under sustained warfare, and under what conditions each pathway sustains or undermines organizational survival. Institutional theory predicts that conformity with institutional pressures enhances survival. Crisis-agency theory predicts that under institutional disruption, the institutional pathway can suppress the self-organizational pathway on which survival depends. The interaction between these predictions had not been resolved empirically. The investigation combined two waves of semi-structured interviews (37 transcripts, 2022–2023), a CAWI survey (n=35), and an agent-based model in NetLogo evaluated through approximately 22,200 simulation runs across four experimental batteries.

Fulfillment of the research tasks. The dissertation set seven research tasks, and it completed all seven in full.

1. Synthesized organizational-adaptation theoretical frame within the crisis-agency frame and formulated a working definition of mechanisms for computational formalization (Chapter 1).
2. Determined the defining features of the wartime emergency as a compound system with adversarial threat, overlapping timeframes, and dual demand structure (Chapter 1).
3. Established the temporal structure of the crisis: six phases reducing to three regimes (crisis, protracted adaptation, consolidation, Chapter 2).
4. Identified 27 mechanisms of organizational adaptation (11 new) through interviews and produced survey distributions calibrating eight parameter sets, providing the empirical basis for computational implementation (Chapter 3).
5. Formalized the mechanisms into an agent-based model implementing 38 behavioral rules drawn from six established ABMs (Chapter 4).

6. Validated the model, establishing that three of eight tested domains pass unconditionally, three pass with qualifications, and two (fiscal dynamics and Jungle-to-Zoo transitions) fall outside the model's validated scope (Chapter 5).
7. Established the conditions under which each pathway operates or gives way to the other, identifying the institutional paradox, three tipping points, and selective irreversibility through computational experiments (Chapter 6).

Findings. Under sustained warfare, the organizational and self-organizational pathways operate simultaneously. The crisis unfolds through six phases that reduce to three regimes, each shifting the balance between the two pathways. Organizations adapt through 27 mechanisms distributed across environmental, organizational, self-organizational, and bridging channels, 11 of them identified abductively from the fieldwork without a prior theoretical template. The self-organizational pathway engages before formal channels do: voluntary military support, the mechanism with the cleanest interview support, preceded government coordination in every documented case.

Configurations with multiple open coordination channels produce higher organizational survival than configurations that concentrate coordination in one pathway. No single mechanism is independently necessary. The five transformational mechanisms tested as binary toggles were equifinal, consistent with the interview evidence that organizations improvised through whatever connections were at hand. Decentralized configurations outperformed centralized ones at every tested level of government capacity.

The experiments reveal an institutional paradox. Government is necessary for organizational survival under warfare. Without it, the system collapses. But after a threshold, the system shifts toward state-organized coordination at the expense of voluntary cooperation: when institutions are strong enough, organizations stop mobilizing on their own. The government collapse experiment made this concrete. Organizations survived better under prolonged institutional weakness than under normal government strength, because weaker extraction left more room for volunteer-driven adaptation. Temporary weakness produced the lowest survival: organizations absorbed the costs of disruption and then the costs of resumed extraction. The viable band between too little government and too much is narrow. Whether organizations mobilize at all depends less on how severe the crisis is than on whether they were already disposed to act and whether institutions leave room for it. Adaptation is dispositional rather than reactive.

The analysis identifies three tipping points that mark the system's viability limits: military attrition, institutional capacity, and network connectivity. Network connectivity is not merely associated with survival; it is a precondition for it. Two independent analyses, one of organizational population collapse and the other of trade-network fragmentation, show that both critical transitions occur at nearly the same value of the base vision range. Below that value, organizations die from economic isolation before direct threat exposure becomes decisive. Network fragmentation, rather than threat exposure, is therefore the proximate cause of organizational death. The phase-diagram analysis identifies four regimes: Viable, Stressed, Degraded, and Collapsed, with government capacity as the dominant driver. The Degraded regime extends Bevzenko's (2018) three-phase model of social tension by identifying a fourth state: organizations persist at reduced capacity, without the relational infrastructure needed for recovery.

War damage is selectively irreversible. Cultural diversity declines significantly and does not recover. Economic indicators are confounded by design differences and fall in a domain with lower validation reliability. Across the reliable indicators, the pattern is clear: material infrastructure recovers when the threat recedes, but solidarity capital, the fuel of the self-organizational pathway, is consumed by the activation this adaptation requires. This is resilience without adaptation (Pugachova, 2025b): the system retains material capacity while losing the social fabric on which future adaptation would depend.

Taken together, organizational resilience under sustained warfare depends on the redundancy of multiple overlapping coordination channels rather than on any single mechanism. The organizational pathway is necessary but suppressive beyond a threshold. Three structural conditions determine the outcome: a sharp nonlinear altruism threshold that governs the disposition toward volunteering, decentralized institutional configurations that leave space for self-organization, and network connectivity as the precondition for survival. Viability is bounded by three tipping points, and the wartime transformation is selectively irreversible.

Contributions. This study makes the following contributions:

The study advances the crisis-agency framework (Bevzenko, 2022) by formalizing the institutional paradox computationally and quantifying the threshold at which institutional provision shifts from supporting to suppressing self-organizational adaptation. To our knowledge, it also provides the first demonstration of the structural advantage of the self-organizational pathway across the tested range of government capacity, threat intensity, and pre-invasion institutional structure under sustained warfare.

The study extends the three-phase model of social tension (Bevzenko, 2018) by quantitatively locating a fourth, Degraded, regime in the phase diagram. In this regime, organizations persist at permanently reduced capacity without the relational infrastructure needed for recovery.

To our knowledge, the study is the first to establish network connectivity as an immediate condition of organizational survival under sustained warfare rather than a resource for post-disaster recovery, extending Aldrich's (2012) account of social capital in post-disaster recovery. The population tipping point and the network percolation threshold closely converge, and network fragmentation, rather than direct threat exposure, is the proximate cause of organizational death.

The study further develops disaster scholarship by showing that organizational adaptation is dispositional rather than reactive: pre-existing prosocial dispositions, and the structural conditions that allow them to operate, determine adaptation outcomes more strongly than the severity of the crisis itself. It also develops the pattern of resilience without adaptation described by Pugachova (2025b) by specifying it computationally and quantifying its effects: material infrastructure may recover after the threat recedes, while cultural diversity and solidarity do not.

To our knowledge, the study provides the first systematic inventory of mechanisms of organizational adaptation under sustained warfare. Of the 27 identified mechanisms, 11 are new to the literature. The survey adds population-level parameter distributions that bridge qualitative fieldwork and computational formalization.

This study develops the first agent-based model of organizational adaptation to social disruption under sustained warfare. The model serves as the instrument for testing the interaction between the organizational and self-organizational pathways. The study also advances agent-based modeling practice through two methodological frameworks developed by the author: an appropriateness-assessment framework for determining when ABM is the right method (Serdyuk, 2026), and a validation-method selection framework based on 76 modeling scenarios (Serdyuk, 2025b).

Limitations and Directions for Future Research. The model was built to test the interaction between two pathways of adaptation, not to predict specific organizational outcomes, and its simplifications reflect this focus: unitary agents without internal dynamics, a domestic-only landscape, absent burnout, binary sectors, and a single government super-agent. The empirical base is constrained by convenience sampling, retrospective reports, survival bias, and modest sample sizes.

Several interview findings (J-curve burnout, stayer-leaver tensions, international markets, work as psychological shelter) fall outside the model's architecture. The toggle framework covered only five transformational mechanisms.

These limits bound the inferential scope to settings sharing key characteristics with Ukraine after the full-scale russian invasion: a pre-existing market economy, a functioning central government, and a large-scale war with a directional threat front.

Three directions for future research are particularly promising.

The institutional paradox should be formalized as a general mechanism, not specific to warfare; testing whether the same trade-off between the two pathways appears in peacetime regulatory environments is also a promising theoretical extension.

Modeling the burnout mechanism would require moving beyond the unitary-agent assumption and conducting a longitudinal study to capture the J-curve trajectory.

Docking against other crisis ABMs and applying inverse generative social science would test whether the mechanisms identified here generalize beyond the Ukrainian wartime context.

When the full-scale russian invasion began, most observers, allies and adversaries alike, expected Ukrainian organizations to collapse within weeks. They did not. This was not a coincidence, nor was it merely the heroism of people making hard choices in the face of fear and uncertainty. It rested on a social fabric built long before the crisis:

prosocial dispositions, a decentralized institutional environment that left room for initiative, and the connections between organizations that allowed multiple overlapping adaptive pathways to operate. The computational model revealed why these structural conditions mattered by identifying the thresholds, tipping points, and irreversibilities that observation alone could not isolate.

The people who described their experience for this research did not use the language of mechanisms and thresholds. They described choices made under fear and uncertainty, sustained by trust in people they had not yet met. This work does not diminish those choices. It shows what made them count.

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APPENDICES

APPENDIX A

INTERVIEW STUDY DETAIL

This appendix documents the qualitative research instruments and analytical infrastructure underlying the interview study introduced in Chapter 3. Section A.1 reproduces the interview guide for both waves, including the ethical protocol and notes on interview conduct. Section A.2 presents the deductive codebook used to code 37 transcripts, with mechanism definitions, inclusion criteria, contradiction conditions, boundary rules, and theoretical origins (A.2.1–A.2.2), followed by aggregate code counts across all 37 transcripts (A.2.3) and a summary of unmatched passages identifying candidate model extensions (A.2.4).

All interviews were conducted and transcribed in Ukrainian. The guide below appears in English.

A.1. Interview Guide

A.1.1. Research Context

This guide was used for 37 semi-structured interviews conducted across two waves with owners and managers of Ukrainian commercial and non-commercial organizations. The first wave (September 2022 to April 2023, 26 interviews) took place 6 to 14 months after the full-scale russian invasion of February 24, 2022. The second wave (October to December 2023, 11 interviews) was conducted approximately 20 months after the invasion began.

The study employed a deliberately open interviewing strategy. The first wave used a near-unstructured format with a single opening question designed to elicit respondent-driven narratives without imposing a theoretical structure. The second wave introduced more standardized questions and an organizational metadata section to enable systematic comparison. It retained the open-ended character of the core questions.

All interviews were conducted remotely via video or voice call and recorded with oral informed consent. Interviews were conducted and transcribed in Ukrainian, transcripts were translated into English for coding purposes. Respondents were informed that transcripts would be reviewed by them before use and that no personally identifying information would be disclosed.

A.1.2. Ethical Protocol

The following was read to the respondent before the beginning of each interview.

Thank you for agreeing to participate in this interview. The purpose of this conversation is to understand how your organization has been affected by the full-scale invasion and how it has adapted to the new conditions.

Before we begin, I would like to note the following:

- The interview will be transcribed by the interviewer. The transcription will not be shared with third parties.
- Your personal data and identifying organizational details will not be disclosed. Findings will be reported in aggregate form.
- There are no right or wrong answers. I am interested in your experience and perspective.
- You may decline to answer any question or stop the interview at any time.
- You will receive a transcript for review and approval before the data is used in the study.

A.1.3. First Wave Interview Guide

September 2022 to April 2023; 26 interviews.

The first wave used a near-unstructured format with a single opening question. The design avoided imposing theoretical categories on a phenomenon not yet fully understood. It produced rich, respondent-driven narratives suitable for deductive coding with abductive discovery. Follow-up probes were used flexibly to explore emerging themes.

Opening question.

1. What happened to your organization on and after February 24, 2022?

Note. This question was posed without further specification. Respondents were invited to construct their own narrative, choosing their own starting point, emphasis, and temporal scope.

Follow-up probes (used flexibly as needed).

The probes below were available to the interviewer and were used when the respondent's narrative did not naturally cover these areas. Not all probes were used in every interview.

Crisis impact and organizational survival.

2. How did you manage to restore normal operations? What did the process look like?

3. Did your organization experience existential stresses? How did the organization survive?

Probe: financial reserves, contingency plans, prior crisis experience (COVID-19, 2014 russian invasion).

Processes and structural changes.

4. How did organizational processes change after the invasion? What was disrupted and what continued?

Probe: planning horizons, decision-making speed, formalization versus flexibility, new projects or products.

5. Were there changes in norms, rules, or standards of responsibility?

People and interpersonal dynamics.

6. How did the invasion affect your interactions with colleagues? Did the style of communication become more or less formal?

Probe: management style, emotional climate, team cohesion, trust.

7. Were there situations when people behaved unexpectedly? In what way?

Probe: volunteering, joining the military, unexpected departures, commitment, or disengagement.

Relocation and workforce dispersal.

8. What happened with your employees in terms of location? Did people relocate within Ukraine or leave the country?

Probe: employee safety measures, evacuation, remote work arrangements, and office closures.

External environment.

9. How did the relationship with the state and government agencies change?

Probe: taxes, regulation, mobilization, benefits, booking.

10. How did the relationship with partners and clients change?

Probe: supply chains, markets, international clients, trust.

Closing.

Is there anything else you would like to add? Anything important that we have not discussed?

A.1.4. Second Wave Interview Guide

October to December 2023; 11 interviews.

The second wave introduced a more structured format with standardized questions and an organizational metadata section. The structure enabled systematic comparison across respondents and longitudinal comparison with first-wave data for the five cross-wave respondents. The questions remained open-ended to preserve the depth of the first-wave approach.

Section A: Organizational metadata.

The following factual questions were asked at the start of the interview to establish the organizational profile.

1. How long has the company been operating in Ukraine? (years)

2. Is it a separate company or a division of an international company?

3. Number of people working in the Ukrainian office.

4. Are the owners or founders from Ukraine or not?

5. Did the owners or founders stay in Ukraine or leave?

6. How many levels of hierarchy do you have? Which level are you on?

7. Are there employees who have moved within Ukraine or who have left the country? Are there those who have remained close to the front line? What is the approximate distribution?

8. Are you currently in Ukraine, or have you left?

9. How many employees have been mobilized? (number or percentage)

Section B: General change assessment.

1. If you compare how things were before February 24, after February 24, and now, what has changed?

Note. This question serves as the second-wave analog of the first-wave opening question. It explicitly requests a three-period comparison (pre-invasion, immediate aftermath, and current state at approximately 20 months).

Section C: Thematic blocks.

Each topic below was introduced as a prompt. The interviewer allowed the respondent to speak freely and used follow-up probes as needed.

Block 1: Work and productivity.

2. In terms of work and productivity, what has changed compared to before February 24?

Probe: efficiency, planning horizons, new products or services, remote work, blackout impact, workload distribution.

Block 2: Interpersonal relationships.

3. In terms of interpersonal relationships, has anything changed since February 24?

Probe: team dynamics, trust, emotional climate, relationships between employees in Ukraine and those abroad, burnout, fatigue, and psychological support.

Block 3: Organization-employee relations.

4. In terms of the relationship between people and the company, what has changed? This includes salary reviews, raises, promotions, and support for mobilized employees.

Probe: career progression, compensation, benefits, support programs, layoffs, hiring, retention.

Block 4: Relations with the state.

5. In terms of relations with the state, if we compare February 24 and now, has anything changed?

Probe: taxation, regulation, mobilization policy, booking, government contracts, volunteering for state programs, Diia City, interaction with local authorities.

Block 5: Internal tensions.

6. I have heard that in other companies, there are sometimes conflicts between employees who have left Ukraine and those who have stayed. Sometimes these are not direct conflicts but tension or accusations. What do you think about this? Have you seen anything like that in other organizations, or in your organization?

Note. This question was framed as an observation about other companies to reduce social desirability bias and encourage candid responses.

Block 6: Prospects and opportunities (used selectively).

7. Have people’s prospects and opportunities changed compared to before the invasion?

Probe: career ceilings, mobility, learning opportunities, new roles, entrepreneurial initiatives.

Closing.

Is there anything else you would like to add? Anything important that we have not discussed?

A.1.5. Notes on Interview Conduct

Both waves followed the principles of semi-structured interviewing. The interviewer's role was to listen actively, encourage elaboration, and follow the respondent's narrative rather than enforce a rigid question sequence. Questions were posed in conversational form and adapted to the flow of discussion. When a respondent's narrative naturally covered a topic, the corresponding question was omitted.

All interviews were conducted and transcribed in Ukrainian. Transcripts were translated into English for the purposes of this research.

First-wave interviews lasted approximately 20 to 90 minutes. Second-wave interviews lasted approximately 30 to 75 minutes. The variation reflected differences in organizational complexity, respondent communicativeness, and the depth of issues discussed.

Five respondents participated in both waves. For these cross-wave respondents, the second-wave interview explicitly referenced first-wave themes and asked about changes since the previous conversation. This component enabled tracking of mechanism evolution across the two time points.

The study was conducted during an active war, which required practical adaptations. All interviews were conducted remotely due to security considerations, travel restrictions, and the geographic dispersal of respondents. Interview scheduling accommodated air-raid alerts and power outages.

A.2. Sample Composition

Table A.1 documents the composition of the interview sample at the level of granularity supported by the anonymization protocol. Sectors are reported at category level, regions at the macro-regional level, sizes in employee bands, and roles in five-category groupings. The five cross-wave respondents are indicated in the Wave column.

Table A.1. Anonymized respondent composition (n = 32).

ID	Sector	Region	Size	Role	Wave
R01	Trade/Retail	West	11–50	Owner / co-owner	1
R02	IT/Services	Central	over 250	Senior management	1, 2
R03	Manufacturing	East	under 10	Owner / co-owner	1
R04	Other	Multiple locations	51–250	Middle management or specialist	2
R05	Education/Culture	Central	under 10	Owner / co-owner	1
R06	Manufacturing	Central	11–50	Owner / co-owner	1
R07	IT/Services	Central	51–250	Top management	1, 2
R08	Legal/Consulting	Central	11–50	Senior management	1
R09	Volunteer/NGO	West	under 10	Top management	1
R10	IT/Services	Multiple locations	over 250	Top management	2
R11	IT/Services	Multiple locations	under 10	Top management	1
R12	IT/Services	West	under 10	Top management	1
R13	Other	Multiple locations	over 250	Senior management	1
R14	IT/Services	North	51–250	Top management	1
R15	Other	Central	under 10	Other	1
R16	Healthcare	Multiple locations	over 250	Middle management or specialist	2
R17	Other	Central	under 10	Owner / co-owner	1
R18	IT/Services	South	51–250	Senior management	1, 2
R19	Volunteer/NGO	North	11–50	Top management	1
R20	Other	Not recorded	Not recorded	Senior management	1
R21	Healthcare	Multiple locations	over 250	Middle management or specialist	2
R22	Manufacturing	North	under 10	Owner / co-owner	1
R23	Other	Not recorded	Not recorded	Other	1
R24	Construction/Real Estate	Central	51–250	Top management	1, 2
R25	Manufacturing	North	11–50	Owner / co-owner	1
R26	IT/Services	Multiple locations	51–250	Top management	2
R27	Construction/Real Estate	North	under 10	Top management	1
R28	Legal/Consulting	Central	51–250	Senior management	1
R29	Other	Central	over 250	Senior management	1
R30	Volunteer/NGO	West	11–50	Senior management	1
R31	IT/Services	North	51–250	Senior management	2
R32	Manufacturing	North	51–250	Senior management	1, 2

Note: Five respondents interviewed in both waves are indicated by "1, 2" in the Wave column; together with the 27 single-wave respondents they account for the 37 transcripts in the corpus.

A.3. Deductive Codebook

The codebook below contains the 27 mechanisms that are testable through interview evidence. The computational model implements additional rules inherited from parent agent-based frameworks; those operate below the resolution of qualitative data and are documented separately in the model description.

A.3.1. Methodology

The 27 mechanisms in Table A.1 form the interview-testable subset of the 38 model rules. Eleven additional rules operate below the resolution of qualitative interview data and are documented in the model description rather than the codebook.

The coding unit is a passage: one or more contiguous sentences from a single respondent that describe a discrete organizational behavior, decision, event, or perception. A single passage may be coded to multiple mechanisms when it contains evidence for more than one.

Each passage was evaluated against every mechanism in the inventory and could receive multiple codes. For each relevant mechanism, the passage was marked S (supported) if it described behavior consistent with that mechanism, C (contradicted) if it described behavior incompatible with that mechanism or the explicit substitution of a different process, or N (nuanced) if it offered partial support that revealed complexity the model simplifies. A passage was additionally marked X (unmatched) if it described organizationally relevant behavior that no mechanism in the inventory could account for, signaling a candidate new mechanism.

The codebook was built in two stages, following three method sources. MacQueen et al. (1998, p. 32) set out the six-part code definition structure used in Table A.1: code label, brief name, full definition, inclusion criterion (S), exclusion criterion (C), and boundary rules for distinguishing adjacent codes. Timmermans and Tavory (2012, p. 170) describe abductive analysis as the mode between pure deduction and pure induction. In this mode, researchers code data against theoretical expectations and treat anomalies as sites for theoretical revision. Vu et al. (2020, p. 5) extend abductive reasoning to mechanism-based social-systems modeling. Under this approach, each codebook entry is a candidate mechanism that is tested against transcript evidence and revised when necessary.

The first stage turned theoretical expectations into testable mechanism definitions. Six analytical frameworks supplied the expectations: crisis-agency, institutional, network and social-capital, disaster response sociology, dynamic capabilities, and population ecology. Each expectation was operationalized into one or more codebook mechanisms, and each mechanism was given explicit rules for what counts as supported, contradicted, or nuanced evidence.

The second stage identified mechanisms that the theory did not anticipate. During initial interview analysis, passages describing organizationally relevant behavior that did not fit any existing mechanism were flagged as unmatched (X-codes). When X-codes accumulated around recurring patterns, those patterns were formalized into new mechanism definitions and added to the codebook. The completed codebook was then applied to all 37 transcripts. The theoretical-origin column in Table A.1 records the origin of each mechanism: theory-aligned entries cite the framework they operationalize; novel entries emerged through abductive discovery; combined entries integrate theoretical expectations with empirical refinement. After all transcripts were coded, code counts were aggregated across the full dataset.

The 27 mechanisms can be classified along two orthogonal dimensions. By origin, 10 are theory-aligned, 11 are novel, and 6 carry combined labels (decomposition documented in Section A.3.2 below). By pathway in the crisis-agency framework, 11 are environmental, 2 are organizational, 10 are self-organizational, and 4 are bridging. This decomposition is used in the body chapter's analysis of demand–pathway mapping. The two decompositions cross-cut: a theory-aligned mechanism can be environmental or self-organizational, and a novel mechanism can occupy any pathway. Both decompositions are referenced from Table A.1's columns.

A.3.2. Mechanism Definitions and Inclusion Criteria

Table A.2 presents the deductive codebook. The theoretical-origin column carries three labels. Theory-aligned mechanisms operationalize a specific theoretical expectation; the source field names the framework and citation. Novel mechanisms emerged through abductive discovery during residual analysis and have no prior theoretical template. Combined mechanisms integrate a theoretical expectation with substantial empirical refinement during coding. Of the 27 codebook entries, 10 are theory-aligned, 11 are novel, and six of the 27 (A3, B3, B8, C1, C2, E2) carry combined labels that capture both origins.

Table A.2. Deductive Codebook: Mechanism Definitions, Coding Criteria, and Theoretical Origins

Code	Mechanism	Definition	S (Supported)	N (Nuanced)	C (Contradicted)	Boundary	Theoretical origin and source
A1	Resource-exhaustion mortality	Organizations exit the population when they cannot sustain money, people, or supply flows.	Organization described as ceasing operations after exhausting financial reserves, workforce, or supply access.	Near-collapse followed by external rescue (grants, ownership change, emergency financing) without full exit.	Persistent operation despite documented exhaustion of money, people, and supply flows.	A1 concerns exit from the population; B3 and B9 concern geographic relocation without exit.	Theory. Epstein and Axtell (1996); SugarScape agent-mortality.
A2	Cultural in-group favoritism	Organizations weight partners and government interactions by cultural similarity, producing endogenous cultural clustering.	Explicit description of partner selection or trust based on shared values, language, or orientation.	Cultural similarity plays a role alongside other dominant criteria such as price or geographic proximity.	Partnership choices described as exclusively function-driven, with cultural compatibility treated as irrelevant.	A2 concerns cultural weighting at the selection stage; E4 concerns trust formation after selection.	Theory. Hammond and Axelrod (2006); cultural tag dynamics.
A3	Structural trait homophilic drift	Flexibility, hierarchy, and mil-friendliness traits drift toward trade partners and under institutional pressure, producing structural homogenization.	Structure described as becoming more (or less) hierarchical, flexible, or military-oriented through compliance or partner interactions.	Traits change in some dimensions but not others, or change reversibly as conditions fluctuate.	Structure remains unchanged across prolonged interactions with partners and government.	A3 codes structural consequences of interactions; B6 codes the comply-or-evade decision itself; A4 codes risk-tolerance dynamics separately.	Combined. Epstein (2003); qualitative interviews.
A4	Endogenous risk-tolerance shift	Organizational risk appetite recalibrates under existential threat rather than remaining fixed at birth.	Explicit description of risk appetite changing in response to events, with the direction of change named.	Change in one risk domain (for example, financial) without change in another (for example, strategic).	Risk appetite described as stable throughout the war, with decisions attributed to pre-existing disposition.	A4 concerns risk-tolerance dynamics; B5 concerns action selection that may reflect current risk tolerance.	Theory. Dignum et al. (2020); ASSOCC architecture, reformulated as endogenous.

Code	Mechanism	Definition	S (Supported)	N (Nuanced)	C (Contradicted)	Boundary	Theoretical origin and source
A5	Size-dependent vision range	Larger organizations observe wider portions of their environment than smaller ones, producing size-dependent decision informedness.	Larger organizations described as informed about conditions beyond their immediate locale; smaller organizations described as operating on local cues only.	Size correlates with information reach only in specific domains, such as supply chains but not labor markets.	Small firms described as equally well-informed as large ones about non-local conditions.	A5 concerns the geographic reach of perception; B1 concerns the type of perception used (local versus aggregate).	Theory. Epstein and Axtell (1996); SugarScape vision.
B1	Local perception anchoring	Organizational decisions rest on directly observed local conditions rather than aggregate national indicators.	Decisions described as based on observable local conditions (neighborhood, clients, staff safety).	Blends local observation with official or media information, weighted toward local.	Decisions based primarily on national media or abstract strategic analysis, with local conditions secondary.	B1 concerns the type of information used; B2 concerns information flowing through networks.	Theory. Bourgais et al. (2020); BEN perception cycle.
B2	Network information diffusion	Organizations learn about threats and conditions through business ties independently of official sources.	Actionable safety or operational information received through business networks.	Receives network information but discounts or cross-verifies against other sources before acting.	Relies only on official sources or direct observation, without using business-network channels.	B2 concerns network-sourced information; B1 concerns perception anchoring regardless of source.	Theory. Gilbert et al. (2001); SKIN partner-information diffusion.
B3	Trade-link relocation anchoring	Organizations with strong local trade ties stay longer under threat than safety thresholds alone would predict.	Business ties described as a reason for staying or delaying relocation.	Ties matter but are overridden once safety falls below a threshold.	Leaves despite strong local ties, with ties having no retention effect on the relocation decision.	B3 concerns the decision to stay or go; B9 concerns where to go once moving is chosen.	Combined. Qualitative interviews; Aldrich (2012).
B4	Return-home intention	Relocated organizations return to origin once	Relocated organization described as planning	Partial return: hybrid arrangement,	Declared intent not to return despite	B4 concerns the return decision; B3 concerns the initial	Novel. Qualitative

Code	Mechanism	Definition	S (Supported)	N (Nuanced)	C (Contradicted)	Boundary	Theoretical origin and source
		safety and resources permit.	or executing return when conditions allow.	offices in both locations, or leadership returns while staff remain dispersed.	conditions permitting it.	stay decision; B9 concerns destination selection.	interviews (second wave).
B5	Multi-demand behavioral deliberation	Organizations weigh safety, business, military support, and mutual aid simultaneously and select one action per tick.	Described behavior maps to a discrete action choice among multiple competing demands.	Action blends multiple intentions without a single dominant category.	Behavior driven by a single consideration with no evidence of competing demands being weighed.	B5 concerns the deliberation architecture; B6 and B7 concern specific branches within it (compliance, domain expansion).	Theory. Dignum et al. (2020); Bourgais et al. (2020).
B6	Compliance lock-in	Early compliance or evasion choices become self-reinforcing through hierarchy drift and cultural convergence, producing two diverging trajectories.	Stable compliance or evasion orientation linked to earlier choices and accompanied by structural or cultural drift.	Compliance described as ritual or ceremonial rather than substantive.	Frequent reversals of compliance orientation without a self-reinforcing pattern.	B6 codes the lock-in mechanism; A3 codes the structural drift that supports the lock-in; B5 codes action selection without a lock-in claim.	Theory. Bourgais et al. (2020); Goudet et al. (2017).
B7	Domain expansion	Organizations take on functions far outside their original mandate, including defense production, humanitarian relief, and military-adjacent services.	Organization described as developing defense, humanitarian, or military-adjacent functions.	Partial or temporary expansion that reverts as conditions stabilize.	Deliberate resistance to expansion despite external pressure and opportunity.	B7 concerns civilian expansion into non-core domains; D1 concerns porous military-civilian boundary at the organizational level.	Novel. Qualitative interviews.
B8	Horizon-dependent	Short-horizon organizations behave differently from long-	Planning horizon described as directly	Horizon affects some decision domains but not	Horizon length described as having	B8 concerns how horizons shape decisions; C1	Combined. Qualitative interviews;

Code	Mechanism	Definition	S (Supported)	N (Nuanced)	C (Contradicted)	Boundary	Theoretical origin and source
	decision weighting	horizon organizations under identical external conditions.	shaping what actions the organization takes.	others, such as operations but not hiring.	no effect on the type of actions taken.	concerns the population-level horizon trajectory.	Bevzenko (2025).
B9	Selective relocation destination	Relocating organizations choose destinations by safety and workforce availability, producing spatial concentration in safer and workforce-rich regions.	Safety and workforce availability named as the dominant selection criteria for a relocation destination.	Personal connections, housing cost, or infrastructure factor in alongside safety and workforce.	Other criteria dominate (for example, cheap rent or prestige address) without safety or workforce reference.	B9 concerns destination selection; B3 concerns the decision to move at all; B4 concerns the return decision.	Novel. Qualitative interviews.
C1	Planning horizon contraction	Population-level shift from long to short horizons under sustained dual stress, with gradual partial recovery.	Described horizon contraction during crisis and any later recovery.	Contraction without recovery, or recovery driven by external imposition rather than adaptive shift.	Horizon described as unchanged throughout the war despite sustained stress.	C1 codes the population-level adaptive-trait trajectory; B8 codes how a given horizon shapes individual-organization decisions.	Combined. Qualitative interviews; Bevzenko (2025).
C2	Altruism activation	Organizational altruism activates under the co-occurrence of institutional breakdown and visible peer distress, and decays gradually as conditions normalize.	Altruism surge during crisis onset and gradual decay as conditions stabilize.	Surge followed by complex non-smooth decay (reactivation, localized persistence, selective donors).	Stable or absent altruistic behavior across the whole observation period.	C2 codes the adaptive-trait trajectory of altruism; K4 codes voluntary military support as a specific action domain.	Combined. Qualitative interviews; Bevzenko (2025).
D1	Civilian-military permeability	Continuous permeability between civilian and military functions without identity change;	Organization described as contributing to defense along a spectrum while	Unidirectional permeability only (civilian to military but not reverse).	Strict separation between civilian and military activity, with no cross-	D1 codes the permeability of the boundary at the organizational level;	Novel. Qualitative interviews.

Code	Mechanism	Definition	S (Supported)	N (Nuanced)	C (Contradicted)	Boundary	Theoretical origin and source
		organizations contribute to defense along a spectrum rather than through binary role shifts.	retaining civilian identity.		boundary contribution.	B7 codes domain expansion into military-adjacent civilian functions.	
D2	Jungle-to-Zoo transition	Regime shift from decentralized volunteer response to centralized coordinated response as the crisis progresses, with reversibility determined by safety trajectory.	Described transition from improvised decentralized response to formal centralized coordination.	Partial transition: formalized in some domains while improvised in others.	Coordination behavior inconsistent with a regime-shift pattern (for example, stable across the period).	D2 codes the regime shift in defense coordination; D1 codes the porous boundary that allows civilian participation.	Novel. Qualitative interviews.
E2	Crisis-induced cooperation	Pre-crisis competitive relations flip to cooperative relations when shared threat exceeds a threshold.	Former competitors described as sharing resources, information, or logistics under shared threat.	Cooperation limited to specific domains or episodes without full realignment of the relationship.	Competitive relations preserved or intensified despite shared threat.	E2 codes the flip from competition to cooperation; E4 codes trust formation within cooperative relations.	Combined. Qualitative interviews; Larson (2012).
E4	Three-route trust formation	Trust develops through three distinct formation routes: swift, earned, and habitual.	Trust described as built via one of the three routes (swift, earned, or habitual).	Trust built through a mixed route, or fragile across contexts.	Trust described as relying on a mechanism outside the three routes, such as formal certification alone.	E4 codes the trust-building process; A2 codes cultural in-group weighting that may precede trust; E2 codes the competition-to-cooperation flip.	Theory. Hung et al. (2004).
G4	Mobilization workforce shock	Conscription extracts workers abruptly from civilian organizations, producing capacity shocks	Abrupt loss of specific employees to conscription disrupting operations.	Discrete loss events spread over time rather than as a single shock.	Mobilization described as having no workforce impact on the organization.	G4 codes workforce shocks from conscription; G5 codes how	Novel. Qualitative interviews.

Code	Mechanism	Definition	S (Supported)	N (Nuanced)	C (Contradicted)	Boundary	Theoretical origin and source
		rather than gradual attrition.				organizations interact with government more broadly.	
G5	Intermediated government interaction	Organizations interact with government through industry associations, IT clusters, and coordination platforms rather than directly.	Intermediate bodies described as the primary channel for government interaction.	Both direct and intermediated channels used, depending on the issue at stake.	Direct government interaction without intermediaries across all salient topics.	G5 codes the channel of government interaction; G4 codes one specific government-generated shock (mobilization).	Novel. Qualitative interviews.
J3	COVID pre-adaptation	Organizations with pandemic-era adaptations (remote work, continuity plans, distributed operations) adapt faster to the invasion shock.	Explicit reuse of COVID-era protocols, reserves, or capabilities after the invasion.	Partial transfer (remote work yes, but crisis-specific demands require fresh adaptation).	COVID-era adaptations described as irrelevant or inapplicable to wartime conditions.	J3 codes transfer of prior-crisis capabilities; K2 codes how existing rigidity can itself be protective under shock.	Novel. Qualitative interviews.
K1	Three-phase temporal pattern	Organizations move through shock, crisis management, and normalization phases with distinct behavioral signatures.	Described three-phase sequence with shifts in priorities or routines across phases.	Different number of phases, overlapping phases, or non-linear transitions.	Crisis experience described as a single undifferentiated period without discernible phase structure.	K1 codes the system-level temporal sequence; C1 codes the planning-horizon trajectory that co-varies with phase.	Novel. Qualitative interviews.
K2	Structural inertia protection	Rigid organizations survive sudden shock better than flexible ones because existing routines remain usable.	Rigid organization described as surviving because preserved routines remained usable under shock.	Rigidity protective in early shock but harmful later, or protective in some sectors but not others.	Rigidity described as purely harmful, with no protective effect under shock.	K2 codes when rigidity is protective; A3 codes structural drift over time; J3 codes transfer of	Theory. Hannan and Freeman (1984).

Cod e	Mechanism	Definition	S (Supported)	N (Nuanced)	C (Contradicted)	Boundary	Theoretical origin and source
						capabilities from a prior crisis.	
K3	HR repurposing	HR functions redirect from development tasks (hiring, training, performance management) to crisis support tasks (evacuation, mental health, mobilization support).	HR described as taking on evacuation, mental-health, or mobilization-support functions.	Partial redirection alongside continued pre-invasion HR development tasks.	HR described as maintaining a purely pre-invasion scope throughout.	K3 codes HR function redirection; B7 codes organization-wide domain expansion.	Novel. Qualitative interviews.
K4	Voluntary military support	Organizations contribute to defense spontaneously and preceding government coordination.	Voluntary defense contributions described as spontaneous and preceding government coordination.	Voluntary contribution alongside later formal coordination channels.	Military support described as mandated or reluctant rather than voluntary.	K4 codes spontaneous voluntary contributions; G4 codes mobilization as an exogenous shock; D1 codes permeability at the organizational level.	Novel. Qualitative interviews.

A.3.3. Aggregate Code Counts

Table A.3 presents aggregate code counts across all 37 transcripts from 32 respondents. The table addresses two analytical questions: whether theoretical expectations hold against the interview evidence, and whether novel mechanisms receive empirical support. X-codes for unmatched passages appear separately in Table A.4.

Table A.3. Aggregate Coding Results by Mechanism (37 Transcripts)

Code	Mechanism	S	C	N	Assessment
A1	Resource-exhaustion mortality	1	0	0	Weak evidence
A2	Cultural in-group favoritism	2	0	0	Weak evidence
A3	Structural trait homophilic drift	10	0	5	Supported, sector-dependent
A4	Endogenous risk-tolerance shift	0	2	0	Contradicted as fixed trait; reclassified
A5	Size-dependent vision range	1	0	0	Weak evidence
B1	Local perception anchoring	12	0	0	Supported
B2	Network information diffusion	1	0	0	Weak evidence
B3	Trade-link relocation anchoring	5	0	3	Supported
B4	Return-home intention	2	0	0	Weak evidence
B5	Multi-demand behavioral deliberation	10	0	0	Supported
B6	Compliance lock-in	1	0	1	Weak evidence
B7	Domain expansion	16	1	0	Supported
B8	Horizon-dependent decision weighting	2	0	0	Weak evidence
B9	Selective relocation destination	3	0	0	Qualified support
C1	Planning horizon contraction	26	0	0	Supported (strongest)
C2	Altruism activation	12	0	13	Supported, complex decay
D1	Civilian-military permeability	8	0	2	Supported
D2	Jungle-to-Zoo transition	4	0	4	Partial support
E2	Crisis-induced cooperation	4	0	0	Supported
E4	Three-route trust formation	3	0	4	Partial support
G4	Mobilization workforce shock	9	0	5	Supported
G5	Intermediated government interaction	10	0	2	Supported
J3	COVID pre-adaptation	11	0	2	Supported
K1	Three-phase temporal pattern	16	0	0	Supported
K2	Structural inertia protection	3	0	0	Qualified support

K3	HR repurposing	6	0	0	Supported
K4	Voluntary military support	22	0	0	Supported

A single passage may receive multiple mechanism codes. "Supported" label indicates at least five S-codes with no or few C-codes. "Qualified support" indicates S-codes dominate, but with explicit scope conditions shown in N-codes (the mechanism operates as modeled in some circumstances but not others). "Partial support" indicates mixed evidence across S, C, and N. "Weak evidence" indicates fewer than four total codes; such mechanisms rest primarily on theoretical grounding. "Contradicted as fixed trait; reclassified" applies to A4, whose original formulation as a fixed trait was contradicted by the interview evidence, and which was therefore reformulated as an endogenous adaptive shift.

Coding determined how each mechanism was parameterized, not whether it was included. Mechanisms with stronger empirical support received higher confidence in their parameter ranges. Mechanisms with weaker support (fewer than 4 codes in total) were flagged for additional validation using other methods.

One mechanism required reformulation based on the coding results. The original A4 formulation described risk tolerance as a fixed organizational trait assigned at founding. The interview evidence contradicted this: respondents described risk appetite as recalibrating in response to existential threat, with the direction and magnitude of change depending on the organization's pre-invasion baseline. The mechanism was therefore reformulated as an endogenous shift under threat, and the computational implementation was revised accordingly. The contradicted-as-fixed-trait coding (two C-codes) is recorded in Table A.3 as evidence for the reclassification rather than as a reason to drop the mechanism.

A.3.4. Unmatched Passages

Table A.4 summarizes passages that received X-codes during deductive coding. These passages describe organizationally relevant wartime behavior that does not correspond to any mechanism in the codebook. Unlike the novel mechanisms identified through earlier abductive analysis and then incorporated into the codebook, the X-codes in Table A.4 represent patterns that remain unaccounted for in the current model. They identify candidate extensions for future iterations.

Table A.4. Unmatched Passages (X-Codes) Grouped by Potential Model Gap

Theme	Count	Representative finding	Model subsystem affected
Burnout and cumulative exhaustion	12	Sustained high effort creates a capacity ceiling unrelated to financial or workforce metrics.	No burnout mechanism in the agent architecture.
Client compliance and sanctions effects	4	Western clients require sanctions-compliance documentation that reshapes eligibility for contracts.	No client-compliance layer in the trade subsystem.
Mobilization as social-capital destroyer	6	Mobilization removes employees who held relationships with external partners, severing ties indirectly.	Partnership-memory subsystem does not couple to workforce attrition.
Intra-organizational polarization	5	Social tension between employees who stayed and those who left or served in the armed forces.	Unitary-agent architecture cannot represent internal divisions.
International market buffer	4	Foreign clients serve as a survival buffer; export revenue is insulated from domestic collapse.	Domestic-only landscape in the current model.
Work as psychological shelter	3	Continuing routine work is reported as a psychological anchor independent of its economic function.	No psychological-state dimension at the agent level.
Energy infrastructure disruption	8	Blackouts reduce productivity independently of direct military strikes.	Landscape subsystem lacks an energy-availability layer.
Occupied territory dynamics	3	Organizations with personnel under occupation are neither relocated nor destroyed.	Landscape subsystem treats territory as binary safe/unsafe.

Unmatched passages were identified through residual analysis during deductive coding. Each theme combines multiple X-coded passages that point to the same model gap. All items represent deliberate simplifications or acknowledged limitations of the current model. Themes are not weighted by frequency alone; a theme with few codes but strong explanatory potential is noted as a priority for future work.

APPENDIX B

SURVEY INSTRUMENT, RESULTS, AND MECHANISM MAPPING

B.1. Rationale and Purpose

An agent-based model must be grounded in empirical evidence. Every parameter that meaningfully affects model output requires an empirical source, or the model becomes a record of the researcher's assumptions rather than of the system it claims to represent.

Appendix A documented the mechanisms that the qualitative interviews were able to test, together with a smaller set of additional rules that operate below the resolution of interview data. Together, these rules are implemented in the model through many internal parameters: weights that combine inputs into composite scores, thresholds that determine when behaviors activate, and rates that control how agent traits change over time. Most of these parameters have no direct counterpart in any observable quantity, which is characteristic of agent-based models.

Before calibration, a sensitivity analysis was run on the parameters judged most likely to affect the outputs used for validation. Morris elementary effects and one-factor-at-a-time tests ranked them by their actual influence on model behavior, so that the empirical effort could focus on the ones that mattered most. Parameters outside this set were kept at theoretically motivated default values, on the grounds that the sensitivity analysis had shown their effect to be small or that they controlled technical details below the resolution of the validation targets.

The screened parameters were then divided into three groups by data source.

The first group of parameters lacks a direct empirical counterpart, as the values describe weights and thresholds within the model's decision rules rather than observable properties of real organizations. These are set programmatically, through a search algorithm (BehaviorSearch) that adjusts their values until the model output matches a set of validation targets derived from macro data and survey distributions.

Other parameters are anchored to official statistics: mobilization rates from Ukrainian General Staff reports, displacement figures from the International Organization for Migration, fiscal parameters from the Ministry of Finance, organizational population counts from the State Statistics Service, and infrastructure damage rates from the World Bank Rapid Damage and Needs Assessment.

The third group describes individual organizational behavior that official statistics do not record but that respondents from those organizations can report themselves: perceived safety during the crisis, risk tolerance, hierarchy before the invasion, the share of partnerships that failed to recover, and similar population-level distributions. Macro statistics cannot produce these distributions because they aggregate above the level of the individual organization. Interview transcripts cannot produce them in distributional form because they capture individual accounts rather than population statistics. These parameters called for a survey. The CAWI survey documented in this appendix (n = 35, February 2026) was designed to fill that role, with response options drawn from the behavior patterns already described in the interviews.

The survey serves three functions. The first is calibration: it provides population-level distributions for parameters that neither macro statistics nor interviews can supply. Survey-derived parameters span mechanisms of multiple origins, including novel mechanisms identified from interviews, theory-aligned mechanisms from the analytical framework, and computational scaffolding inherited from parent agent-based models.

The second function is meso-level validation: three survey items supply validation criteria or set the empirical reference point for validation targets in the pattern-oriented validation. The third function is cross-validation: on mechanisms where both interviews and the survey describe the same phenomenon, the survey provides a quantitative check on interview coding, strengthening confidence where the sources converge and flagging divergences for explanation. Because the survey was not designed for independent hypothesis testing, this cross-validation does not function as methodological triangulation in the strict sense. It serves instrument refinement rather than independent corroboration

This appendix documents all three functions. Section B.2 describes the sample and administration. Section B.3 presents the complete 38-item instrument with bilingual question text and response distributions. Section B.4 summarizes the two open-ended questions. Section B.5 presents the mechanism mapping: cross-validation of interview findings against survey evidence (Table B.3). Section B.6 documents calibration of model parameters from survey distributions (Table B.4). Section B.7 presents the validation criteria derived from survey items (Table B.5). Section B.8 lists survey items not used in either calibration or validation (Table B.6). Section B.9 documents the survey's limitations and identifies directions for future development.

B.2. Survey Administration and Sample

The survey ran from 14 to 27 February 2026 as a web-based instrument (Microsoft Forms) in Ukrainian. Informed consent was collected on the first screen (Q1). The instrument collected no names, organization identifiers, email addresses, or IP addresses. All 35 respondents who started the survey completed it; the median completion time was 8.5 minutes.

Recruitment combined individual outreach to five of the thirty-two interview respondents (approached via messenger) with broader distribution through Ukrainian professional networks and business associations. The five overlapping respondents represent 14% of the survey sample. The overlap weakens the independence of the cross-validation but does not invalidate it, and leaves parameter calibration unaffected. The resulting sample is a convenience sample. Probability sampling was not feasible because no accessible sampling frame of wartime-active organizations exists, and wartime security considerations limited systematic outreach. The sample is not statistically representative of the Ukrainian organizational population. Its purpose is to provide empirical distributions for agent-level parameters and reference points for aggregate model behavior.

Table B.1 describes the sample achieved. The services sector and Kyiv-based organizations are overrepresented relative to the national distribution, as are medium-sized firms (51 to 250 employees). Most respondents held senior positions (77.1% in owner, top, or senior management), and 80.0% had worked at their organization for 4 or more years, supporting familiarity with pre-invasion conditions. These characteristics reflect the recruitment channels and bound how far the results can be generalized.

Table B.1. Sample Characteristics (n = 35)

Characteristic	**Category**	**n**	**%**
Sector (Q2)	Services (IT, law, consulting, finance, logistics, trade)	29	82.9
	Goods (manufacturing, agriculture, construction, other)	5	14.3
	Both goods and services	1	2.9
Size (Q3)	Fewer than 10	6	17.1
	10–50	9	25.7
	51–250	12	34.3
	More than 250	7	20.0
	Variable over time	1	2.9
HQ region (Q17)	Northern Ukraine (Kyiv, Zhytomyr, Chernihiv)	23	65.7
	Eastern Ukraine (Kharkiv, Sumy, Zaporizhzhia)	5	14.3
	Southern Ukraine (Odesa, Mykolaiv, Kherson)	4	11.4
	Western Ukraine (Ternopil, Volyn, Rivne)	3	8.6
Respondent role (Q4)	Senior management	14	40.0
	Top management	7	20.0
	Owner / founder	6	17.1
	Middle management	6	17.1
	Specialist / staff	2	5.7
Tenure (Q5)	Less than 1 year	1	2.9
	1–4 years	6	17.1
	4–10 years	16	45.7
	More than 10 years	12	34.3

B.3. Survey Instrument and Response Distributions

Table B.2 reproduces the complete 38-item instrument with response distributions. Each row shows the question identifier, the question in Ukrainian (as administered) and in English translation, the response options in Ukrainian and English, and the frequency and percentage for each option. Percentages are calculated against n = 35 except for Q20–Q24 (n = 15, the relocator subsample identified in Q19) and Q25 (n = 20, the non-relocator subsample). Multi-select percentages (Q7) reflect the share of respondents selecting each option and therefore do not sum to 100%. For the three Likert-scale items (Q13, Q33, Q36), the mean and standard deviation appear beneath the final option.

Table B.2. Complete Survey Instrument with Response Distributions (n = 35)

Q	Запитання (UKR)	Question (ENG)	Варіанти відповіді (UKR)	Response options (ENG)	*n*	%
Informed Consent (Q1)						
Q1	*Я прочитав/ла інформацію та даю згоду на участь у дослідженні.*	*I have read the information and agree to participate.*	Даю згоду на участь	Agree to participate	35	100
Organizational Profile (Q2–Q5)						
Q2	*Яка основна галузь діяльності вашої організації?*	*What is the main sector of your organization's activity?*	Послуги (IT, юриспруденція, консалтинг, фінанси, логістика, торгівля тощо) Товари (виробництво, с/г, будівництво тощо) Продуктова IT-компанія [Інше] Медичні послуги [Інше] І товари, і послуги Виробництво будматеріалів [Інше]	Services (IT, law, consulting, finance, logistics, trade, etc.) Goods (manufacturing, agriculture, construction, etc.) Product IT company [Other] Medical services [Other] Both goods and services Manufacturing of construction materials [Other]	27 4 1 1 1 1	77.1 11.4 2.9 2.9 2.9 2.9
Q3	*Скільки людей працює у вашій організації зараз?*	*How many people currently work in your organization?*	Менше 10 10–50 51–250 Більше 250 До війни >10, після початку <10, на 4-й рік знову >10 [Інше]	Fewer than 10 10–50 51–250 More than 250 Before war >10, after start <10, in year 4 again >10 [Other]	6 9 12 7 1	17.1 25.7 34.3 20 2.9
Q4	*Ваша роль в організації.*	*Your role in the organization.*	Вище керівництво (VP, керівник підрозділу)	Senior management (VP, head of division)	14	40

Q	Запитання (UKR)	Question (ENG)	Варіанти відповіді (UKR)	Response options (ENG)	*n*	%
			Топ-менеджмент (CEO, директор) Власник / засновник Середній менеджмент Спеціаліст / працівник	Top management (CEO, director) Owner / founder Middle management Specialist / staff	7 6 6 2	20 17.1 17.1 5.7
Q5	*Як довго ви працюєте в цій організації?*	*How long have you been working in this organization?*	Менше 1 року 1–4 роки 4–10 років Більше 10 років	Less than 1 year 1–4 years 4–10 years More than 10 years	1 6 16 12	2.9 17.1 45.7 34.3
Crisis Response and Priorities (Q6–Q13)						
Q6	*На момент початку повномасштабного вторгнення – скільки ваша організація могла б проіснувати лише на резервах, без доходу?*	*At the start of the full-scale invasion, how long could your organization have survived on reserves alone, with no revenue?*	1–3 місяці 3–6 місяців Більше 6 місяців Важко сказати	1–3 months 3–6 months More than 6 months Difficult to say	14 10 6 5	40 28.6 17.1 14.3
Q7	*Як відреагувала ваша організація в перші тижні повномасштабного вторгнення? (оберіть усе, що підходить) [multi-select]*	*How did your organization respond in the first weeks of the full-scale invasion? (select all that apply) [multi-select]*	Перейшли на дистанційну роботу Переїхали (повністю або частково) у безпечніший регіон Продовжували працювати зі зниженою потужністю Повністю зупинили діяльність Продовжували працювати на нормальному рівні Почали працювати з більшою	Switched to remote work Relocated (fully or partially) to a safer region Continued operating at reduced capacity Completely stopped operations Continued operating at normal level Started working with greater intensity The company was founded in	21 16 11 7 6 4 1 1 1 1	60 45.7 31.4 20 17.1 11.4 2.9 2.9 2.9 2.9

Q	Запитання (UKR)	Question (ENG)	Варіанти відповіді (UKR)	Response options (ENG)	*n*	%
			інтенсивністю Компанію засновано у вересні 2022 р. під час війни [Інше] Були готові, оскільки мали офіси в Луганську раніше і розуміли процеси [Інше] Почали волонтерити – робота та сервіс для міста, мешканців, захисників [Інше] Через 2 місяці відновили роботу філії [Інше]	September 2022 during the war [Other] We were prepared for the invasion since we had offices in Luhansk before and understood the processes [Other] Started volunteering, i.e. client donations – our work and service to the city, residents, defenders [Other] After 2 months resumed branch operations [Other]		
Q8	*На найгіршому етапі після вторгнення, як змінився дохід вашої організації порівняно з рівнем до вторгнення?*	*At the worst point after the invasion, how did your organization's revenue change compared to pre-invasion levels?*	Впав більш ніж на 50% Впав на 25–50% Впав менш ніж на 25% Не змінився Зріс Важко сказати Клієнти за кордоном, війна впливає на них безпосередньо [Інше] Відповідь вище [Інше] Точно впав, але через злиття важко порівнювати [Інше] Спершу все зупинилося, потім відновлювалися; на 4-й рік можемо ~10 міс. без доходу [Інше]	Dropped more than 50% Dropped 25–50% Dropped less than 25% Did not change Increased Difficult to say Clients are abroad, so the war directly affects them [Other] Answer above [Other] Definitely dropped, but difficult to say since we had a merger and it's hard to compare figures [Other] Initially everything stopped. Then we started reviving. In year 2 started saving money. In year 4 we can survive ~10 months without revenue [Other]	9 8 4 3 1 6 1 1 1 1	25.7 22.9 11.4 8.6 2.9 17.1 2.9 2.9 2.9 2.9

Q	**Запитання (UKR)**	**Question (ENG)**	**Варіанти відповіді (UKR)**	**Response options (ENG)**	***n***	**%**
Q9	*Як змінилася кількість персоналу зараз порівняно з кількістю до вторгнення?*	*How has the number of personnel changed now compared to pre-invasion levels?*	Збільшилася Практично не змінилася Трохи зменшилася (<10%) Зменшилася на 10–25% Зменшилася на 25–50% Зменшилася більш ніж на 50% Важко сказати	Increased Practically unchanged Slightly decreased, less than 10% Decreased 10–25% Decreased 25–50% Decreased more than 50% Difficult to say	12 4 1 8 8 1 1	34.3 11.4 2.9 22.9 22.9 2.9 2.9
Q10	*Що було головним пріоритетом вашої організації в ПЕРШІ МІСЯЦІ після вторгнення?*	*What was the main priority of your organization in the FIRST MONTHS after the invasion?*	Фізична безпека працівників Збереження бізнесу (дохід, клієнти, активи) Допомога силам оборони або громаді Не можу виділити один головний пріоритет Важко сказати Приховати, що працюємо з України [Інше] Safety and security of employees, helping defense forces, in the 2nd month – preserving the business for the families of remaining staff and clients willing to work. We're B2B and without us two types of clients struggle. There are suppliers with goods but no clients and online resources with clients but no goods – we connect them [Other]	Physical safety of employees Preserving the business (revenue, clients, assets) Helping Ukraine's defense forces or the community Cannot single out one main priority Difficult to say Hide that we work from Ukraine, without helping employees or the Armed Forces [Other] Safety and security of employees, helping defense forces, in the 2nd month – preserving the business for the families of remaining staff and clients willing to work. We're B2B and without us two types of clients struggle. There are suppliers with goods but no clients and online resources with clients but no goods – we connect them [Other]	19 3 3 7 1 1 1	54.3 8.6 8.6 20 2.9 2.9 2.9

Q	Запитання (UKR)	Question (ENG)	Варіанти відповіді (UKR)	Response options (ENG)	*n*	%
Q11	*Що є головним пріоритетом вашої організації ЗАРАЗ?*	*What is the main priority of your organization NOW?*	Забезпечення безперервності бізнесу Пошук нових ринків або продуктів Не можу виділити один головний пріоритет Важко сказати	Ensuring business continuity (revenue, clients, assets) Searching for new markets or products Cannot single out one main priority Difficult to say	24 3 7 1	68.6 8.6 20 2.9
Q12	*Що найбільше спонукало вашу організацію повернутися від режиму «в першу чергу безпека» до звичайної діяльності?*	*What most prompted your organization to return from 'safety first' mode to regular operations?*	Адаптувалися – навчилися працювати попри постійну небезпеку Безпекова ситуація в нашому регіоні покращилася Резерви закінчувалися – треба було заробляти Продовжуємо працювати в режимі «безпека понад усе» Не стосується – не переходили в режим безпеки Важко сказати Клієнти або партнери вимагали відновлення роботи	We adapted – learned to work despite constant danger Security situation in our region improved Financial reserves were running out – needed to earn We continue operating in safety-first mode Does not apply – we did not switch to safety-first mode Difficult to say Clients or partners demanded resumption of work	18 5 4 3 2 2 1	51.4 14.3 11.4 8.6 5.7 5.7 2.9
Q13	*Як би ви охарактеризували загальне ставлення вашої організації до ризику? (1 = безпека понад усе; 5 = працюємо якомога довше, навіть при високому ризику)*	*How would you characterize your organization's overall attitude toward risk? (1 = Safety above all; 5 = Work as long as possible, even at high risk)*	1 2 3 4 5	1 2 3 4 5	4 3 8 15 5 M = 3.40 SD = 1.19	11.4 8.6 22.9 42.9 14.3

Q	**Запитання (UKR)**	**Question (ENG)**	**Варіанти відповіді (UKR)**	**Response options (ENG)**	***n***	**%**
Internal Structure (Q14–Q16)						
Q14	*ДО ВТОРГНЕННЯ, як приймалися ключові рішення у вашій організації?*	*BEFORE THE INVASION, how were key decisions made in your organization?*	Невелика група на вершині ухвалювала рішення, інші виконували Менеджери мали значну автономію у своїх напрямах Більшість працівників могли ухвалювати рішення самостійно Одна людина ухвалювала майже все Важко сказати	A small group at the top decided, others executed Managers had significant autonomy in their areas Most employees could make independent decisions in their work One person decided almost everything Difficult to say	16 10 4 3 2	45.7 28.6 11.4 8.6 5.7
Q15	*Як змінився підхід до ухвалення рішень ЗАРАЗ порівняно з тим, як було до вторгнення?*	*How has the approach to decision-making NOW changed compared to before the invasion?*	Залишився приблизно таким самим Став дещо більш децентралізованим Став значно більш децентралізованим Став дещо більш централізованим Став значно більш централізованим Важко сказати Неактуально, впливали інші процеси [Інше]	Remained approximately the same Became somewhat more decentralized Became much more decentralized (more people can make decisions independently) Became somewhat more centralized Became much more centralized (fewer people make decisions) Difficult to say Irrelevant, other processes had an impact [Other]	19 3 3 3 2 4 1	54.3 8.6 8.6 8.6 5.7 11.4 2.9

Q	Запитання (UKR)	Question (ENG)	Варіанти відповіді (UKR)	Response options (ENG)	*n*	%
Q16	*Як змінився горизонт планування у вашій організації зараз порівняно з часом до вторгнення?*	*How has the planning horizon changed now compared to before the invasion?*	Залишився приблизно таким самим Став дещо коротшим Став значно коротшим (тільки найближча перспектива) Став довшим Став значно довшим (планування на роки вперед) Важко сказати	Remained approximately the same Became somewhat shorter Became much shorter (only the immediate term) Became longer Became much longer (planning years ahead) Difficult to say	14 12 6 1 1 1	40 34.3 17.1 2.9 2.9 2.9
Relocation (Q17–Q25)						
Q17	*У якій області знаходився ваш головний український підрозділ у січні 2022 року?*	*In which oblast was your main Ukrainian office located in January 2022?*	м. Київ Житомирська обл. Одеська обл. Харківська обл. Запорізька обл. Сумська обл. Волинська обл. Миколаївська обл. Тернопільська обл. Херсонська обл. Чернігівська обл. Рівненська обл.	Kyiv city Zhytomyr oblast Odesa oblast Kharkiv oblast Zaporizhzhia oblast Sumy oblast Volyn oblast Mykolaiv oblast Ternopil oblast Kherson oblast Chernihiv oblast Rivne oblast	16 6 2 2 2 1 1 1 1 1 1 1	45.7 17.1 5.7 5.7 5.7 2.9 2.9 2.9 2.9 2.9 2.9 2.9
Q18	*Протягом перших місяців після вторгнення, наскільки безпечно ви почувалися у місці вашої діяльності?*	*During the first months after the invasion, how safe did you feel at your operating location?*	Надзвичайно небезпечно Небезпечно Дещо небезпечно Відносно безпечно Повністю безпечно Важко сказати	Extremely unsafe Unsafe Somewhat unsafe Relatively safe Completely safe Difficult to say	10 11 5 6 2 1	28.6 31.4 14.3 17.1 5.7 2.9

Q	Запитання (UKR)	Question (ENG)	Варіанти відповіді (UKR)	Response options (ENG)	*n*	%
Q19	*Чи переїхала ваша організація (повністю або частково) в інший регіон через вторгнення?*	*Did your organization relocate (fully or partially) to another region because of the invasion?*	Ні Так, частково (частина функцій) Так, повністю Лише добровільне переміщення; призупинили рахунки в небезпечних зонах [Інше] HQ лишився у Києві, відкрили офіси у Львові та Варшаві; частка дистанційних зросла [Інше] Люди поїхали, офіс лишився [Інше]	No Yes, relocated partially (some functions moved) Yes, relocated fully Only voluntary relocation. Especially Chernihiv, Kharkiv, Odesa. Halted operations of some accounts in danger zones [Other] HQ stayed in Kyiv, opened offices in Lviv and Warsaw. Share of remote workers increased [Other] People left, the office remained [Other]	20 10 2 1 1 1	57.1 28.6 5.7 2.9 2.9 2.9
Note. Q20–Q24 restricted to relocators (n = 15). Q25 restricted to non-relocators (n = 20).	*Note.* Q20–Q24 restricted to relocators (n = 15). Q25 restricted to non-relocators (n = 20).	*Note.* Q20–Q24 restricted to relocators (n = 15). Q25 restricted to non-relocators (n = 20).	*Note.* Q20–Q24 restricted to relocators (n = 15). Q25 restricted to non-relocators (n = 20).	*Note.* Q20–Q24 restricted to relocators (n = 15). Q25 restricted to non-relocators (n = 20).	*Note.* Q20–Q24 restricted to relocators (n = 15). Q25 restricted to non-relocators (n = 20).	*Note.* Q20–Q24 restricted to relocators (n = 15). Q25 restricted to non-relocators (n = 20).
Q20	*У яку область переїхав ваш головний український підрозділ?*	*To which oblast did your main Ukrainian office move? (n = 15, relocators only)*	Львівська обл. За кордон м. Київ Харківська обл. Закарпатська обл. Важко сказати Не переїжджали Житомирська обл.	Lviv oblast Abroad Kyiv city Kharkiv oblast Zakarpattia oblast Difficult to say Did not relocate Zhytomyr oblast	4 3 2 1 1 1 1 1	26.7 20 13.3 6.7 6.7 6.7 6.7 6.7

Q	Запитання (UKR)	Question (ENG)	Варіанти відповіді (UKR)	Response options (ENG)	*n*	%
			Дистанційна робота не прив'язана до локацій [Інше]	Remote work is not tied to locations [Other]	1 1	6.7 6.7
Q21	*Через який час після початку вторгнення відбувся переїзд?*	*How long after the start of the invasion did the relocation occur? (n = 15, relocators only)*	Протягом перших 2 тижнів Більше 6 місяців 1–3 місяці 2 тижні – 1 місяць Не було переїзду HQ [Інше] 3–6 місяців Переїзду не було [Інше]	Within the first 2 weeks More than 6 months 1–3 months 2 weeks to 1 month There was no HQ relocation [Other] 3–6 months There was no relocation [Other]	4 3 3 2 1 1 1	26.7 20 20 13.3 6.7 6.7 6.7
Q22	*Що стало основним поштовхом для переїзду?*	*What was the main trigger for the relocation? (n = 15, relocators only)*	Пряма військова загроза Працівники переїхали в інші регіони Не можу виділити один головний фактор Важко сказати Переїзду не було [Інше]	Direct military threat Employees relocated to other regions Cannot single out one main factor Difficult to say There was no relocation [Other]	8 3 2 1 1	53.3 20 13.3 6.7 6.7
Q23	*Що найбільше вплинуло на вибір місця для переїзду?*	*What most influenced the choice of relocation destination? (n = 15, relocators only)*	Фізична безпека регіону Не можу виділити один головний фактор Важко сказати Працівники виїхали через ризики мобілізації та безпекові проблеми [Інше] Наявність інших організацій нашого сектору Наявність інфраструктури (електрика, інтернет,	Physical safety of the region Cannot single out one main factor Difficult to say Employees left due to mobilization risks and security challenges [Other] Presence of other organizations in our sector Infrastructure availability (electricity, internet, transport)	6 3 2 1 1 1 1	40 20 13.3 6.7 6.7 6.7 6.7

Q	Запитання (UKR)	Question (ENG)	Варіанти відповіді (UKR)	Response options (ENG)	*n*	%
			транспорт) Переїзду не було [Інше]	There was no relocation [Other]		
Q24	*Як би ви оцінили загальну вартість переїзду організації відносно вашого річного доходу?*	*How would you estimate the total cost of relocating relative to annual revenue? (n = 15, relocators only)*	Важко сказати 25–50% Менше 10% річного доходу Компанія не доплачує, тому вартість = 0 [Інше] Переїзду не було [Інше]	Difficult to say 25–50% Less than 10% of annual revenue Company doesn't pay people extra for this, so cost = 0 [Other] There was no relocation [Other]	8 3 2 1 1	53.3 20 13.3 6.7 6.7
Q25	*Якщо ваша організація НЕ переїздила, що було головною причиною?*	*If your organization did NOT relocate, what was the main reason? (n = 20, non-relocators only)*	Наш регіон залишався відносно безпечним Важко сказати Працівники працювали дистанційно звідки вважали безпечно [Інше] Працівники не хотіли переїжджати Закрили офіс у Києві, потім відкрили наприкінці 2022 р. [Інше] Перейшли у дистанційний формат [Інше] Юр. адреса не змінилась [Інше] Бізнес можна вести дистанційно; працівники переміщалися самостійно [Інше] Працюємо дистанційно; хтось за кордоном, хтось повернувся	Our region remained relatively safe Difficult to say Employees worked remotely from wherever they were and considered safe [Other] Employees did not want to relocate Closed the Kyiv HQ, then reopened it at the end of 2022 [Other] Switched to remote format [Other] Company's registration location remained unchanged [Other] Business can be run remotely, some employees relocated at their own discretion [Other] Working remotely. Some employees moved abroad and	11 1 1 1 1 1 1 1 1 1	55 5 5 5 5 5 5 5 5 5

Q	Запитання (UKR)	Question (ENG)	Варіанти відповіді (UKR)	Response options (ENG)	*n*	%
			до Києва [Інше] У нас локальний бізнес – прив’язаний до ринку «7-й км» [Інше]	work from there, some returned and work from Kyiv [Other] We have a local business – tied to the 7km market [Other]		
Partnership Networks (Q26–Q29)						
Q26	*Яка частка вашої партнерської мережі була втрачена через вторгнення?*	*What proportion of your partnership network was lost due to the invasion?*	Практично нічого (<10%) Деяка частина (10–24%) Приблизно половина (25–49%) Важко сказати Нічого не втратили (хмарна інфраструктура) [Інше]	Practically none (less than 10%) Some (10–24% lost) About half (25–49% lost) Difficult to say Nothing lost: as tech our infrastructure is in a non-Ukrainian cloud [Other]	11 15 4 4 1	31.4 42.9 11.4 11.4 2.9
Q27	*Скільки часу знадобилося, щоб побудувати нові або відновити старі партнерські відносини до рівня, достатнього для повноцінної роботи?*	*How long did it take to build new or restore old partnership relations to a level sufficient for full operations?*	Менше 1 місяця 1–3 місяці 3–6 місяців Більше 6 місяців Ще не відновилися Не стосується – партнерства не порушувались Важко сказати	Less than 1 month 1–3 months 3–6 months More than 6 months Have not yet recovered Does not apply – partnerships were not disrupted Difficult to say	1 3 6 8 5 7 5	2.9 8.6 17.1 22.9 14.3 20 14.3
Q28	*При виборі НОВИХ ділових партнерів після вторгнення, що було найважливішим?*	*When choosing NEW business partners after the invasion, what was most important?*	Взаємодоповнюючі бізнес-можливості Спільні цінності та погляди на війну Фінансова стабільність партнера Репутація або особисті	Complementary business capabilities Shared values and similar views on the war Financial stability of the partner Reputation or personal	3 3 2 1 12 9	8.6 8.6 5.7 2.9 34.3 25.7

Q	Запитання (UKR)	Question (ENG)	Варіанти відповіді (UKR)	Response options (ENG)	*n*	%
			рекомендації Не можу виділити одну головну характеристику Не стосується – не шукали нових партнерів Важко сказати Готовність партнерів до співпраці [Інше]	recommendations Cannot single out one main characteristic Does not apply – did not seek new partners Difficult to say Partners' willingness to cooperate [Other]	4 1	11.4 2.9
Q29	*Якщо компанія переїхала – чи допоміг переїзд знайти нових партнерів?*	*If the company relocated, did the relocation help find new partners?*	Допоміг – кращі можливості на новому місці Ніякої різниці Не стосується – не переїжджали або не шукали Важко сказати Не переїжджали [Інше]	Helped – better partnership options at the new location No difference Does not apply – did not relocate or did not seek new partners Difficult to say Did not relocate [Other]	2 9 19 3 2	5.7 25.7 54.3 8.6 5.7
Government Relations (Q30–Q33)						
Q30	*Як би ви загалом оцінили вплив державних органів на діяльність вашої організації?*	*How would you generally assess the impact of government agencies on your organization's operations?*	Активна підтримка Створення умов (підтримка в обмін на виконання вимог) Не втручаються в нашу діяльність Створюють труднощі (бюрократія, тиск, обмеження) Недостатня взаємодія для оцінки Важко сказати Перевірки наших клієнтів почастішали [Інше]	Active support Setting conditions (support in exchange for meeting requirements) Do not interfere with our operations Creating difficulties (excessive bureaucracy, pressure, restrictions) Insufficient interaction to assess Difficult to say	3 6 12 5 6 2 1	8.6 17.1 34.3 14.3 17.1 5.7 2.9

Q	Запитання (UKR)	Question (ENG)	Варіанти відповіді (UKR)	Response options (ENG)	*n*	%
				Inspections of our clients became more frequent [Other]		
Q31	*Як ваша організація взаємодіє з державними органами?*	*How does your organization interact with government agencies?*	Виконання вимог (податки, звітність, регуляції) – і не більше Активна співпраця (контракти, програми, публічна підтримка) Уникнення – мінімізуємо взаємодію Немає взаємодії	Compliance with requirements (taxes, reporting, regulations) and nothing more Active cooperation (contracts, joint programs, public support) Avoidance (we try to minimize interaction) No interaction	20 10 3 2	57.1 28.6 8.6 5.7
Q32	*Чи вплинула мобілізація на наявність робочої сили для вашої організації?*	*Has mobilization affected the availability of workforce for your organization?*	Не вплинула або ледь вплинула Вплинула помірно – нестача кадрів Вплинула суттєво – втрата ключових працівників Важко сказати Компанія мінімізувала наймання чоловіків у нових позиціях [Інше]	Did not affect or barely affected Affected moderately – experiencing staff shortages Affected substantially – lost key employees Difficult to say Unfortunately the company minimized hiring men in Ukraine for new positions [Other]	6 21 5 2 1	17.1 60 14.3 5.7 2.9
Q33	*Як би ви загалом оцінили досвід взаємодії вашої організації з державними органами? (1–5)*	*How would you rate the experience of your organization's interaction with government agencies? (1–5)*	1 2 3 4 5	1 2 3 4 5	0 6 15 13 1 M = 3.26 SD = 0.78	0 17.1 42.9 37.1 2.9

Q	Запитання (UKR)	Question (ENG)	Варіанти відповіді (UKR)	Response options (ENG)	*n*	%
Military Relations (Q34–Q36)						
Q34	*Як би ви загалом оцінили вплив військових структур на діяльність вашої організації?*	*How would you generally assess the impact of military structures on your organization's operations?*	Активно підтримують (захист, співпраця) Не втручаються в нашу діяльність Висувають вимоги (ресурси, персонал, поступки) Недостатня взаємодія для оцінки Важко сказати Перекриття доріг, «бусифікація», рейди на склади клієнтів [Інше]	Actively support our operations (protection, cooperation) Do not interfere with our operations Setting demands (resources, personnel, concessions) Insufficient interaction to assess Difficult to say Road closures, 'busification', raids on clients' warehouses and offices – difficult [Other]	6 16 1 9 2 1	17.1 45.7 2.9 25.7 5.7 2.9
Q35	*Як ваша організація взаємодіє з військовими структурами?*	*How does your organization interact with military structures?*	Активна підтримка (постачання, волонтерство, донати з власної ініціативи) Співпраця на запит (виконання звернень) Моральна підтримка (публічна, без матеріальної) Виконання вимог (мобілізація, вилучення ресурсів як неминуче) Уникнення – мінімізуємо взаємодію Важко сказати На рівні компанії взаємодії немає, але засновники	Active support (supplies, volunteering, donations on own initiative) Cooperation on request (fulfilling requests) Moral support (public support without material participation) Compliance with demands (accepting mobilization, resource seizure as inevitable) Avoidance (we try to minimize interaction) Difficult to say No interaction at the company level, but founders hate russia	17 8 1 2 4 1 1 1	48.6 22.9 2.9 5.7 11.4 2.9 2.9 2.9

Q	Запитання (UKR)	Question (ENG)	Варіанти відповіді (UKR)	Response options (ENG)	*n*	%
			ненавидять росію [Інше] Ми не взаємодіємо [Інше]	[Other] We don't interact [Other]		
Q36	*Як би ви оцінили досвід взаємодії вашої організації з військовими? (1–5)*	*How would you rate the experience of your organization's interaction with military structures? (1–5)*	1 2 3 4 5	1 2 3 4 5	0 0 13 13 9 M = 3.89 SD = 0.80	0 0 37.1 37.1 25.7
Open-Ended Questions (Q37–Q38)						
Q37	*Якщо коротко: що було головним фактором, який допоміг вашій організації вижити після початку повномасштабного вторгнення?*	*Briefly: what was the main factor that helped your organization survive after the start of the full-scale invasion?*	(Відкрите запитання)	(Open-ended)	26/35	–
Q38	*Що важливого про адаптацію вашої організації до умов війни ми могли не врахувати в цьому опитуванні?*	*What important aspects of your organization's adaptation to war conditions might we have overlooked in this survey?*	(Відкрите запитання)	(Open-ended)	17/35	–

B.4. Open-Ended Responses

Both open-ended questions serve gap detection at two different levels. Responses are summarized thematically below.

Q37. The main factor that helped the organization survive (n = 26).

Q37 asks respondents to name the single factor they consider most important for their organization’s survival, without offering predefined categories. The themes that emerge can be compared against the mechanism inventory to see whether it captures the factors respondents themselves consider most important.

Four themes recur across the responses.

Team cohesion and employee dedication. Respondents identified their employees’ willingness to continue working under duress as the decisive factor, often framed as loyalty and mutual support rather than formal organizational commitment.

International client base or foreign parent company. Having clients or ownership outside Ukraine was a frequently cited survival factor, including IT firms with global user bases, subsidiaries of foreign parent companies, and services firms with European or US client concentration.

Pre-invasion preparation and prior crisis experience. Respondents credited earlier adaptations, including COVID-era remote work, 2014 displacement from Crimea or Donbas, and pre-invasion contingency plans, as reducing the cost of the February 2022 shock.

Rapid leadership decisions and flexibility. Respondents attributed survival to specific actions taken within the first weeks of the invasion: early relocation, an immediate pivot to remote work, decentralized decision-making, or reorienting civilian product lines toward military-adjacent applications.

Two of the four themes correspond to mechanisms already implemented in the model. Pre-invasion preparation maps to J3 (pre-crisis adaptation). Rapid leadership decisions and flexibility map to the organizational flexibility trait and to the relocation and domain-expansion mechanisms (B3 and B7). Team cohesion and employee dedication are represented in aggregate form through the workforce attrition rate, which captures how quickly organizations lose personnel under danger. The model does not vary this rate across individual organizations, but the aggregate representation is sufficient for the current scope. An international client base is absent from the model. The model represents trade and partnership only among organizations within Ukraine and does not include foreign market exposure as a factor. This falls outside the scope of the current model.

Q38. What the survey may have overlooked (n = 17).

Q38 asks respondents directly what the survey may have missed about their organization's adaptation to the war. Three themes recur, and one additional observation is preserved because it considers the compliance mechanism.

Depth of pre-planned business continuity. Several respondents described detailed pre-invasion preparations, including pre-booked accommodation, cross-training so that each function was covered by at least two employees, stockpiled backup infrastructure, and pre-planned evacuation routes.

Regional variation and infrastructure conditions. Respondents noted that the instrument did not capture region-specific operating conditions: blackouts, strike proximity, and permanent loss of regional business lines in occupied or heavily damaged territories.

Employment topics that the instrument did not cover. Multiple respondents flagged HR-adjacent dimensions: employment of veterans and internally displaced persons, owners joining the armed forces and later returning to civilian roles, and the administrative complexity of military registration and reservation of critical employees.

Informal accommodations with the mobilization regime. One respondent argued that the closed-ended items cannot distinguish among the different informal accommodations organizations make with mobilization. These grey-zone strategies are a substantial but sensitive part of wartime business practice.

Most themes from Q37 and Q38 correspond to mechanisms the model already implements. Rapid leadership decisions and flexibility map to the organizational flexibility trait and the domain-expansion mechanism (B7 in Table B.3). Team cohesion and employee dedication are represented in aggregate form through the workforce attrition rate. Mobilization's effect on organizations is captured by the recruitment pipeline. Regional variation is represented through the model's abstract spatial grid. The comply-versus-evade choice is discrete, but the underlying propensity scores are continuous and vary across agents, which captures part of the grey-zone spectrum described by one respondent.

The survey did not ask about burnout or cumulative exhaustion, and no respondents raised these topics in their open-ended responses. The earlier qualitative interviews identified burnout as a recurring theme. The survey instrument does not cover it. This gap is reported in the cross-validation table in the next section.

Three themes point to areas for future development. First, **pre-invasion preparation and prior crisis experience** (J3 in Table B.3) is documented in the interview codebook and supported by both the interviews and the survey, but the model does not implement a rule that gives organizations with prior crisis experience an advantage over those without it. Second, an **international client base** or foreign parent company falls outside the scope of the current model, which represents trade only among Ukrainian organizations. Third, staff **cohesion and employee dedication** are represented only at the population level through a uniform attrition rate. The model does not account for retention differences across individual organizations, so the difference between firms that retained their employees and those that lost them is not captured.

B.5. Mechanism Mapping

The survey's functions are to cross-validate interview findings, calibrate model parameters, and validate model output. Tables B.3 through B.6 document each function. Table B.3 cross-validates interview-identified mechanisms against survey evidence. Table B.4 lists every survey item that sets a model parameter, labeled by the mechanism that hosts the parameter. Table B.5 lists all survey items referenced in the validation scripts. Table B.6 documents survey items not used in any of these roles, with reasons.

Interview Cross-Validation

Nine of the codebook mechanisms were measured by both the interviews and the survey, so the two sources can be compared directly. Table B.3 reports these nine direct comparisons. The dissertation body chapter (Section 3.5) and Appendix D (Table D.3) report a broader synthesis of fifteen mechanism-level comparisons that includes six additional mechanisms where interview evidence is reported alongside survey gaps or absences. The Interview finding column in Table B.3 reports counts from the interview coding, where each passage was coded as S (supported), C (contradicted), N (nuanced, meaning partial support that reveals complexity the model simplifies), or X (unmatched, meaning behavior that no mechanism in the inventory accounts for).

For eight of the nine mechanisms, the interviews and the survey produced the same finding, strengthening the evidence for those mechanisms. The ninth, A4 (risk-tolerance shift), produced a difference worth explaining. The survey was administered at a single point in time and found that most respondents described their organizations as risk-seeking. The interviews, conducted over two waves a year apart, captured how risk tolerance changed during the war. These results do not contradict each other: the survey captured where organizations ended up after the shift, and the interviews captured the shift itself.

The remaining mechanisms in the codebook were not compared against survey evidence. For mechanisms that the interviews already supported with strong evidence, adding corresponding survey items would have made the questionnaire longer without adding new information. Other mechanisms describe processes that a survey administered at one point in time cannot observe, such as how networks form and break apart, how organizations adapt over months, or how decision thresholds activate under changing conditions. These mechanisms are validated through interview evidence and pattern-oriented tests against macro data reported in the calibration and validation chapter.

Table B.3. Interview-Identified Mechanisms Cross-Validation Against Survey Evidence

Code	Mechanism	Interview evidence	Survey item(s)	Survey finding	Conclusion
C1	Planning horizon (adaptive trait)	26 S, 0 C	Q16	51.4% shortened, 40% unchanged, 5.7% lengthened.	Convergent. Universal contraction with partial recovery supported.
K1	Three-phase temporal pattern	16 S, 0 C	Q10–Q12	Safety-first 54.3% initially → business-first 68.6%; habituation as dominant trigger (51.4%).	Convergent. Priority shift and normalization trajectory supported.
K4	Voluntary military support	22 S, 0 C	Q34–Q36	48.6% active on own initiative; 22.9% on request; military rating 3.89 vs. government 3.26.	Convergent. Spontaneous support pattern supported.
G4	Mobilization workforce shock	9 S, 0 C	Q32	74.3% of organizations affected; 60% moderate shortages; 14.3% lost key employees.	Convergent. Discrete workforce shock pattern supported.
B7	Domain expansion	14 S, 1 C	Q37 open-ended	UAV reorientation and defense-adjacent pivots reported among survival factors.	Convergent (indirect). Domain expansion supported through open-ended evidence.
B6	Comply vs. evade decision	9 S, 0 C, 7 N	Q31, Q38	86/14 raw comply/evade; ritual compliance visible in open-ended Q38 responses on grey-zone mobilization practices.	Convergent with nuance. Compliance dominance supported; ritual/ceremonial mode only partially captured by closed-ended items.
A3	Structural trait homophilic drift	10 S, 0 C, 5 N	Q14, Q15	54.3% unchanged decision-making, 17.2% more decentralized, 14.3% more centralized.	Convergent. Sector-dependent drift supported with weaker magnitude than interviews suggested.
J3	COVID pre-adaptation	11 S, 2 N	Q6, Q38	Reserve distribution with modal 1–3 months; open-ended responses describe pre-booked hotels, cross-	Convergent with nuance. Reserve transfer supported; qualitative depth of preparation beyond what closed items capture.

				training, and contingency plans.	
A4	Endogenous risk-tolerance shift	0 S, 2 C	Q13	Mean 3.4/5, SD 1.19; skewed toward risk-seeking.	Divergent by design. Interviews captured change over time; survey captured the post-change steady state. Both are consistent with the reclassification of risk tolerance as an endogenous adaptive trait.

B.6. Calibration

As described in the introduction, one group of screened parameters describes organizational behavior that only the survey can measure, because official statistics are too aggregate and interview transcripts cannot produce population-level distributions. Table B.4 documents each of these parameters, showing the survey item, the committed value, the mechanism to which the parameter belongs, and the derivation logic.

Not all parameters in the table belong to mechanisms identified through the interviews. Some belong to mechanisms inherited from earlier agent-based frameworks on which this model builds (SugarScape, SKIN, BEN, ASSOCC, Hammond–Axelrod, WorkSim, and Lambert–Knemeyer partnership theory). The survey calibrates these parameters because they describe observable organizational behavior, even though the mechanisms themselves did not originate in the interview data. A small number of parameters operate inside the adaptive-trait or partnership-scoring rules without belonging to a single named mechanism. The mechanism column notes the origin of each parameter. All items in Table B.4 belong to Layer 2 of the four-layer calibration architecture described in the introduction.

Table B.4. Survey-Based Calibration: Items That Set Model Parameter Values

Survey item(s)	Parameter	Value committed	Host mechanism	Derivation
Q12, Q18	civilian-safety-threshold-base	0.35	Adaptive trait (below codebook)	Layer 2: Q18 mean perceived safety 2.5/5 normalized to 0.35, adjusted downward from default 0.40 to reflect Q12

				habituation pattern (51.4% adapted to constant danger).
Q13	risk-tolerance (agent initial)	Normal(0.60, 0.30)	A4 endogenous risk-tolerance shift	Layer 2: Likert mean 3.40/5 → 0.60; Likert SD 1.19/4 → 0.30. Each civilian draws a fixed trait at setup.
Q14	org-hierarchy (agent initial)	Normal(0.63, 0.20)	A3 structural trait homophilic drift (initial condition)	Layer 2: ordinal-scale fit to pre-invasion decision-making distribution.
Q16	initial-planning-horizon	0.38 (scalar) + three-bin mixture	C1 planning horizon contraction	Layer 2: weighted midpoint mapped to [0,1]. Agent-level mixture: 53% U(0.15, 0.40) for shortened, 41% U(0.40, 0.60) for unchanged, 6% U(0.60, 0.80) for lengthened.
Q27	memory-decay-time; permanent-partner-loss-fraction	35 ticks; 0.143	Partnership memory (below codebook; decay parameter); computational scaffolding (permanent-loss parameter, SKIN partnership mechanism)	Layer 2: weighted median recovery duration approximately 105 days → 35 ticks. Permanent-loss fraction from 14.3% who reported partnerships that never recovered.
Q28	seek-compat-culture-weight	0.35	Computational scaffolding (Lambert–Knemeyer partnership scoring)	Layer 2: interpretation of response distribution. Only 8.6% named shared values as primary criterion; 34.3% reported no single dominant criterion. Weight set below default 0.50.
Q31	initial current-intention assignment	86% comply / 14% evade	B6 compliance lock-in	Layer 2: 57.1% compliance-only + 28.6% active cooperation = 85.7% ≈ 86%. Initial intention assigned at setup; recomputed every tick.
Q35	org-mil-friendliness (agent initial)	Beta(4.0, 2.1)	K4 voluntary military support	Layer 2: right-skewed shape fit to 48.6% active / 22.9% on request / 11.4% avoidance. Each civilian draws a fixed trait at setup.

Host mechanism labels with letter-number codes (such as C1, A3, or K4) identify mechanisms documented in the interview codebook. "Computational scaffolding" identifies mechanisms inherited from parent frameworks or partnership theory. "Adaptive trait (below codebook)" and "partnership memory (below codebook)" identify parameters that operate inside the adaptive-trait or partnership-scoring rules without mapping to a single named mechanism.

B.7. Validation

The survey also contributes to validation. The model is validated by running the simulation and comparing its outputs at specified time points against observed real-world patterns. Each pattern has an acceptance range: if the model output falls within that range, the criterion passes. Three survey items appear in these comparisons. Table B.5 documents each of them, showing the criterion, the acceptance band, a description of what the criterion tests, and a note on whether the band comes from the survey itself or from an independent source.

The distinction between dependent and independent bands matters for interpreting the results. For Q16 and Q27, the acceptance bands are derived from sources external to the survey: the NBU Business Activity Expectations Index for Q16, and Latin Hypercube ensemble statistics for Q27. The survey items explain why a particular pattern is expected, but they do not set the threshold the model must meet. Q31 works differently. It sets the initial compliance distribution at the start of the simulation: 86% comply, 14% evade. Every simulated day, each organization recalculates this choice based on its current conditions. The compliance share at later points in the simulation is therefore not a repetition of the starting value but a product of the model's internal dynamics. The criterion checks whether that share stays within a plausible range.

Table B.5. Survey Items Referenced in Validation Scripts

Survey item	Criterion	Band / target	Mechanism validated	Note
Q16	V7.3	pct-long-horizon > 25 at tick 200	C1 planning horizon contraction	Independent. The threshold is derived from the NBU Business Activity Expectations Index (external macro source), not from Q16. V7.3 validates recovery dynamics; the Q16 mixture sets only the starting point.

Q27	N4	count-trade-links-total ∈ [30, 300] at tick 300	Partnership memory (below codebook; motivating the deficit pattern)	Indirect. Band derived from Layer-3 LHS ensemble statistics (mean = 112), not from Q27 directly. Q27's 14.3% permanent-loss finding appears only as the motivating rationale for why a persistent post-shock deficit is expected.
Q31	V4 fitness; V4.4	pct-civilians-complying ∈ [40, 95] at tick 200 and [30, 95] at tick 400 (GA fitness); comply/evade ratio ∈ [4, 50] at tick 200 (POM)	B6 compliance lock-in	V4 fitness is robust: initial assignment is recomputed every tick by select-intention, so late-tick share is emergent rather than tautological with Q31 input. V4.4 band was widened from [2, 4] to [4, 50] to accommodate the survey-anchored 86/14 split; the criterion now tests persistence rather than level.

Criterion codes (V4.4, V7.3, N4) correspond to pattern-oriented validation experiments. "V4 fitness" refers to a target used during the automated parameter search (Layer 4 calibration). The search algorithm adjusts parameter values until the model's compliance share falls within an acceptable range, using the same logic as the validation criteria. The "Notes" column indicates whether each acceptance band is derived from the survey item itself or from an independent source.

B.8. Items Not Used for Calibration or Validation

Not every survey item was used. Eight items were collected but excluded from both calibration and validation. Table B.6 documents each of them, with a reason code and an explanation. Three codes are used. "Macro" means that a better number is available from an official source such as the State Statistics Service or the Ministry of Finance. "Sample" means that the convenience sample is too small or too unrepresentative of the Ukrainian organizational population to be used as a distribution. "Gap" means that the response distribution has no clear signal, or that no matching parameter exists in the model. Some items carry two codes because both reasons apply.

Table B.6. Survey Items Not Used for Calibration or Validation

Item	Topic	Reason	Explanation
Q2	Sector	Sample	Convenience sample is 83% services, not representative. The model uses a two-sector abstraction with uniform random assignment.
Q3	Organization size	Macro, Sample	State Statistics Service provides the Ukrainian size distribution, used directly by the model. The survey is over-weighted to medium firms.
Q6	Survival on reserves	Macro, Sample	Initial money brackets tied to State Statistics Service size brackets, not a separate survey-derived reserve distribution.
Q8	Revenue at worst point	Macro	NBU Business Activity Expectations Index provides a monthly macro trajectory used for calibration.
Q9	Staff change	Macro	Workforce attrition uses OHCHR casualty data; workforce migration uses IOM displacement data. Q9 measures a four-year net change that combines multiple processes.
Q17	Pre-invasion oblast	Sample	The spatial dimension is an abstract 51×51 grid with eight urban workforce centers from aggregate population statistics, not a geographic map.
Q24	Relocation cost	Gap	53% of relocators answered “Difficult to say.” No relocation-cost parameter exists in the model.
Q32	Mobilization workforce impact	Macro	Mobilization rate parameter derived from Ukrainian General Staff reports. Q32 describes how organizations experience mobilization, which is an emergent output.

The remaining six items serve other functions. Q1, Q4, and Q5 are consent and quality-control items. Q37 and Q38 are the open-ended questions summarized in section B.3. Q7 is a multi-select question whose distribution appears in Table B.2 but is not used to set any single parameter

B.9. Limitations and Future Development

The mapping documented in the tables above has several limitations that should be explicitly stated.

Two survey items cannot serve as independent checks on model behavior. Q13 (risk tolerance) and Q35 (military friendliness) are used to set starting values, but the model does not update these traits during the simulation. Each organization keeps the value it was assigned at setup. If the model were tested against the Q13 or Q35 distributions at the end of a run, it would return the same distributions it received, which would not be informative. Q16 (planning horizon) raises a related concern: the model updates the planning horizon, but the survey response is still used both to set the starting value and as a comparison target, so the two roles are not fully separated.

The open-ended responses in section B.3 revealed three further limitations. Pre-invasion preparation and prior crisis experience (J3 in Table B.3) is supported by both the interviews and the survey, but the model does not implement a rule that gives prior crisis experience an advantage. An international client base or foreign parent company falls outside the scope of the current model, which represents trade only among Ukrainian organizations. Staff cohesion and employee dedication are represented only at the population level through a uniform attrition rate, without variation across individual organizations.

None of these limitations changed any pass-or-fail result reported in the calibration and validation chapter. The final calibration step adjusts several weights that combine the model's inputs, thereby absorbing any bias introduced by the survey-based starting values. Three currently failing criteria, V1.1, V4.4, and V7.2, can be partly explained by this bias in addition to the explanations already given. No currently passing criterion is affected.

Several of these limitations point to concrete directions for future development. Adding update rules for risk tolerance and military friendliness would allow Q13 and Q35 to serve as independent comparison targets rather than starting values only. The starting values would then come from a separate pre-invasion source, or they could be added to the parameters that the calibration adjusts automatically. Implementing a pre-crisis adaptation rule and adding per-organization variation in employee retention would extend the model into areas where both the interviews and the survey produced supporting evidence.

APPENDIX C

ODD MODEL DESCRIPTION

The model's "Organizational Adaptation Under Warfare (V1.01)" description follows the ODD protocol for describing agent-based models (Grimm et al., 2006), as updated by Grimm et al. (2020).

Section C.1 states the model's purpose and the empirical patterns it must reproduce. Section C.2 documents the entities, state variables, and scales. Section C.3 describes the twelve-phase tick schedule. Section C.4 presents the design concepts. Section C.5 specifies initialization. Section C.6 covers input data. Section C.7 documents the submodels grouped by functional role.

C.1. Purpose and Patterns

C.1.1. Purpose

The general purpose of the model is explanation and theoretical exposition. It investigates the mechanisms of organizational adaptation to social disruption caused by a full-scale armed invasion, using wartime Ukraine since February 2022 as the empirical reference system. The model formalizes 27 empirically identified mechanisms, drawn from 37 semi-structured interviews (2022–2023) and a CAWI survey (n = 35, February 2026), into 38 computational rules. These rules are used to explore how formal institutional (organizational) and informal self-organizational pathways of adaptation interact under sustained warfare.

The overarching research question is: how do organizational and self-organizational pathways interact under sustained warfare, and under what conditions does each pathway sustain or undermine organizational survival? The model addresses two supporting questions directly. RQ3 asks under what conditions the organizational pathway enhances adaptation, under what conditions it suppresses self-organizational adaptation, and where the threshold between the two lies, as well as how different pre-invasion configurations of the organizational/self-organizational balance shape resilience trajectories. RQ4 asks where the viability boundaries of the organizational/self-organizational system lie and whether the wartime shift in their balance is reversible.

The model draws on fifteen sources. Six are established agent-based models: SugarScape (Epstein & Axtell, 1996), the Hammond–Axelrod ethnocentrism model (Hammond & Axelrod, 2006), ASSOCC (Dignum et al., 2020), WorkSim (Goudet et al., 2017), SKIN (Gilbert et al., 2001), and Epstein's organizational-dynamics model (Epstein, 2003). Two are modeling architectures: the BDI/BEN decision cycle (Bourgais et al., 2020) and MBSSM (Vu et al., 2020). Seven are theoretical frameworks: population ecology (Hannan & Freeman, 1984), institutional theory (DiMaggio & Powell, 1983), disaster response (Quarantelli, 1997), dynamic capabilities (Teece et al., 2007), emergency network theory (Lambert & Knemeyer, 2004; Larson, 2012; Hung et al., 2004), social capital theory (Watts & Strogatz, 1998; Aldrich, 2012; Centola & Macy, 2007), and crisis-agency theory (Bevzenko, 2022). The 38 model rules are classified by pathway: organizational (O), self-organizational (SO), or bridging (B), following the crisis-agency framework. Appendix D, Table D.2 lists all 38 rules.

C.1.2. Patterns

The model is evaluated by its ability to reproduce empirical patterns drawn from Ukrainian wartime data. Patterns are organized by validation domain.

Displacement and workforce dynamics. Organizations relocate westward as the threat front advances, with well-connected organizations resisting relocation longer due to trade-link anchor effects (Aldrich, 2012). Workforce outflow rate greatly exceeds the return rate, producing rapid depletion during threat advance and slow recovery during stabilization. Permanent diaspora loss prevents full recovery.

Business survival and economic dynamics. Front-zone organizational populations collapse by 70–90%, reproducing enterprise closure rates documented in frontline oblasts.

Rear-zone financial disparity emerges between origin and destination communities. Civilian births through splitting and spontaneous founding partially replace organizational deaths.

Military structure and government fiscal trajectory. Military unit count and aggregate combat power emerge from the tension between attrition and mobilization, with a replenishment-before-creation pipeline priority. Government institutional capacity rises from near-zero during initial invasion chaos to moderate levels, following an empirically grounded fiscal trajectory.

Infrastructure damage and Jungle–Zoo dynamics. Cumulative infrastructure damage creates persistent spatial scarring that outlasts the front's passage. Decentralized civilian–military cooperation (the Jungle pattern) emerges under threat with weak government; centralized specialization (the Zoo pattern) re-emerges as safety and government capacity recover.

Cultural dynamics, planning horizon, and network structure. Cultural tags converge within interaction networks, generating spatially patterned trust clusters. Planning horizons contract under sustained crisis and recover with a population-level ceiling, reproducing the survey finding that approximately 40% of organizations never recovered their pre-invasion planning horizons. Trade networks fragment during displacement and rebuild through partnership formation, trust accumulation, and hub brokering.

C.2. Entities, State Variables, and Scales

C.2.1. Entities

The model contains four entity types and five breeds of network links. A summary of the model's key attributes is provided in Table C.1. The model does not represent the opposing forces directly; instead, the war's effects enter through an exogenous environment comprising the moving threat front, stochastic rear-area strikes, and the nine-phase scenario schedule.

Table C.1. Model summary

Attribute	**Value**
Spatial scale	51 × 51 patch grid (abstract landscape)
Temporal scale	1 tick = 3 days; 300 ticks ≈ 2.5 years
Agent population	800 civilians, 120–140 military, 1 government
Network layers	5 link breeds (trade, supply, requisition, coordination, long-tie)
Model rules	38 (27 interview-testable + 11 computational scaffolding)
Structural toggles	cultural-transmission?, trust-enabled?, reputation-enabled?, hub-brokering-enabled?, long-ties-enabled?
Society presets	5 (baseline, total-defense, decentralized, centralized, dual-economy)
Configurations	5 presets × 2^5 toggles = 160

The model's 38 rules are each governed by a corresponding set of 38 numerical parameters: slider weights, activation thresholds, decay rates, and trait-update coefficients. The two counts coincide because each rule is controlled by a single tunable parameter that determines its operational behavior at simulation time. This is the same set of 38 parameters that the Morris elementary effects screening in Appendix D, Section D.10, ranks by influence; the parameter inventory and rankings are reported in Appendix D, Table D.8.

Figure C.1 summarizes the four entity types, their key state variables, and the five link breeds connecting them.

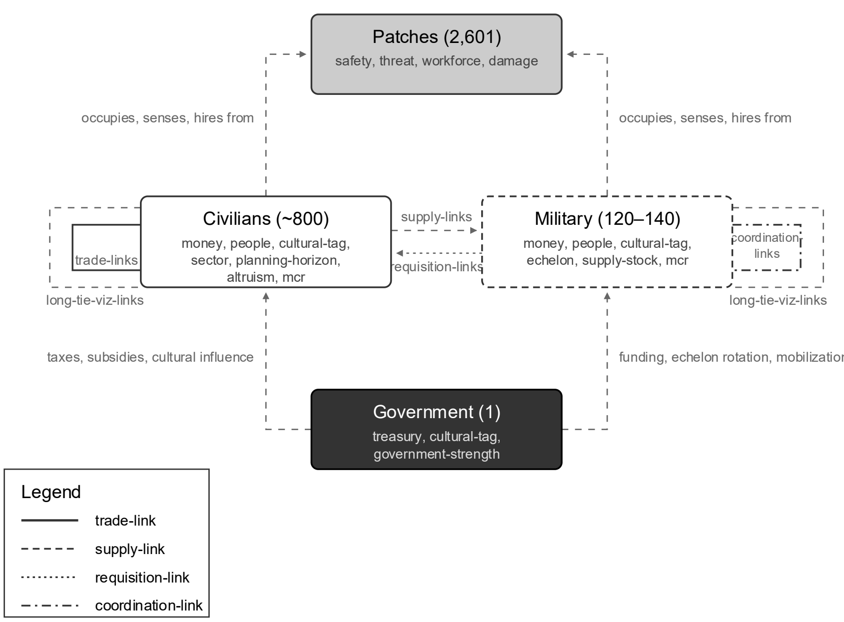

Figure C.1. Entity types and link breeds

Patches represent spatial units of an abstract landscape. Each patch holds environmental state for safety, threat level, workforce availability, cumulative infrastructure damage, and disaster effects. Eight urban-center workforce peaks create an asymmetric economic geography with higher density in the west, roughly corresponding to Ukraine's population distribution.

Civilian organizations are the primary agents, each representing a commercial entity that engages in production, bilateral trade, tax payment, and under crisis conditions may relocate to safer territory or expand into military-support functions. Each civilian carries approximately 35 state variables spanning financial resources, workforce, sector (goods or services), an 11-bit cultural tag governing interaction preferences, structural traits (flexibility, hierarchy), two adaptive traits (planning horizon, altruism), a mil-civ-ratio index that controls behavioral blending between civilian and military roles, partner memory with trust levels, and a simplified BDI cognitive state. The civilian population is dynamic: new organizations enter through splitting and spontaneous founding, while existing ones exit through resource depletion or sustained exposure to danger.

Military organizations represent brigade-level formations that enhance local safety through their presence, share situational awareness with other units, extract supplies from nearby civilians, and rotate through a three-tier echelon system (front, operational, reserve). Their state variables largely overlap with civilians but additionally include echelon assignment, a cooperativeness index toward civilians, and lists of long-tie partners for cross-front information exchange. The military population grows through government-managed mobilization and shrinks through combat losses.

The government is a singleton super-agent responsible for taxation, subsidy distribution, military funding, the personnel pipeline (recruitment, replenishment, unit creation, echelon rotation), and cultural broadcasting. It is positioned in the administrative rear and operates on all agents globally. Its institutional capacity (government-strength) follows a phase-driven schedule, rising from near-zero during the initial invasion chaos to moderate levels as the state reconstitutes.

Network links connect organizations through five typed breeds. Trade-links form between civilian organizations that exchange goods or services. Supply-links form between compliant civilians and nearby military units through voluntary provision. Requisition-links form when military units forcibly extract resources. Coordination-links form between military units with similar norms. Long-tie-viz-links visualize preserved long-distance partnerships after displacement. All links carry weight (cumulative volume), recency (last-active-tick), and frequency (interaction-count).

C.2.2. State Variables

Patch state variables are listed in Table C.2.

Table C.2. Patch state variables

Variable	**Type**	**Range**	**Description**
workforce-pool	Float	≥ 0	Available hireable population
workforce-capacity	Integer	≥ 2	Maximum workforce from urban-center peaks
initial-workforce-capacity	Integer	≥ 2	Original capacity ceiling for recovery
base-safety	Float	0–1	Structural safety from distance to east edge
threat-level	Float	0–1	Current warfare threat; diffused from front
military-bonus	Float	≥ 0	Safety from military presence and coordination
safety	Float	0–1	Effective composite safety
local-threat-front	Float	map x	Per-patch front position estimate
disaster-boost	Float	≥ 0	Temporary safety reduction from strikes
cumulative-damage	Float	0–1	Long-term infrastructure damage
patch-attractiveness	Float	≥ 0	Cached workforce-migration attractiveness

Table C.3 lists the state variables shared by all organization breeds (civilians, military, government).

Table C.3. Common organization state variables shared by all breeds

Variable	**Type**	**Range**	**Description**
money	Float	≥ 0	Financial reserves

Variable	Type	Range	Description
prev-money	Float	≥ 0	Money at previous tick
people	Integer	≥ 0	Workforce count
sector	String	–	“goods”, “services”, or “none” (military)
cultural-tag	List	11 binary	Cultural group identity
org-flexibility	Float	0–1	Structural flexibility
org-hierarchy	Float	0–1	Government alignment
goods-stock	Float	≥ 0	Goods inventory
services-stock	Float	≥ 0	Services inventory
supply-stock	Float	≥ 0	Defense supply inventory
production-output	Float	≥ 0	Last tick’s production
mil-civ-ratio	Float	0–1	Civilian–military behavioral permeability
planning-horizon	Float	0–1	Temporal depth of decision-making
altruism	Float	0–1	Egoism–altruism spectrum
safety-history	List	up to 10	Sliding window of safety readings
financial-history	List	up to 10	Sliding window of money readings
belief-safety	Float	0–1	Perceived safety
belief-financial-trend	Integer	−1, 0, +1	Financial trend
current-intention	String	–	Selected intention for current tick
partner-memory	List	–	[agent, age, trust] triples
vision-range	Integer	≥ 1	Observable patch radius

Civilian-only state variables (additional to the common ones in Table C.3) are listed in Table C.4.

Table C.4. Civilian-only state variables

Variable	Type	Range	Description
risk-tolerance	Float	0–1	Safety vs. profit trade-off
origin-x	Integer	map x	X-coordinate at creation
relocation-penalty	Float	0–1	Post-relocation efficiency loss
org-mil-friendliness	Float	0–1	Willingness to supply military
belief-partner-reliable?	Boolean	–	Whether partner-memory is non-empty
network-info-safety	Float	0–1	Blended own + partner safety
domain-expanded?	Boolean	–	Whether hybrid functions created
pre-reloc-degree	Integer	≥ 0	Trade-link count before relocation
pre-reloc-trust-sum	Float	≥ 0	Trust sum before relocation
ticks-since-relocation	Integer	≥ −1	Time since last relocation

Variable	Type	Range	Description
long-tie-partners	List	–	Preserved distant partners

Military-only state variables (additional to the common ones in Table C.3) are listed in Table C.5.

Table C.5. Military-only state variables

Variable	Type	Range	Description
risk-tolerance	Float	0–1	Advance vs. defend preference
org-civ-friendliness	Float	0–1	Cooperativeness toward civilians
mil-echelon	String	–	“front”, “operational”, or “reserve”
mil-long-tie-partners	List	–	Garrison partners preserved on deployment
ticks-on-front	Integer	≥ 0	Front service time since promotion

Government-only state variables are listed in Table C.6.

Table C.6. Government-only state variables

Variable	Type	Range	Description
belief-workforce	Float	≥ 0	Total workforce across patches
belief-economy	Float	≥ 0	Average civilian money-to-people ratio
prev-safety / prev-workforce / prev-economy	Float	various	Previous-tick values for trend detection
belief-safety-trend / belief-workforce-trend / belief-economy-trend	Integer	−1, 0, +1	Trend indicators

Link state variables, common to all five link breeds, are listed in Table C.7.

Table C.7. Link state variables (all five breeds)

Variable	Type	Range	Description
link-weight	Float	≥ 0	Cumulative volume transferred
last-active-tick	Integer	≥ 0	Tick of most recent interaction
interaction-count	Integer	≥ 0	Number of recorded interactions

Approximately 200 global parameters govern scoring weights, thresholds, rates, and calibration constants.

C.2.3. Scales

Spatial scale. The model uses a 51 × 51 grid (x: −25 to +25, y: −25 to +25) with no wrapping. The landscape represents an abstract east-to-west geography loosely mapped to Ukraine: the eastern edge represents the initial contact line, and safety increases toward the west. Eight urban-center workforce peaks are distributed asymmetrically with higher capacity in the west. The abstraction captures the directional structure of the war rather than specific geographic coordinates.

Temporal scale. Time proceeds in discrete ticks. One tick represents approximately three days. The default simulation runs for 300 ticks (approximately 2.5 years), after which a frozen-conflict phase begins with zero front movement.

Population scale. One model person corresponds to approximately 189 real people (derived from the military-people-cap of 4,800 representing approximately 907,000 total military headcount). The 800 civilian organizations map to Ukraine's commercial sector at roughly 1:400, with size classes drawn from national enterprise statistics (86% micro, 9.5% small, 4.4% medium, 0.1% large). The 120–140 military organizations correspond to Ukraine's approximately 130 brigade-equivalent formations. The agent count is constrained by the experimental program: running 160 structural configurations with 30 replications each requires a population small enough for tractable computation.

C.3. Process Overview and Scheduling

Each tick, the model executes twelve phases in fixed order. Agents execute in random order within each phase (the NetLogo default). The government acts unconditionally each tick without stochastic intention selection. Figure C.2 shows the twelve phases grouped into three functional blocks: Perceive (Phases 1–3), Decide and Act (Phases 4–5), and Update and Record (Phases 6–12).

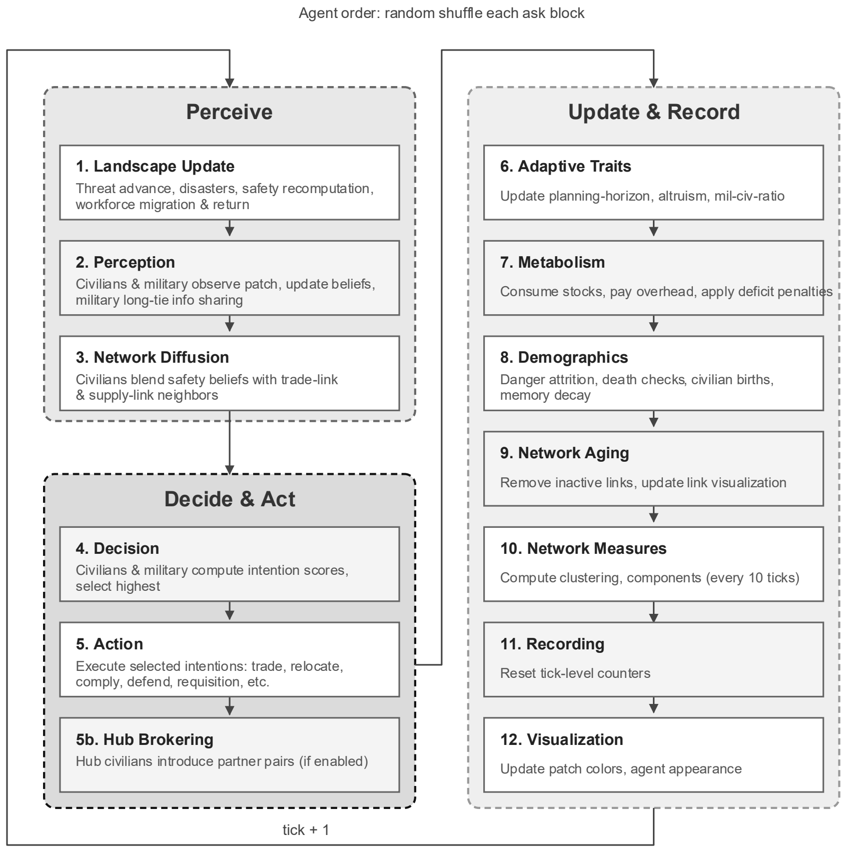

Figure C.2. Twelve-phase tick execution sequence

Phase 1: Landscape update. The model checks whether the current war phase's end-tick has been reached and, if so, advances to the next phase and updates government-strength. Each patch's front position is then updated using a weighted average of its own value (threat-smooth-self = 0.9) and the mean of its Moore neighbors (threat-smooth-neighbor = 0.1), plus global drift and uniform random jitter drawn from [−2, +2]. The resulting front is smooth but spatially heterogeneous. Threat is seeded at 1.0 east of the front and spatially diffused in two passes (coefficient 0.35). Stochastic disasters occur with probability dependent on a base rate plus phase intensity, subject to a five-tick cooldown. Thirty percent of strikes target deep-rear urban centers; the remainder target the front zone. Each strike damages organizations and workforce within the blast radius, adding to both a temporary disaster-boost layer (decaying at 8% per tick) and a permanent cumulative-damage layer. Effective patch safety is then recomputed as:

$$\text{safety} = \text{clamp}_{01}(\text{base-safety} - \text{threat-level} + \text{military-bonus} \times 0.1 - \text{disaster-boost} - \text{cumulative-damage} \times 0.8)$$

where base-safety is a linear gradient from 0.0 at the east edge to 1.0 at the west, and military-bonus is an inverse-distance gravity field projected by nearby military units and militarized civilians. Coordinated military pairs with cultural similarity above 0.4 contribute a superlinear safety amplification bonus. Workforce migration follows: workers on patches with threat exceeding 0.30 flee into a national transit buffer at rate 0.27, following a quadratic flight function of threat level ($f(T) = \text{wf-migration-quad-a}(-0.91) \times T^2 + \text{wf-migration-quad-b}(1.37) \times T$). Each tick, 1.0% of the transit buffer is permanently lost to diaspora emigration, and approximately 9.7% attempt return to safe patches through a gravity-based allocation model. Safe patches slowly recover workforce capacity.

Phase 2: Perception. Each civilian organization updates its beliefs: local safety from the current patch, financial trend by comparing money to its previous-tick value, and partner reliability from partner-memory. Values are appended to 10-tick sliding history windows. Each military organization updates its belief-safety from the local threat level (a direct observation, unlike civilians who observe derived safety) and updates its echelon assignment based on doctrinal rules. This information asymmetry means that military units detect approaching danger earlier and more specifically than civilians.

Phase 3: Network information diffusion. Each civilian computes network-info-safety as 70% own belief-safety plus 30% mean belief-safety of all agents connected through trade-links and supply-links. Civilians with supply-links to military units receive military belief-safety values based on direct frontline threat observation, providing earlier warning of approaching danger. This blended safety signal is used for the relocation threshold decision, creating an information advantage for well-connected organizations and explaining why they resist panic relocation longer.

Phase 4: Intention selection. Before competitive scoring, two priority overrides are tested. The relocation override fires when the civilian’s network-blended safety falls below a personalized threshold: threshold = 0.2 + (1 − risk-tolerance) × 0.3, ranging from 0.2 for the most risk-tolerant to 0.5 for the most risk-averse. A network anchor term (min(0.15, trade-link-count × 0.03)) stabilizes well-connected agents: roughly five trade partners are needed before the anchor materially raises the effective threshold. The return-home override fires when the origin has recovered sufficient safety and the organization has adequate resources. If neither override fires, seven intentions compete on numerical scores: operate, seek-partner, comply, evade, support-defense, support-civilian, and defend. Each score combines the agent's beliefs, structural traits, and adaptive traits with rule-specific weights. The highest-scoring intention is selected. Planning-horizon modulates scoring: short-horizon agents react to immediate conditions, medium-horizon agents incorporate 10-tick trend slopes, and long-horizon agents additionally assess global landscape safety. Figure C.3 shows the complete civilian decision cycle, including the two reactive overrides, the seven scored intentions, planning-horizon modulation, and the domain expansion check.

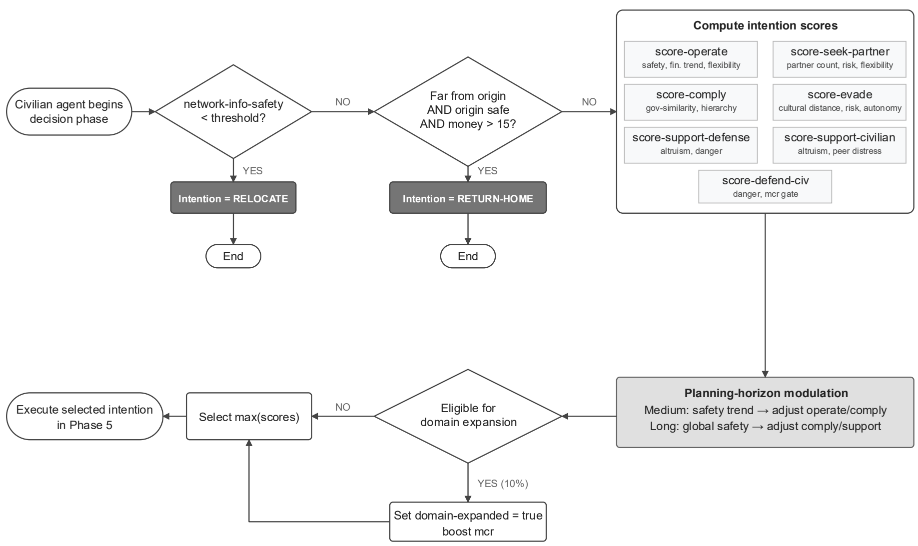

Figure C.3. Civilian intention selection cycle

Each military unit scores echelon-gated intentions. Front units evaluate defend, advance, withdraw, coordinate, requisition, and support-government. Operational units evaluate stage and withdraw. Reserve units evaluate garrison. The highest score wins.

Phase 5: Action execution. Each civilian executes its selected intention. During the operate intention, organizations produce goods or services, trade with remembered partners via geometric-mean pricing (Epstein and Axtell, 1996), conduct long-tie trade with preserved distant partners at reduced volume, and divert revenue to expanded domain functions if applicable. The seek-partner intention scores candidates on a multiplicative compatibility × complementarity composite (Lambert & Knemeyer, 2004), initializes trust through the three-route model (Hung et al., 2004), and processes reputation referrals. Phase-sensitive scoring modulates which dimension dominates: short-horizon agents receive a complementarity boost, long-horizon agents a compatibility boost, testing Larson's (2012) prediction computationally. The relocate intention selects a destination from visible safe patches, records a social capital snapshot (pre-relocation degree and trust sum), and preserves the highest-trust partner as a long-tie. Comply and evade represent the normative engine: compliant civilians pay full tax, converge culturally toward the government, and drift toward higher hierarchy; evading civilians pay half tax, counter-conform culturally, and drift toward lower hierarchy and higher flexibility. Support-defense and support-civilian transfer resources to military units or distressed neighbors respectively. Domain expansion is a one-time irreversible transition to hybrid civilian–military function, triggered probabilistically when altruism exceeds 0.4.

Each military unit executes its selected intention: defending, advancing, withdrawing, staging, garrisoning, requisitioning from local civilians, coordinating with culturally similar nearby units (sharing situational awareness and converging structural traits), or supporting the government.

The government then executes unconditionally. Taxation extracts revenue at a rate of 0.27 (matching the Ukrainian mean corporate income tax rate), scaled by government-strength and local safety, with evading civilians paying half. Subsidies go to distressed civilians in safe zones, weighted by cultural similarity. Military funding is allocated across echelons with front-weighting. The mobilization pipeline uses stochastic recruitment (Poisson, mean 25 per tick) to fill a national recruit pool; replenishment follows a deficit-weighted priority (most under-strength units receive personnel first); new units are created only when no existing unit is critically under-strength, matching the Ukrainian General Staff's decision to prioritize replenishment over new brigade formation. A spending floor decouples fiscal expenditure from institutional capacity during crisis phases. Figure C.4 traces the military personnel pipeline from the national workforce through the recruit pool, reserve replenishment, and echelon rotation to front-line deployment and death.

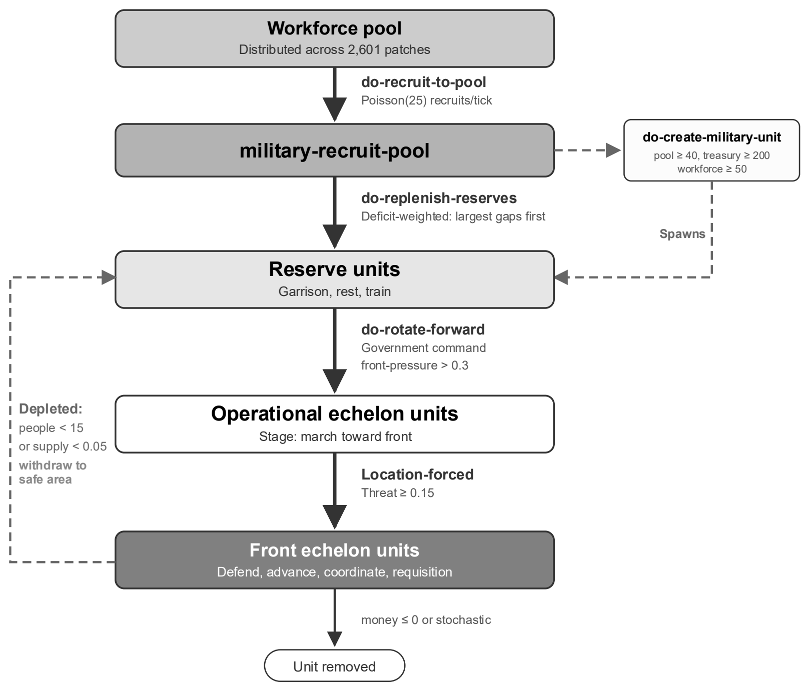

Figure C.4. Centralized military personnel pipeline

Hub brokering follows government actions: civilians whose total degree across trade-links and supply-links meets or exceeds a threshold (default 5) introduce pairs of their trade partners to each other, adding mutual partner-memory entries with discounted swift trust.

Phase 6: Adaptive trait update. Planning horizon contracts by 0.015 per tick when both the safety-history slope and the financial-history slope are simultaneously negative (sustained dual crisis). It expands by 0.004 per tick when both trends are simultaneously non-negative (recovery), subject to a population-level soft ceiling of approximately 0.70 that stochastically gates recovery. This asymmetry produces faster contraction than recovery, matching the empirical trajectory. Altruism increases by 0.015 per tick when three conditions co-occur: non-positive financial trend, local safety below 0.4, and two or more nearby civilians visibly distressed. It decays by 0.003 otherwise. The mil-civ-ratio updates through four mechanisms: crisis militarization (low safety and weak government raise it), action-driven drift (defense behaviors increase it further), supply-deficit decay (unsustainable defense lowers it), and peace dividend (high safety lowers it).

Phase 7: Metabolism. Organizations consume goods-stock and services-stock at a rate scaled by local safety, pay flat money overhead, and suffer people and money penalties for deficits. Military units consume supply-stock and pay echelon-differentiated operating costs.

Phase 8: Demographics. Organizations on low-safety patches lose people stochastically (danger attrition). Organizations with money ≤ 0 or people ≤ 0 die; their workforce returns to the local patch pool. Civilians above resource thresholds may split (15% probability per tick), creating offspring with 40% of resources and mutated traits. New organizations may also be founded on safe, workforce-rich patches. Partner-memory entries age, trust decays by 0.002 per tick, and entries exceeding 35 ticks are removed. When a partner dies, 14.3% of the surviving agent's partner-memory slots are permanently destroyed, modeling irreversible network scarring.

Phases 9–12. Links older than 35 ticks are removed (Phase 9). Clustering coefficient, component count, and mean path length are computed every 10 ticks (Phase 10). The migration-flow counter is reset (Phase 11). Patch colors and agent appearances are refreshed (Phase 12). The tick counter increments after Phase 12.

C.4. Design Concepts

C.4.1. Basic Principles

The model synthesizes mechanisms from multiple theoretical sources, each mapped to specific computational mechanisms and classified by its role in the crisis-agency framework. Table C.8 summarizes these mappings.

Table C.8. Theoretical sources and their model mechanisms

Source	**Mechanism in model**	**Pathway**
SugarScape (Epstein & Axtell, 1996)	Spatial resources, bilateral trade, cultural tags, threat front	B
SKIN (Gilbert et al., 2001)	Complementary-capability partnerships, partner memory	SO
BEN (Bourgais et al., 2020)	Simplified BDI cognitive cycle (perceive → decide → act)	B
ASSOCC (Dignum et al., 2020)	Multi-need decision architecture	B
Hammond and Axelrod (2006)	In-group favoritism via cultural similarity weights	SO
WorkSim (Goudet et al., 2017)	Institutional rules as binding constraints (taxation, mobilization)	O
Lambert and Knemeyer (2004)	Multiplicative compatibility × complementarity partnership scoring	SO
Larson (2012)	Phase-sensitive partnership strategy	SO
Hung et al. (2004)	Three-route trust (swift, earned, habitual)	SO
Aldrich (2012), Burt (2005)	Social capital destruction, brokerage, recovery	SO
Watts and Strogatz (1998), Centola and Macy (2007)	Small-world rewiring, complex contagion constraint	SO
Bevzenko (2022)	Planning horizon, altruism (crisis-agency theory)	B

Note. Pathway: O = organizational, SO = self-organizational, B = bridging.

ASSOCC (Dignum, 2021; Dignum et al., 2020) models how people and organizations balance competing priorities during the COVID-19 pandemic. Rather than maximizing a single utility function, agents pursue a hierarchy of needs (Maslow, 1943): survival, safety, belonging, esteem, and self-actualization. Context determines which need dominates. ASSOCC demonstrates that health, social, and economic dynamics cannot be modeled separately because individual decisions depend on all three simultaneously. For the present model, ASSOCC's core contribution is the principle that crisis agents must score competing needs rather than optimize a single objective. Organizations in ASSOCC, however, do not reorganize their internal structures in response to a crisis.

Epstein (2003) addresses this gap. His model asks whether simple behavioral rules can cause organizations to spontaneously generate optimal structures. Workers and managers follow local rules in a dynamic environment of flowing opportunities; hierarchies form and dissolve without central planning. When organizations balance profit and market share simultaneously, they oscillate between flat and hierarchical structures in a recurring pattern Epstein calls a "traveling wave" (Epstein, 2003, p. 13). For the present model, the contribution is the treatment of structural traits (flexibility, hierarchy) as continuous variables that drift through interaction rather than fixed categories.

SugarScape (Epstein & Axtell, 1996) shows how markets emerge from bilateral exchange without central coordination. Agents with different resource endowments and metabolism rates trade when both can benefit, with prices set at the geometric mean of their internal valuations. SugarScape also introduces the cultural tag mechanism: agents carry binary identity strings that influence cooperation decisions, producing emergent cultural clustering from local interaction. Contributions to the present model include the spatial resource landscape, bilateral trade mechanics, demographic rules (death by resource depletion, birth by splitting), and the cultural tag system. SugarScape's agents are, however, purely reactive, following condition-action rules without internal beliefs or competing goals.

Hammond and Axelrod (2006) investigate how cooperation emerges among agents with different group identities. Agents carry a binary tag indicating group membership and can either cooperate or defect with their neighbors. Ethnocentrism (cooperating with in-group members while defecting against out-group members) dominates all other strategies without requiring reciprocity, reputation, or strategic calculation. For the Ukrainian wartime context, where cultural identity shapes inter-organizational trust and cooperation, this provides a computationally tested foundation for group-based partner selection. The contribution to the present model is the ethnocentric weighting of partner selection (preferential cooperation with culturally similar partners), which is layered on top of the 11-bit tag mechanism inherited from SugarScape.

SKIN (Gilbert et al., 2001) models how firms innovate through learning and partnerships. Knowledge is represented as structured triples of capability, skill, and expertise. Successful partnerships renew because positive experiences build trust; multiple firms can pool knowledge to form innovation networks. Contributions include the complementary-capability partnership logic, the partner memory mechanism, and the reputation-referral chain. SKIN's partnership dynamics unfold in a stable innovation environment; however, not under conditions of forced displacement and network destruction.

WorkSim (Goudet et al., 2017) models employment flows at the institutional level. Workers move between contract types, unemployment, and inactivity; firms hire based on bounded-rational demand forecasts. An accounting framework tracks every worker's movement between states. Contributions include the principle that government fiscal and regulatory constraints are binding: taxation, subsidies, and mobilization are not optional features but non-negotiable institutional rules that shape what organizations can do.

Structural traits (flexibility, hierarchy) are dynamic variables that drift through interaction: trade converges traits between partners at a 3% blend rate, compliance pushes hierarchy upward, and evasion pushes hierarchy downward while raising flexibility. This blend rate is intentionally slower than the per-interaction cultural tag-flipping, so that values align quickly while organizational structures change gradually.

The 38 model rules jointly produce 28 causal pathways, distinct from the 27 interview-testable mechanisms, classified by their position in the Coleman boat: 4 situational (macro-to-micro), 13 action (micro-to-micro), 6 transformational (micro-to-macro), 4 feedback, and 1 systemic (network percolation threshold). The crisis-agency pathway classification (O/SO/B) cross-cuts the MBSSM classification: a situational mechanism can be organizational (the fiscal cycle) or self-organizational (disaster cascading), and a transformational mechanism can be self-organizational (cultural convergence through tag-flipping) or bridging (structural homogenization through institutional drift). The complete mechanism inventory with both classifications appears in the dissertation body.

C.4.2. Emergence

Several system-level patterns emerge from individual-level rules without being directly imposed: westward migration waves, emergency trade network topology, phase-dependent partnership composition, cultural clustering and trust stratification, the government–organization relationship spectrum (comply vs. evade), Jungle/Zoo regime dynamics, emergent hub coordinators, social capital destruction and small-world rewiring, planning horizon population distribution, military force structure, and workforce spatial distribution. Two elements are imposed: the threat front direction and intensity follow the exogenous scenario schedule, and government-strength follows a phase-driven trajectory. However, a spending floor decouples fiscal expenditure from institutional capacity when government-strength is below the floor, making the fiscal and mobilization consequences of the capacity trajectory emergent.

This pattern corresponds to mechanism D2 (Jungle-to-Zoo transition) in Appendix A's codebook and is tested empirically by experiment B10 (Behavioral Permeability) in Appendix E, Section E.4.

C.4.3. Adaptation

Organizations adapt through four mechanisms. Intention selection is the primary mechanism: each tick, each agent evaluates scoring functions for available intentions, producing behavioral differentiation even among agents with identical traits because local conditions vary. Two endogenous adaptive traits change in response to sustained conditions: planning horizon contracts under dual crisis and expands during recovery, while altruism rises under institutional failure combined with peer distress. The mil-civ-ratio governs behavioral permeability between civilian and military functions through four interacting feedback loops. Together, these produce the emergent Jungle/Zoo regime dynamics. Figure C.5 maps the four MCR feedback loops: crisis militarization, action-driven drift, domain expansion, and three demilitarization channels, – onto the Jungle–Zoo spectrum.

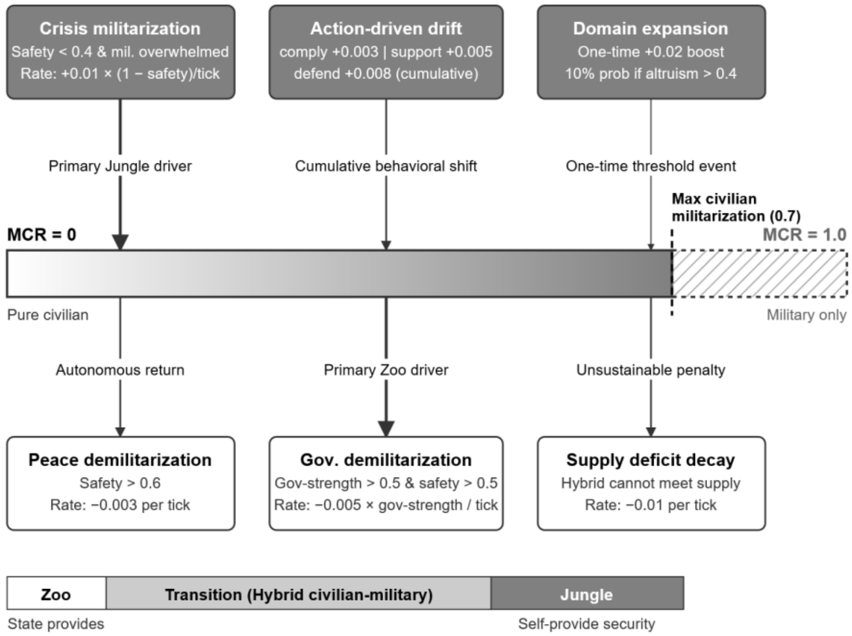

Figure C.5. MCR drift mechanisms and the Jungle–Zoo spectrum

Structural traits drift through interaction (trade blends traits between partners; compliance and evasion shift hierarchy). Domain expansion is a one-time irreversible transition to hybrid civilian–military function, modeling the wartime creation of new organizational functions.

C.4.4. Objectives

Organizations do not maximize an explicit utility function. Civilians use multi-criteria scoring that implicitly encodes competing objectives: economic production, partnership building, institutional alignment, tax avoidance, collective defense, and mutual aid. These objectives frequently conflict: a culturally distant, risk-tolerant organization may score highly on both operate and evade, with local safety determining the winner. Military objectives are echelon-gated. The government follows fixed rules parameterized by government-strength and cultural preference. Survival is emergent: organizations that select intentions appropriate to local conditions tend to survive; those in sustained danger with inadequate resources or networks tend to die.

C.4.5. Learning

Partner memory constitutes experiential learning: successful interactions create or refresh “agent, age, trust” entries. Trust accumulates through repeated transactions (0.08 per trade), decays during inactivity (0.002 per tick), and is initialized via swift-trust computation from categorical cues (cultural similarity, sector match). Habitual partners (trust > 0.8) bypass neighborhood search, committing resources to proven relationships. Adaptive traits constitute population-level learning: planning horizon learns whether the environment demands reactive survival or permits strategic thinking, while altruism learns that mutual aid is necessary when the state cannot provide.

C.4.6. Prediction

The planning horizon creates a gradient from purely reactive (short, < 0.33) to locally predictive (medium, 0.33–0.66) to globally strategic (long, > 0.66). Short-horizon agents react to immediate conditions only. Medium-horizon agents additionally use 10-tick trend slopes: deteriorating safety discounts the operate score and boosts compliance. Long-horizon agents additionally compute global landscape mean safety, boosting defense-oriented scores when the entire landscape is in crisis. The gradient is endogenous: agents under sustained crisis acquire prediction capabilities they did not have at initialization. No agent models other agents’ future behavior.

C.4.7. Sensing

Every organization observes its current patch’s safety and its own financial state. Vision-range (default 3 patches, +2 for organizations with more than 20 people, +2 for hub-status civilians) determines the spatial extent of partner search, destination evaluation, and military movement. Civilians compute network-info-safety by blending own safety with partner-reported safety, extending effective sensing beyond physical location. Military units observe raw threat directly, giving them earlier and more specific danger information than civilians, who observe derived safety. The government perceives aggregate beliefs by averaging across all patches and all civilians, reflecting a system-level intelligence apparatus lagged by one tick.

C.4.8. Interaction

Eight categories of direct interaction operate in the model. Bilateral trade between civilians drives economic exchange, network formation, trust accumulation, cultural convergence through tag-flipping, and structural homogenization through trait blending. Long-tie trade extends this to displaced partners at reduced volume, carrying only simple contagions (resources, information, safety beliefs) but not complex ones (cultural and structural influence), following the Centola and Macy (2007) constraint. Voluntary supply from civilians to military builds civilian–military trust and creates supply-links; the government reimburses 50%. Involuntary requisition by front-echelon military extracts resources from nearby civilians, modulated by cultural compatibility and the unit's cooperativeness. Military coordination between culturally similar units shares situational awareness and converges structural traits, with coordinated pairs producing a superlinear safety amplification bonus. Garrison social contact builds passive coordination between co-located reserve units. Government taxation is unconditional (civilians can only evade to reduce it by half). Hub brokering by high-degree civilians introduces partner pairs, facilitating future trade.

C.4.9. Stochasticity

Stochasticity enters through initialization (heterogeneous populations, spatial placement, cultural tags), environmental dynamics (threat jitter, disaster occurrence and targeting), agent ordering (NetLogo random ask), demographics (splitting probability, recruitment, domain expansion, cultural tag mutation), and decision inputs (workforce competition from randomly ordered hiring, partner availability from vision-range at time of search).

C.4.10. Collectives

The government is a structurally imposed singleton whose institutional capacity varies by phase. Cultural groups are emergent collectives defined by tag-sum thresholds: organizations with 3 or fewer 1s in their 11-bit tag belong to group 0 ("traditionalist"), 4–7 to group 1 ("pragmatist"), and 8 or more to group 2 ("adaptive"). Military echelons are a structurally imposed classification determining available intentions and funding priority. Hub coordinators are emergent: civilians whose total degree meets or exceeds the threshold gain enhanced vision and broker introductions. Trade network components are emergent collectives identified analytically every 10 ticks.

C.4.11. Observation

Data for testing the model is collected through five categories of reporters. Population and demographic reporters track organizational counts, deaths, and births. Economic reporters track financial health, production, workforce utilization, and fiscal state. Behavioral intention reporters track the aggregate distribution of civilian intentions each tick. Spatial reporters track front position, zone populations, and zone-partitioned trait averages. Network and cultural reporters track clustering coefficient, component count, path length, trust levels, cultural diversity, and the Jungle/Zoo regime classification. All reporters are available as BehaviorSpace output variables for systematic parameter sweeps. Interface plots provide real-time visualization for qualitative pattern recognition during exploratory runs.

The interface provides seven visualization modes selectable through the viz-mode chooser. The default mode colors patches by safety (blue gradient) and agents by cultural group (sky, orange, magenta for civilians; green for military). The intentions mode colors each agent by its current selected intention, enabling direct observation of behavioral composition across the landscape. The cultural clusters mode highlights cultural group boundaries and convergence patterns. The flex/hierarchy mode maps structural traits to color, showing interaction-driven homogenization. The wealth/people mode visualizes the spatial distribution of organizational resources. The workforce landscape mode shows available labor pools across patches, revealing depletion near the front and concentration around urban centers. The networks mode visualizes trade-links, supply-links, and coordination-links with thickness proportional to link weight, enabling direct observation of network topology, fragmentation during displacement, and recovery through new partnership formation.

C.5. Initialization

The setup procedure executes seven sub-procedures in sequence: setup-calibration, setup-globals, setup-landscape, setup-government, setup-civilians, setup-militaries, and setup-society-preset.

C.5.1. Landscape

The landscape is a 51 × 51 grid (x: −25 to +25, y: −25 to +25) with no wrapping. Base safety is computed as (max-pxcor − pxcor) / (max-pxcor − min-pxcor), producing a linear gradient from 0.0 at the east edge to 1.0 at the west. Eight urban centers define the economic geography, with workforce capacity at each patch summing contributions from all peaks within radius 15 (each declining linearly with distance). At initialization, workforce-pool equals workforce-capacity everywhere. Figure C.6 illustrates the landscape configuration, showing the eight urban workforce peaks, the east-to-west safety gradient, the echelon threshold zones, and the government position.

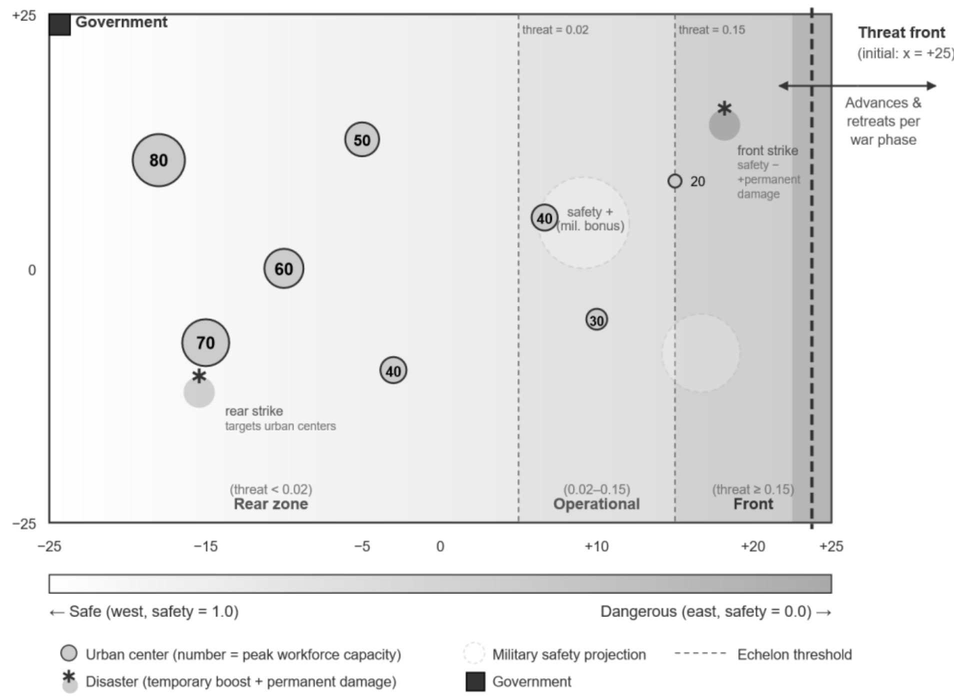

Figure C.6. Spatial landscape structure and safety computation

Table C.9 lists the eight urban-center workforce peaks with their grid coordinates and capacity values.

Table C.9. Urban-center workforce peaks

Peak	X	Y	Capacity	Position
1	−18	10	80	Far northwest
2	−15	−8	70	Southwest
3	−10	0	60	West-center
4	−5	12	50	Center-north
5	−3	−10	40	Center-south
6	5	5	40	East-center
7	10	−5	30	East-south
8	15	8	20	Far east

At tick 0, threat-level is 0 everywhere, military-bonus is 0, disaster-boost is 0, and cumulative-damage is 0, so effective safety equals base-safety. The threat front is at the east edge (x = +25). No patches are under threat.

C.5.2. Scenario Schedule

The warfare scenario is an internal data structure of nine phase tuples, each specifying end-tick, direction, intensity, and government-strength. The default scenario models the full-scale invasion arc from February 2022. Table C.10 reproduces the default scenario schedule that drives the threat front and government strength across the nine simulated war phases.

Table C.10. Default scenario schedule

Phase	Ticks	Direction	Intensity	Gov-strength	Description
0	0–30	advance	0.50	0.10	Rapid invasion; government near-collapse
1	30–50	hold	0.00	0.20	Stabilization; minimal recovery
2	50–80	retreat	0.30	0.30	Counteroffensive; growing capacity
3	80–110	hold	0.00	0.40	Consolidation; institutional rebuilding
4	110–160	advance	0.15	0.50	Grinding war; half capacity
5	160–200	retreat	0.10	0.55	Attrition-phase pushback
6	200–250	advance	0.08	0.50	Stalemate oscillation
7	250–300	retreat	0.08	0.50	Stalemate oscillation
8	300+	hold	0.00	0.50	Frozen conflict

During advance phases, the front drifts westward at a rate proportional to intensity. During retreat phases, it drifts eastward. Hold phases produce no directional drift; the front evolves through stochastic jitter and neighbor smoothing only.

C.5.3. Government

A single government agent is positioned in the top-left corner (administrative rear). Starting treasury is 30,000 × government-strength = 3,000. The cultural tag is an 11-bit binary list generated with 60% probability of 0 per locus, cached globally for all cultural-similarity computations. Initial beliefs: safety = 0.8, workforce = sum of all patch pools, economy = 0.5. All trend beliefs are 0.

C.5.4. Civilian Organizations

800 civilian organizations are placed on random patches with workforce-capacity > 10 (biased toward urban centers), displaced by a random direction and distance up to 3 patches. People and money are drawn from a four-tier distribution modeling the Ukrainian

commercial sector. Table C.11 reports the size-class distribution used to assign initial workforce capacity to the 800 civilian organizations.

Table C.11. Civilian size-class distribution

Tier	Probability	People	Money	Interpretation
Micro	86.0%	3–9	8–24	< 10 employees
Small	9.5%	12–41	40–99	10–49 employees
Medium	4.4%	50–199	200–499	50–249 employees
Large	0.1%	200–399	1200–2999	250+ employees

Sector is assigned uniformly at random (goods or services). Cultural tags are 11-bit binary lists generated with a spatial west-bias: the probability of 0 at each locus is proportional to distance from the east edge, so western civilians are more likely traditionalist and eastern civilians more likely adaptive. Risk tolerance is drawn uniformly from [0, 1) and fixed for the life of the organization. Structural traits (flexibility, hierarchy) are correlated with cultural identity, with additive uniform noise. Military-friendliness is uniform on [0, 1].

Planning horizon is initialized at initial-planning-horizon (default 0.38) ± uniform(0.1), clamped to [0, 1]. The default value of 0.38 reflects the weighted median from survey question Q27. Altruism is initialized at 0.5 ± uniform(0.1). All agents begin with mil-civ-ratio = 0 (pure civilian), empty partner-memory, and the operate intention.

C.5.5. Military Organizations

120 + random(20) military units are initialized. Seventy-three percent are placed on patches with safety between 0.2 and 0.6 (the contested zone); 27% on patches with safety > 0.7 in the western half. Money is 80 + random(60), people is 30 + random(30), supply-stock is 15. Cultural tags are inherited from the government with a 10% per-locus mutation rate. Structural traits reflect military institutional structure: risk-tolerance 0.3 + U(0, 0.5), flexibility 0.05 + U(0, 0.25), hierarchy 0.7 + U(0, 0.3), civil-friendliness 0.3 + U(0, 0.4). Mil-civ-ratio is 1.0 (pure military). Echelon is assigned based on initial threat level at the unit’s location.

C.5.6. Society Presets

After baseline initialization, one of five society presets may be applied, each representing a distinct configuration of the organizational/self-organizational balance for the experimental program. Table C.12 specifies the five society presets used in the experimental program and maps each to its crisis-agency interpretation.

Table C.12. Society presets and their crisis-agency interpretation

Preset	**Key modifications**	**Crisis-agency interpretation**
Baseline	None	Empirical Ukrainian configuration
Total-Defense	High mil-friendliness, +0.1 altruism, 30% domain-expanded	Front-loads SO capacity; retains civilian identity
Decentralized	Low hierarchy, high flexibility, weak government fiscal	Structurally favors SO pathway
Centralized	High hierarchy, low flexibility, elevated tax and subsidy	Maximizes O pathway; suppresses SO capacity
Dual-Economy	All agents receive non-zero MCR; military get civilian sectors	Dissolves O/SO boundary

Crossed with five transformational-mechanism toggles (cultural-transmission?, trust-enabled?, reputation-enabled?, hub-brokering-enabled?, long-ties-enabled?), the presets produce $5 \times 2^5 = 160$ experimental configurations.

C.6. Input Data

The model uses no external time-series data during simulation. The scenario schedule and workforce peaks are internal data structures constructed during initialization. All approximately 200 parameters are set by the setup-calibration procedure. An optional external CSV design matrix enables systematic parameter sweeps for calibration. No GIS data or external spatial data are used. All dynamics arise from internal mechanisms and parameter values established during initialization.

C.7. Submodels

This section describes the model's submodels, organized by functional role: environment (7.1–7.4), civilian cognition and behavior (7.5–7.8), military cognition and behavior (7.9–7.11), government (7.12), and cross-cutting processes (7.13–7.16). Each subsection explains the submodel's purpose and general logic before listing its procedures and key parameters.

C.7.1. Threat Front Dynamics

The threat front submodel represents the moving front line of the full-scale war. It is the primary exogenous driver of the entire model: all downstream safety calculations, disaster targeting, migration decisions, and military echelon assignments depend on where the front currently lies. The front is governed by a nine-phase scenario schedule that specifies successive periods of advance, retreat, or stalemate, loosely calibrated to the trajectory of the 2022 invasion. Rather than modeling the front as a hard boundary, the submodel produces a diffuse, stochastic front with spatial heterogeneity through neighbor smoothing and random jitter, reflecting the empirical reality that front-line positions are locally irregular and constantly shifting.

advance-scenario-phase. Checks whether the current war phase's end-tick has been reached. If so, increments the scenario-phase index and updates government-strength to the new phase value.

update-threat. Each patch's local-threat-front is updated as a weighted average of its own value (0.9) and its Moore neighbors' mean (0.1), plus global drift (−intensity for advance, +intensity for retreat, 0 for hold) and uniform random jitter [−2, +2]. The result is clamped to world coordinates. The global threat-front-x is set to the mean of all patch-level fronts. Threat-level is seeded at 1.0 east of the front and diffused in two passes (coefficient 0.35).

C.7.2. Local Disasters

The disaster submodel generates spatially localized destructive events representing missile strikes, bombardments, or infrastructure sabotage. Disasters serve two functions in the model: they create acute economic shocks that can trigger relocation cascades, and they accumulate long-term infrastructure scarring through the cumulative-damage system. The 70/30 split between frontline and rear-area targeting reflects a distinctive feature of the current war: systematic long-range strikes against urban infrastructure hundreds of kilometers from the contact line, producing insecurity even in nominally safe regions.

check-local-disasters. Evaluates disaster probability each tick: p = base-disaster-rate (0.03) + phase-intensity × 0.10, subject to a 5-tick cooldown. If triggered, selects a spatial center: with probability 0.30, a deep-rear urban center (±3 patch jitter from a randomly selected workforce peak); otherwise, near the front (threat-front-x ± 5). Severity is drawn from U[0.3, 0.8], radius from [3, 8] patches. Affected patches receive disaster-boost (temporary safety penalty), cumulative-damage (permanent scar, capped at 1.0), workforce-capacity reduction proportional to severity, and immediate workforce-pool loss.

apply-disaster-damage. Handles agent-level asset destruction within the blast zone. Civilians lose money (×0.4 × severity), goods-stock and services-stock (×0.5 × severity), and people (×0.1 × severity). Military units lose money (×0.3 × severity), people (×0.15 × severity), and supply-stock (×0.4 × severity).

C.7.3. Patch Safety Computation

Patch safety is the primary environmental signal consumed by all agent decision-making. It transforms the raw threat field, military presence, and damage history into a single composite score for each patch, bounded to [0, 1]. The layered composition allows the model to represent multiple war realities simultaneously: the front itself, the protective umbrella of military forces (including coordinated combined-arms effects), the acute shock of strikes, and the slow accumulation of infrastructure damage. Military presence can partially offset proximity to the front but cannot compensate for sustained bombardment, and rear areas can lose safety abruptly from deep strikes while recovering only gradually. Figure C.7 shows how the five input layers compose into a single safety score that is consumed by civilian perception, network diffusion, and world mechanics

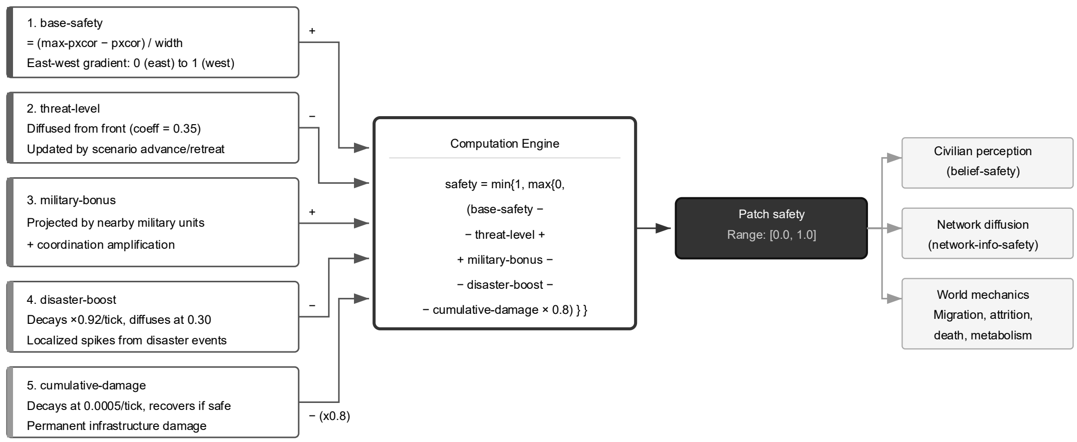

Figure C.7. Patch safety computation: five-layer integration

update-patch-safety. Military-bonus is reset, then recomputed as an inverse-distance gravity field from all military units (strength = √(people / 20) / distance) and militarized civilians (discounted at 60% efficiency). Coordinated military pairs with cultural similarity above 0.4 contribute a superlinear amplification bonus. Disaster-boost decays multiplicatively (×0.92/tick) and is diffused spatially (coefficient 0.3). Cumulative-damage is diffused slowly (coefficient 0.03). Effective safety is:clamp_{01}(base-safety − threat-level + military-bonus × 0.1 − disaster-boost − cumulative-damage × 0.8). Patch-attractiveness is cached for workforce return: capacity^attract-wf-exponent(0.7) × (1 − threat)^attract-safety-exponent.

C.7.4. Workforce Migration and Return

The workforce submodel governs the movement of anonymous labor pools across the landscape. Unlike the organization-level agents, workforce pools are patch-level populations representing the general labor force available for hiring. The submodel captures three dynamics documented in Ukrainian displacement data: rapid danger-driven flight from threatened areas, permanent diaspora attrition from the transit pool, and slow gravity-based return to recovering patches. The core empirical regularity is the sharp asymmetry between outflow and return: areas near the front empty within weeks, while repopulation unfolds over years and never fully reaches pre-invasion levels in heavily damaged zones. Figure C.8

illustrates the three-pool workforce dynamics: rapid danger-driven outflow, permanent diaspora attrition from the transit buffer, and slow gravity-based return to recovering patches.

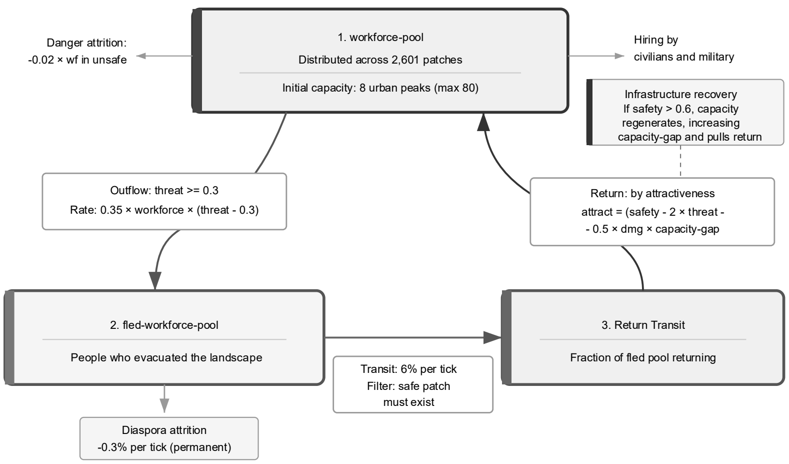

Figure C.8. Workforce migration: outflow, transit, and return dynamics

regenerate-workforce-pools. On patches with safety below 0.5, workforce-pool suffers danger attrition at rate 0.02. Cumulative-damage decays by 0.0005/tick. On safe patches (safety > 0.6), workforce-capacity recovers toward initial capacity at rate 0.1 × safety.

migrate-workforce-from-threat. Patches with threat > 0.30 lose workforce to the national transit buffer. The fled fraction follows a quadratic function of threat: f(T) = wf-migration-quad-a(−0.91) × T^2 + wf-migration-quad-b(1.37) × T, scaled by outflow rate (0.27). The quadratic form captures the observation that flight rates increase with threat but saturate at an extreme threat, when escape becomes difficult.

return-workforce-to-recovering-patches. Each tick, 1.0% of the transit buffer is permanently lost to diaspora. Of the remainder, 9.7% attempt return. Returning workers are distributed proportionally to an attractiveness score: A = gap^α × exp(−2.0 × threat − 0.5 × damage), with an overcrowding ceiling at 150% of capacity.

C.7.5. Civilian Perception

The perception submodel implements the "Beliefs" layer of the simplified BDI cognitive architecture. It translates raw environmental and economic data into the subjective beliefs that drive civilian decision-making. Perception runs once per tick for every civilian organization, before intention scoring. The network information diffusion step extends each civilian's effective awareness beyond its immediate patch: by blending own-patch safety with partner-reported safety, well-connected organizations obtain a more accurate and less volatile picture of the threat landscape than isolated ones.

perceive-environment. Updates belief-safety from current patch safety. Computes belief-financial-trend by comparing money to prev-money (+1, 0, or −1). Sets belief-partner-reliable? to true if partner-memory is non-empty. Appends current values to 10-tick sliding history windows. Updates vision-range (base 3, +2 if people > 20, +2 if hub-status).

diffuse-info-through-network. Computes network-info-safety as 70% own belief-safety plus 30% mean belief-safety of all agents reachable through trade-links and supply-links. Civilians with supply-links to military units receive military belief-safety values based on direct frontline threat observation, providing earlier warning of approaching danger.

C.7.6. Civilian Intention Scoring

The intention scoring submodel implements the "Desire" and "Intention" layers of the BDI cycle. It is the central decision-making mechanism: each tick, each civilian evaluates competing behavioral options and selects one. The design reflects a core empirical observation from the qualitative study: organizations did not pursue a single goal but constantly balanced safety against profitability, institutional compliance against autonomy, and collective defense contributions against their own operational continuity. Two reactive overrides fire before the deliberative process, capturing the finding that relocation decisions were typically driven by immediate threat perception rather than by strategic calculation. The seven scored intentions are weighted by each agent's beliefs, structural traits, adaptive traits, and environmental conditions, producing behavioral differentiation even among agents with identical traits because local conditions vary.

select-intention. Tests two priority overrides first. The relocate override fires when network-info-safety < (threshold-base + (1 − risk-tolerance) × threshold-range − network-anchor), where threshold-base = 0.2, threshold-range = 0.3, and network-anchor = min(0.15, trade-link-count × 0.03). The return-home override fires when origin-patch safety exceeds a threshold and money is sufficient.

If neither fires, seven intentions are scored. Score-operate = safety × w-safety × (1 − risk-tolerance) + (1 + financial-trend) × w-financial + flexibility × w-flexibility. Score-seek activates when partner-memory is empty or thin. Score-comply weights cultural similarity to government and hierarchy. Score-evade weights cultural distance, risk-tolerance, and autonomy. Score-support-defense is proportional to altruism and local danger. Score-support-civilian activates when altruism > 0.3 and nearby civilians are distressed. Score-defend-civilian is gated by mil-civ-ratio > 0.05 and local danger. Planning-horizon modulation: medium-horizon agents (0.33–0.66) incorporate safety trend from history; long-horizon agents (> 0.66) also incorporate global landscape mean safety. Domain expansion triggers with 10% probability when altruism > 0.4 and money > 40 and not yet expanded. The highest-scoring intention is selected.

C.7.7. Civilian Action Procedures

The action procedures implement the “Act” layer of the BDI cycle. Each procedure translates the selected intention into concrete state changes: resource transfers, spatial movement, network creation, cultural and structural drift. Together, they constitute the 13 action mechanisms identified in the MBSSM classification. The comply and evade procedures contain reinforcing feedback loops: compliance drifts hierarchy upward and culturally converges toward the government, increasing future compliance scores, while evasion drifts hierarchy downward and counter-conforms culturally, increasing future evasion scores. This produces the compliance lock-in and evasion divergence mechanisms documented in the interviews.

do-operate. Production output = min(people, money) × safety × (1 − relocation-penalty). Revenue = output × revenue-rate (0.79 for operate). Attempts trade with remembered partners (habitual route first if trust > 0.8), then long-tie partners. If domain-expanded, diverts domain-expansion-cost fraction of revenue to supply-stock.

do-seek-partner. Scans agents within vision-range. Scores each candidate on multiplicative compatibility × complementarity. Compatibility combines cultural similarity (weight 0.35), hierarchy match, and flexibility match. Complementarity combines a baseline, cross-sector bonus, MCR difference, and resource imbalance. Phase-sensitive: short-horizon agents boost complementarity; long-horizon agents boost compatibility. Selects the highest-scoring candidate. Initializes swift trust: base + culture-weight × cultural-similarity + sector-weight × cross-sector-match. Adds mutual partner-memory entries. Figure C.9 shows the three routes through which civilian organizations find trade partners: the habitual fast-path for trusted partners, the active search with compatibility × complementarity scoring, and the residual route through existing memory during the operate action.

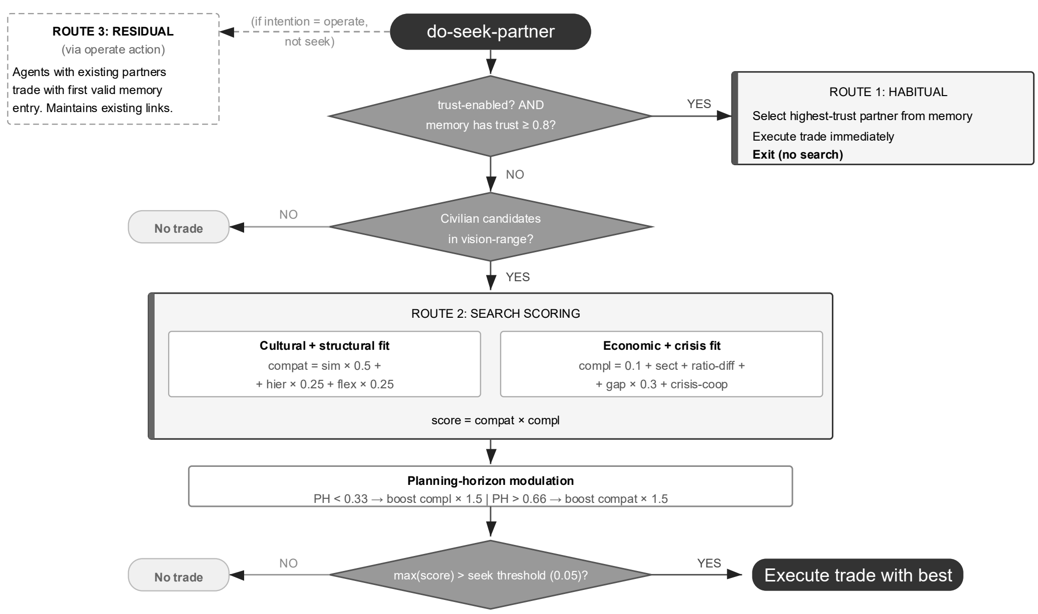

Figure C.9. Three-route partner search architecture

do-relocate. Records social capital snapshot (pre-reloc-degree, pre-reloc-trust-sum). Preserves the highest-trust partner as a long-tie (up to long-tie-keep-count = 1). Selects destination: the safest visible patch within vision-range with workforce > 0. Moves to destination. Sets relocation-penalty to 0.5 (decays 15%/tick).

do-re-enter-market. Moves back toward origin-x. Resets relocation state.

do-comply. Pays full tax (gov-tax-rate × money × government-strength × local-safety-factor). Flips one cultural tag locus toward the government tag (cultural convergence). Increases org-hierarchy by 0.02. Transfers supply to the nearest, neediest, culturally similar military unit if within vision-range. Records supply-link. Government reimburses 50%.

do-evade. Pays half tax. Flips one cultural tag locus away from the government tag (counter-conformity). Decreases org-hierarchy by 0.02, increases org-flexibility by 0.01. Revenue at evade rate (0.64).

do-defend-civilian. Hybrid civilian defense, available to organizations with MCR > 0.1. The organization contributes to local military-bonus through its presence, with effectiveness discounted relative to professional military at 60%.

do-support-defense. Voluntary military supply transfer, proportional to altruism and available resources. Creates a supply-link to the receiving military unit. Government reimburses 50% of the transferred amount, creating a fiscal incentive for voluntary cooperation.

do-support-civilian. Altruistic aid to distressed nearby civilians. Transfers money proportional to money × altruism × civilian-support-civ-transfer-rate (0.08), capped by available resources. This implements the mutual aid pattern that emerged consistently in the qualitative data.

C.7.8. Trade Execution

Bilateral trade is the primary mechanism through which the model simultaneously drives economic exchange, network formation, trust accumulation, cultural convergence, and structural homogenization. Each trade event is a multi-step pipeline that connects the economic layer (resource transfer), the network layer (link creation and trust updating), and the cultural layer (tag-flipping and trait blending). Long-tie trade extends the pipeline to displaced partners but carries only simple contagions (resources, information, referrals), not complex ones (cultural and structural influence), implementing the Centola and Macy (2007) distinction between information that can travel through single distant connections and influence that requires reinforcement from multiple local ties. Figure C.10 traces the eleven-step trade pipeline through four phases: price and volume formation, resource transfer, network and trust updating, and cultural/structural contagion. Steps 10–11 are blocked for long-tie trades

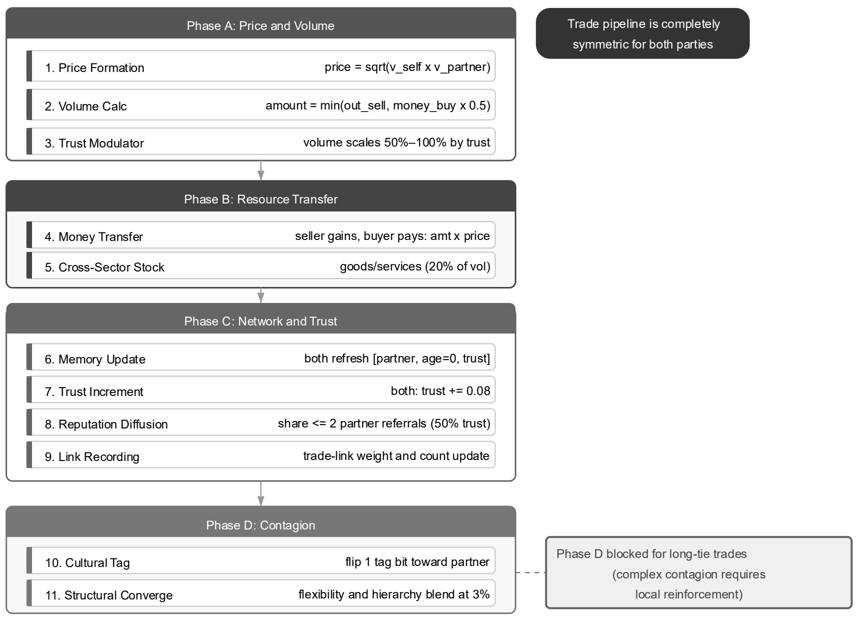

Figure C.10. Bilateral trade pipeline

execute-trade. Twelve-step pipeline: (1) compute seller valuation from production/money ratio, (2) compute buyer valuation, (3) set price to geometric mean, (4) constrain volume by seller capacity and buyer ability, (5) scale by trust factor: (1 − trust-volume-weight) + trust-volume-weight × trust, (6) transfer money, (7) cross-sector stock exchange if different sectors, (8) update partner memory for both parties, (9) increment trust by 0.08, (10) share partner referrals (up to 2 novel partners, discounted at 0.50 trust), (11) cultural tag exchange if co-located (tag-flipping: each party shifts one random locus toward the other's value), (12) structural trait blending at 3% rate if co-located. Record trade-link.

execute-long-tie-trade. Same pipeline but at reduced volume (×long-tie-trade-discount = 0.35). Carries simple contagions only: money transfer, trust increment, partner referrals. Does not carry complex contagions: no cultural tag exchange, no structural trait blending.

C.7.9. Military Perception and Echelon

The military perception submodel parallels civilian perception but with a critical difference: military units observe raw threat-level directly rather than the derived safety composite, giving them earlier and more specific danger information. The echelon system is the institutional structure through which the military organizes its forces. It operates as a three-state machine (front, operational, reserve) that determines which intentions are available, what operating costs are incurred, and how government funding is prioritized. The system produces emergent force-structure dynamics: under sustained attrition exceeding recruitment, unit counts decline gradually, and the front-to-reserve ratio shifts as personnel pressure mounts. Figure C.11 shows the three-state echelon lifecycle: government-ordered promotion from reserve to operational, location-forced promotion to front upon encountering threat, depletion-based demotion back to reserve, and death exit.

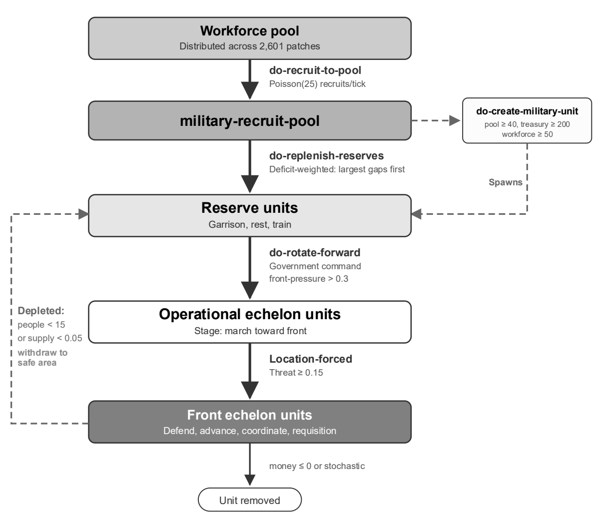

Figure C.11. Military echelon lifecycle and rotation

perceive-environment-military. Updates belief-safety from local threat-level. Processes military long-tie safety averaging: units average their belief-safety bidirectionally with preserved garrison partners, creating cross-front situational awareness without resource transfer. Updates vision-range.

update-echelon. State machine with three states and four transitions. Location-forced promotion: if local threat ≥ 0.15, promoted to front. Depletion-based demotion: if people or money fall below readiness thresholds, demoted to reserve. Government-ordered rotation: commander's order promotes the most-ready reserve unit when front count falls below target. Deployment cooldown: front units must serve a minimum number of ticks before rotation eligibility.

C.7.10. Military Intention Scoring

Military intention scoring follows the same belief-weighted scoring logic as civilian scoring but is gated by echelon membership: front units can defend or advance, operational units can stage, and reserve units can garrison. This constraint reflects military doctrine, where the range of permissible actions depends on organizational position in the force structure. The scoring weights produce emergent behavioral specialization: front units under heavy threat prioritize defense, while well-resourced front units with high flexibility may advance.

select-intention-military. Echelon-gated scoring. Front units score: defend (weighted by local threat), advance (weighted by resources and flexibility), withdraw (triggered by depletion), coordinate (weighted by nearby similar units), requisition (gated by low supply), support-government (weighted by hierarchy). Operational units score: stage (advance toward front), withdraw. Reserve units score: garrison (supply regeneration and recruitment). Planning-horizon modulates defend and support-government scores analogously to civilian modulation. Highest score wins.

C.7.11. Military Action Procedures

The military action procedures translate selected intentions into state changes. The key interactions are requisition (forced resource extraction from civilians, which erodes trust and reciprocity) and coordination (resource sharing and situational awareness between culturally similar units, which amplifies local safety). Garrison serves as the network seed for the military small-world mechanism: co-located reserve units build coordination bonds that are later preserved as long-ties when units deploy to different front sectors.

do-defend. Consumes supply-stock. Contributes to local military-bonus through presence.

do-advance. Moves one patch toward the front (eastward). Consumes supply-stock.

do-stage. Moves toward the front from operational zone. Transitional between reserve and front.

do-requisition. Front-echelon units extract resources from all civilians within vision-range/2. Take-fraction is modulated by cultural incompatibility and org-civ-friendliness (friendlier units take less from compatible civilians). Gains money, people, supply-stock; civilian loses corresponding resources. Records requisition-link (decays at half the normal memory-decay-time).

do-coordinate. Selects the most norm-similar military unit within vision-range. If similarity > 0.4, transfers surplus money proportionally to imbalance. Both units average belief-safety (shared situational awareness). Both converge structural traits at 3%. Records coordination-link. Coordinated pairs contribute a superlinear safety amplification to nearby patches, representing combined-arms effects.

do-support-government. Transfers money to the government. Increases org-hierarchy.

do-garrison. Regenerates supply-stock. Recruits people from local workforce-pool. Co-located reserve units build passive coordination through mutual partner-memory addition and optional cultural tag exchange, solving the cold-start problem for the military coordination network.

do-withdraw. Moves one patch away from the front (westward). Triggered when resources are critically low.

C.7.12. Government Submodel

The government submodel represents the centralized state apparatus as a unique super-agent that executes fiscal and mobilization policies unconditionally each tick. It operationalizes the organizational pathway in the crisis-agency framework: taxation, subsidies, military funding, and mobilization are binding institutional constraints on agent decisions, not suggestions that agents can ignore. The government's cultural tag serves as the reference point for all cultural-similarity computations, creating a fiscal incentive for cultural alignment through culturally weighted subsidy distribution. A spending floor decouples fiscal expenditure from institutional capacity during crisis phases, reproducing the Ukrainian fiscal trajectory in which the government maintained essential expenditure through international borrowing even as domestic tax collection collapsed. Figure C.12 traces the government fiscal cycle: taxation flows in from all civilian organizations, then splits into military funding (50%), civilian subsidies (30%), and unit creation, with a spending floor ensuring non-zero expenditure during crisis

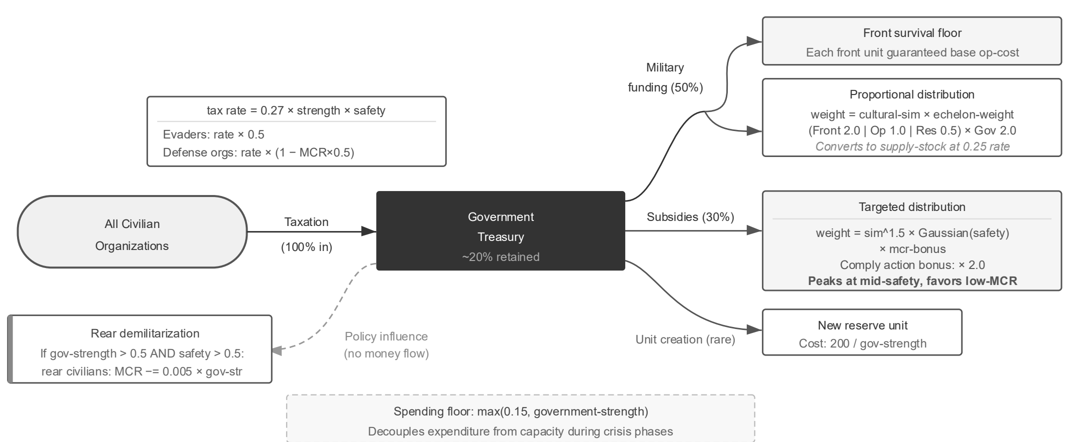

Figure C.12. Government fiscal cycle

perceive-environment-government. Computes aggregate beliefs: belief-safety averaged across all patches, belief-workforce summed across all patches, belief-economy averaged across all civilian money-to-people ratios. Computes trend indicators by comparing to previous-tick values.

do-collect-taxes. Collects from all civilians at rate 0.27, scaled by government-strength and local patch safety (lower collection in danger zones). Evading civilians pay half. Compliant civilians receive one cultural tag flip toward the government tag and a subsidy weight bonus.

do-fund-military. Distributes 50% of treasury to military units, weighted by echelon (front-weighted) and cultural similarity. Military units also receive supply-stock proportional to their monetary allocation. Effective government-strength for spending is max(gov-spending-floor = 0.15, government-strength), decoupling expenditure from capacity during crisis.

do-distribute-subsidies. Distributes 30% of treasury to civilians, targeted to the most financially distressed in safe zones, weighted by cultural similarity (raised to the power of subsidy-bias = 1.5).

do-recruit-to-pool. Adds Poisson(25) recruits per tick from the national workforce to the military recruit pool. Workforce is drawn from the highest-capacity patches.

do-replenish-reserves. Distributes recruits from the pool to existing reserve units, deficit-weighted: the most under-strength units receive personnel first. Replenishment fires before unit creation, reflecting the documented policy of backfilling depleted formations before standing up new ones.

do-create-military-unit. Creates a new military unit only when the recruit pool has sufficient surplus and no existing unit is critically under-strength. New units inherit the government cultural tag with 10% per-locus mutation.

do-rotate-forward. Promotes the most-ready reserve unit to front echelon when the front-line count falls below a target ratio of total military. Preserves garrison coordination partners as military long-ties upon deployment.

do-demilitarize-rear. When safety > 0.5 and government-strength > 0.5, rear-area civilians with MCR above a threshold receive MCR reduction (0.005/tick) with a compensating subsidy bonus. This represents the government's institutional push toward centralized specialization (the Zoo pattern).

C.7.13. Metabolism

The metabolism submodel represents the ongoing cost of organizational existence. Organizations consume stocks and pay overhead each tick regardless of their selected intention, creating a resource drain that must be offset by production, trade, or subsidies. The submodel ensures that survival is not free: organizations that fail to maintain positive resource flows eventually die. Safety-scaled consumption (higher in unsafe areas) represents the wartime cost premium documented in the environmental analysis, where organizations near the front pay more for security, logistics, and employee support.

apply-civilian-metabolism. Consumes goods-stock and services-stock at a rate scaled by local safety (higher consumption in unsafe areas). Pays flat money overhead. If goods-stock or services-stock falls below zero, people and money are penalized. Hybrid organizations (MCR > 0) also consume supply-stock proportional to their MCR.

apply-military-metabolism. Consumes supply-stock (0.5/tick). Pays echelon-differentiated operating costs (front most expensive, reserve least). If supply-stock is insufficient, suffers money and stochastic people penalties.

C.7.14. Adaptive Trait Dynamics

The adaptive trait submodel governs the three endogenously changing traits that constitute the model's novel theoretical contributions. Planning horizon captures a pattern strongly supported by the qualitative evidence: under sustained crisis, organizations shift from reactive short-term responses to longer-term strategic orientation, with recovery that is gradual and often incomplete. Altruism captures the volunteer mobilization pattern also broadly confirmed in the interviews: when formal institutions cannot provide, and nearby peers are visibly in distress, organizations spontaneously redirect resources to defense and mutual aid. The mil-civ-ratio governs behavioral permeability between civilian and military functions and produces the emergent Jungle/Zoo regime dynamics through four interacting feedback loops. Because contraction rates exceed recovery rates for both planning horizon and altruism, extended crises leave persistent population-level traces, a form of partially irreversible organizational adaptation.

update-adaptive-traits. Updates three traits for all organizations each tick.

Planning horizon decreases by 0.015 when both safety-history slope and financial-history slope are simultaneously negative (conjunctive condition: both must decline, preventing contraction from isolated shocks). It increases by 0.004 when both trends are simultaneously non-negative. A population-level soft ceiling (0.70) stochastically gates recovery: each tick, recovery probability = max(0, (ceiling − current-fraction) / ceiling).

Altruism (civilian-only) increases by 0.015 when three conditions co-occur: financial trend ≤ 0, local safety < 0.4, and ≥ 2 nearby distressed civilians (money < 10 or people < 3). Otherwise decays by 0.003.

Mil-civ-ratio updates through four mechanisms: crisis militarization (+0.01/tick when safety < 0.4 and military count below 70% of target), action-driven drift (+0.005 for support-defense, +0.003 for comply, +0.008 for defend; domain expansion triggers +0.02), supply-deficit decay (−0.01/tick when hybrid supply needs unsustainable), and peace dividend (−0.003/tick when safety > 0.6). MCR for civilians is capped at 0.7.

C.7.15. Demographics

The demographics submodel governs the entry and exit of organizations from the simulation and the decay of network memory over time. Death and birth together produce organizational population dynamics: the front zone depopulates rapidly through danger attrition and resource depletion, while safer zones experience gradual replacement through splitting and spontaneous founding. The partner memory decay mechanism controls the lifetime of network relationships: without continued interaction, partnerships dissolve after

35 ticks. The permanent partner loss mechanism models irreversible network scarring from wartime attrition, calibrated from the survey finding that 14.3% of respondents reported never recovering their pre-invasion partnerships.

apply-danger-attrition. Organizations on patches with safety < danger-attrition-safety-threshold (0.5) lose people proportional to (threshold − safety) × attrition-rate. Civilian and military attrition rates are separate interface parameters (civilian-attrition-rate and military-attrition-rate, both default 0.04). Civilian losses return 50% of people to the local workforce pool; military losses are permanent.

check-deaths. Organizations with money ≤ 0 or people ≤ 0 die; on unsafe patches, organizations face stochastic death probability proportional to (1 − safety). Dying civilian organizations release 50% of their workforce to the local patch pool (death-wf-return-fraction = 0.5); the remainder is permanently lost. Dying military units release no workforce. When an organization dies, all partner-memory entries referencing it are removed from surviving partners' memories, producing network scarring proportional to the deceased agent's degree centrality.

check-civilian-births. Splitting: civilians with money > 20 and people above threshold may split with 15% probability per tick, creating offspring with 40% of resources and cultural tags mutated at 2.8% per locus. Spontaneous founding: new organizations may be founded on safe (> 0.5), workforce-rich (> 15) patches with probability (1 − count/800) × 0.5. Founded organizations draw resources from the Ukrainian firm size distribution: 90% micro (3–10 people, 8–25 money), 8% small (12–32 people, 30–70 money), 2% large (40–100 people, 80–200 money).

decay-partner-memories. All memory entry ages increment by 1. Trust decays by trust-decay-rate (0.002) per tick. Entries exceeding memory-decay-time (35 ticks) are removed.

decay-relocation-penalties. Penalties multiplied by 0.85/tick until below 0.01, then set to zero.

C.7.16. Network Dynamics

The network dynamics submodel governs three processes that shape the emergent trade network topology: hub brokering, link aging, and periodic measurement. Hub brokering reflects a pattern observed in humanitarian logistics research: organizations that accumulate many connections gain structural advantages (enhanced vision, introduction capability) that further increase their centrality through preferential attachment. Link aging ensures that the network is dynamic rather than static: without continued interaction, links dissolve, creating the possibility of network fragmentation during displacement and necessitating active rebuilding through new partnerships. The periodic measurement computes standard network statistics that serve as key observation variables for the model's network-related research questions. Figure C.13 organizes the four network formation pathways in a 2×2 matrix of proximity (local vs. long-range) and interaction mode (direct vs. third-party), marking the simple/complex contagion boundary.

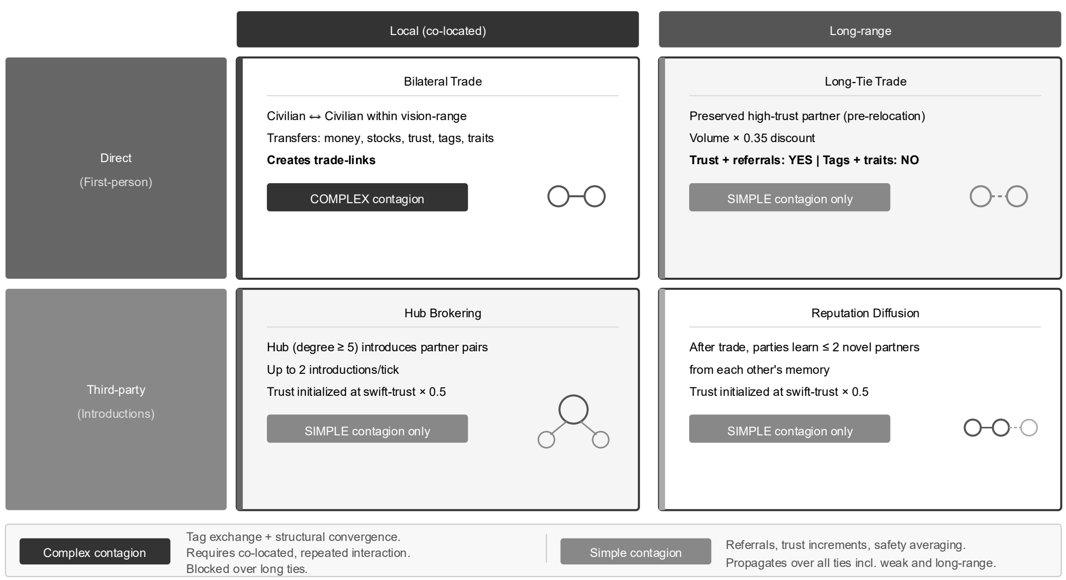

Figure C.13. Network link formation: four pathways and the contagion boundary

do-hub-brokering. Civilians with total degree (trade-links + supply-links) ≥ hub-degree-threshold (5) introduce pairs of their trade partners to each other (up to hub-broker-rate = 2 pairs per tick). Introduced partners receive mutual partner-memory entries with discounted swift trust. Hub-status civilians also receive +2 vision-range bonus.

age-network-links. Removes all links whose last-active-tick is older than memory-decay-time (35 ticks). Updates link thickness and color for visualization.

update-network-measures. Every 10 ticks, computes mean clustering coefficient, weak component count, and mean path length on the trade-link network using the NetLogo nw extension.

Partner memory and trust utilities. add-to-memory creates or refreshes [agent, age, trust] entries. increment-trust adds trust-increment-rate (0.08) per successful interaction. share-partner-referrals transfers up to 2 novel partners to the trade partner, initialized at 50% of computed swift trust. exchange-cultural-tag flips one random tag locus toward the partner's value (Hammond–Axelrod convergence). exchange-structural-traits blends flexibility and hierarchy at a specified rate (3% for trade, 3% for coordination).

APPENDIX D

DETAILED CALIBRATION AND VALIDATION

This appendix documents the details of the calibration and validation process introduced in Chapter 5. Section D.1 documents the validation method selection framework that derived the validation plan for the model. Section D.2 provides the complete rule-by-rule face validation results that the body chapter summarizes in aggregate. Section D.3 presents the mechanism-level cross-validation from a model-verification perspective. Section D.4 records the structural corrections made before calibration. Section D.5 documents the unmatched behavioral patterns that define the model's scope boundaries. Sections D.6 through D.8 document the four-layer calibration architecture: the macro-statistical and survey-derived parameter commitments (D.6), the BehaviorSearch optimization and cross-method comparison (D.7), and the committed parameter set across all four layers (D.8). Section D.9 reports the 21 validation targets used during calibration. Sections D.10 through D.13 document the sensitivity analyses: Morris elementary effects screening method (D.10), Morris results and parameter ranking (D.11), trajectory stability check (D.12), and OFAT domain affinity mapping (D.13).

D.1. Validation Method Selection Framework Application

The validation method selection framework (Serdyuk, 2025b) was developed from computational analysis of 76 research scenarios and maps twelve validation methods against combinations of model purpose, system observability, and development stage. The framework is operationalized as a five-step procedure. Table D.1 documents the complete application of all five steps to the organizational adaptation model.

Table D.1. Validation method selection framework applied to the organizational adaptation model

Framework Step	Recommended Actions	Application to This Model
Step 1: Context Assessment	Evaluate observability, development stage, and primary purpose	Partial observability (IOM, SSS, MoF macro; 37 interviews + 35 surveys micro). Refinement stage (all mechanisms operational, iterative revision). Explanatory purpose with secondary hypothesis generation.
Step 2: Universal Methods	Visualization: apply in all contexts. Expert review: involve domain experts. Structural checks: verify theory-to-code mapping	Visualization: spatial dynamics inspection, trajectory plots, network rendering (ongoing throughout development). Face validation of the 27-mechanism / 38-rule inventory against 37 interview transcripts and 35 survey responses (replacing expert review, since no accessible community combines ABM expertise with Ukrainian wartime organizational experience). Structural checks: BDI/BEN, cultural tags, SKIN trade, adaptive traits, traced against source code for all ten frameworks.
Step 3: Stage Constraints	Refinement stage enables all advanced methods. Filter out: none. Keep: sensitivity analysis, empirical validation, sampling, bootstrapping, causal analysis, data analytics, IGSS, docking	All twelve methods pass the stage gate. Practical constraints further narrow the set in Step 4.
Step 4: Strategy-Specific Methods	Partial observability × explanatory purpose: prioritize sensitivity analysis, empirical validation with available data, and pattern-oriented multi-criteria testing. Consider causal analysis and data analytics. Deprioritize IGSS, docking, bootstrapping, and role-playing where practical constraints apply.	Selected: sensitivity analysis (Morris elementary effects screening + OFAT domain mapping), empirical calibration (macro anchors + survey distributions + Latin Hypercube Sampling + BehaviorSearch optimization), pattern-oriented validation (43 criteria across 8 experiments). Deferred: docking (empirical data provide a more demanding target than comparison with parent models), IGSS (38-parameter space produces a combinatorial space too large for systematic exploration), role-playing (respondents geographically dispersed across Ukraine and abroad), bootstrapping (subsumed by the 30-replication design used throughout).

Framework Step	Recommended Actions	Application to This Model
Step 5: Trade-Offs	Acknowledge what the chosen plan cannot do. Record gaps and their rationale.	No full docking against parent models (BEN, SugarScape, SKIN). No participatory role-playing. No inverse generative search. Trust parameters lack direct empirical proxy; calibrated jointly with network targets as a partial substitute. The entire activation chain from altruism through MCR gating to defending/mutual-aid intentions remains structurally undertested.

D.2. Face Validation: Complete Results

The face validation coded all 37 interview transcripts against the model's 38-rule inventory. Each transcript was coded using a four-category scheme. S (support) indicates that the respondent describes behavior consistent with the model rule. C (contradiction) indicates inconsistent behavior. N (nuance) indicates partial consistency that reveals a dimension the model does not capture. X (unmatched) indicates organizationally relevant behavior with no corresponding model rule. Table D.2 reports all 38 model rules sorted by strength of empirical support.

Table D.2. Face validation: 38 model rules against 37 interview transcripts

Code	Model Rule	Assessment
C1	Planning horizon as endogenous adaptive trait	Strong support (26S, 0C)
K4	Voluntary military support	Strong support (22S, 0C)
B7	Domain expansion	Strong support (16S, 1C)
K1	Three-phase temporal pattern	Strong support (16S, 0C)
C2	Altruism increase under crisis, decay over time	Strong support with nuance (12S, 13N)
B1	Perception: local safety and financial observation	Strong support (12S)
J3	COVID pre-adaptation	Strong support (11S, 2N)
A3	Organizational structure traits	Heavily nuanced (10S, 5N)
B5	Seven civilian behavioral intentions	Strong support (10S)
G5	Government interaction through intermediaries	Strong support (10S, 2N)

Code	Model Rule	Assessment
G4	Mobilization impact	Strong support with nuance (9S, 5N)
D1	Dynamic civilian-military boundary	Strong support (8S, 2N)
K3	HR repurposing from development to crisis support	Strong support (6S)
B3	Relocation threshold with trade-link anchoring	Nuanced (5S, 3N)
D2	Jungle-to-Zoo regime transition	Nuanced (4S, 4N)
E2	Crisis-induced cooperation	Partial support (4S)
E4	Three-route trust (cue, category, earned)	Partial support (3S, 4N)
B9	Destination choice for relocation	Partial support (3S)
K2	Structural inertia as protective factor	Partial support (3S)
B4	Return-home intention	Partial support (2S)
B8	Planning horizon modulation of decisions	Partial support (2S)
A2	Cultural tag and group identity	Partial support (2S)
B6	Comply vs. evade decision	Partial support (1S, 1N)
B2	Network information diffusion	Partial support (1S)
A1	Organizational death conditions	Partial support (1S)
C3	Behavioral typology (2×2: horizon × altruism)	Partial support (1S)
A5	Size-dependent vision range	Partial support (1S)
A4	Risk tolerance as fixed trait	Contradicted (0S, 2C)
E1	Multiplicative partnership scoring	Below interview resolution
E3	Phase-sensitive strategy	Below interview resolution
E5	Reputation diffusion	Below interview resolution
E6	Hub coordination	Below interview resolution
F1	Social capital destruction	Below interview resolution
F2	Long-tie preservation	Below interview resolution
F3	Recovery asymmetry	Below interview resolution
G1	Progressive taxation	Below interview resolution
G2	Biased subsidies	Below interview resolution
G3	Military funding allocation	Below interview resolution

Code	Model Rule	Assessment
H1–H4	Bilateral trade mechanics	Below interview resolution
I1–I5	Warfare and infrastructure	Below interview resolution
J1	Organizational splitting	Below interview resolution
J2	Spontaneous founding	Below interview resolution

Notes on selected mechanisms

Altruism dynamics (C2). The 13 N-codes reflect qualitative diversity in the decline trajectory. Respondents described three distinct patterns: wave-like resurgences triggered by specific events (missile attacks, territorial changes), sudden collapses driven by disillusionment with state institutions, and deliberate organizational efforts to sustain volunteer engagement over time. The model compresses all three into a single uniform decay rate. This simplification is adequate for population-level analysis but means that experimental findings about altruism dynamics should not be interpreted as representing any single organizational trajectory.

Risk tolerance (A4). Two respondents described endogenous shifts in organizational risk appetite during the crisis. One described a shift from risk-averse to risk-seeking after surviving the acute phase. The other described the reverse: initial boldness giving way to caution as the war persisted. The evidence identifies that change occurred but does not specify a change mechanism (trigger, speed, equilibrium). Risk tolerance is retained as a fixed parameter, with the survey's post-crisis distribution (mean 3.4/5) used as the calibration value.

Jungle-to-Zoo regime transition (D2). The mixed support (4S, 4N) is consistent with the sensitivity analysis finding that MCR-gated behaviors show near-zero sensitivity. The nuance codes describe organizations that partially shifted toward defense functions without completing the Jungle-to-Zoo transition. This structural issue is carried forward to the pattern-oriented validation.

Cross-wave evidence. Five respondents participated in both interview waves. One exhibited a trajectory consistent with the model's contraction-recovery-adaptation sequence: collapsed planning recovered to six-month forecasts, charity activity grew, and performance evaluation became more systematic. A second showed a trajectory the model cannot represent: deliberate compliance eroded into regulatory grey-zone operation, and the company became its employees' only psychologically safe space. A third demonstrated forced normalization at the cost of 60% workforce emigration and organizational denationalization through international hiring. These cases illustrate that the model's central mechanisms capture dominant population-level patterns while individual trajectories diverge where psychological and identity dynamics are involved.

D.3. Cross-Validation: Survey Against Interviews

The cross-validation compared survey findings (n = 35, February 2026) against interview coding (37 transcripts, 2022–2023) across 15 mechanism-level comparisons. This comparison serves a model-verification purpose: it tests whether the two empirical sources that informed the model's construction agree on the mechanisms the model formalizes. Table D.3 reports all fifteen comparisons; it extends the cross-validation reported in Appendix B, Table B.3 (which covers the nine mechanisms tested by both the interviews and the survey) with six additional comparisons where interview evidence is reported alongside survey gaps or absences. The complete set of comparisons supports the model-verification analysis in Chapter 3, Section 3.5.

Table D.3. Cross-validation of model mechanisms: survey (n=35) vs. interviews (37 transcripts)

Mechanism	**Assessment**	**Interview Evidence**	**Survey Evidence**
Planning horizon contraction (C1)	Strong convergence	26 S-codes, zero contradictions; recovery in cross-wave cases	51.4% shortened, 40% unchanged, 5.8% lengthened

Mechanism	**Assessment**	**Interview Evidence**	**Survey Evidence**
Priority shift: safety – business (B1, B5, K1)	Strong convergence	B1=12S, B5=10S, K1=16S; three-phase temporal pattern universal	54% safety-first → 69% business-first
Voluntary military support (K4)	Strong convergence	22 S-codes, zero contradictions; universal and pre-governmental	48.6% active support; mil experience 3.89/5 vs gov experience 3.26/5
Mobilization as workforce disruptor (G4)	Strong convergence	Multiple passages on workforce and social capital loss	74.3% affected (60% moderate shortage, 14.3% key employees lost)
Domain expansion (B7)	Convergent (indirect)	14 organizations, 16 S-codes; one contradiction	Open-ended Q37: UAV reorientation, defense-adjacent pivots
Comply/evade distribution (B6)	Convergent with nuance	Compliance dominant; ritual compliance identified	86/14 raw comply/evade; 57% comply-only, 29% active cooperate
Organizational structure change (A3)	Convergent; drift rate reduced	10S, 5N; sector-dependent drift direction	54% unchanged, 17% decentralized, 14% centralized
Partnership disruption and recovery (E2, E4)	Convergent; permanent loss mechanism added	Crisis cooperation (4S); swift trust; erosion documented	43% lost 10–24%; 14% never recovered; 23% took >6 months
Pre-invasion preparation (J3)	Convergent with different emphasis	COVID pre-adaptation (11S, 2N)	Q38: comprehensive BCP, pre-booked hotels, advance infrastructure
Risk tolerance (A4)	Divergent: methodological artifact	0S, 2C; endogenous shifts documented	Mean 3.4/5 stable distribution (cross-sectional snapshot)
Cultural similarity in partner selection (A2)	Divergent: threshold vs. weight	Threshold filter implied; pro-Ukrainian split shaped groups	8.6% chose shared values as top criterion; 34% "cannot single out"
Workforce attrition vs. growth (A1, I4)	Divergent: temporal distance	Primarily loss: displacement, emigration, mobilization	34.3% increased workforce since invasion
Habituation to danger	Complementary (survey adds prevalence)	Three-phase normalization documented (K1)	51.4% returned to normal by "adapting to danger"
Burnout	Complementary (interview only)	~12 passages, qualitatively distinct from altruism decay	Not measured (survey design gap)

Mechanism	Assessment	Interview Evidence	Survey Evidence
International market buffer	Complementary (survey adds 2026 pattern)	International IT firms present but not salient in 2022–2023	Multiple respondents: 100% external clients as primary survival factor

Divergence explanations

Risk tolerance. The two methods measured different things. Interviews captured change over time; the survey captured a cross-sectional snapshot of the 2026 distribution. Organizations shifted their risk appetite and then settled into a new state. Both findings are consistent with endogenous change followed by stabilization.

Cultural similarity. A likely explanation is that cultural compatibility operates as a threshold filter rather than a selection weight. Organizations exclude culturally incompatible partners (perceived pro-russian orientation being the clearest case) before evaluating remaining candidates on other criteria. If culture operates prior to selection, respondents would not rank it as a selection factor.

Workforce dynamics. The three-year gap between data collections accounts for this divergence. Interviews from 2022–2023 documented primarily workforce loss. By 2026, surviving organizations had entered growth phases.

D.4. Structural Corrections Implemented Before Calibration

Six discrepancies between the empirical evidence and the initial model implementation were identified during the face validation and cross-validation. Table D.4 lists the six structural corrections, the supporting evidence, and the implementation change for each. All were applied before the calibration pipeline began.

Table D.4. Structural corrections from qualitative mechanism validation

Correction	Evidence	Change
Compliance precondition removed	Both sources showed one gating condition for the comply intention was not operative	Reduced from three simultaneous conditions to two

Correction	Evidence	Change
Government support persistence added	Cross-wave respondents described sustained government relationships beyond a single interaction	Support now persists with configurable decay rather than expiring after one tick
Partnership loss persistence added	Survey Q27: 14.3% reported partnerships that never recovered	Permanent loss fraction added (set from survey at 14.3%)
Planning horizon recovery revised	Survey Q16: 40% reported unchanged horizons; interviews showed stability alongside contraction	Contraction probability set from survey distribution; recovery includes a population-level ceiling
Structure drift rate reduced	Survey: 54% unchanged; interviews showed sector-dependent drift direction	Blend rate reduced from Epstein (2003) default; drift direction remains sector-independent
Workforce dynamics zone-differentiated	Interviews documented sharply different workforce trajectories in front vs. rear zones	Zone-differentiated attrition using OHCHR casualty data and IOM displacement data

D.5. Unmatched Behavioral Patterns

The face validation coding identified 19 behavioral patterns described by respondents that have no counterpart in the model (X-codes). They fall into two categories.

Patterns at the model's level of abstraction

These represent gaps that could, in principle, be addressed within the current model architecture.

Client compliance blocking employment. International clients imposed requirements that prevented hiring Ukrainian employees or operating from Ukrainian territory. The model's trade mechanics do not represent client-side institutional constraints.

Mobilization destroying inter-organizational trust. Mobilization in the model extracts workforce. Several respondents described a second-order effect: when a key contact person was mobilized, the trust accumulated through that personal relationship was lost entirely. The model's trust mechanism is organization-level and does not depend on specific individuals.

Patterns below the unitary-agent abstraction

These would require intra-organizational or individual-level representation and fall outside the model's design scope.

Burnout. Approximately 12 interview passages described cumulative personal exhaustion following a J-curve trajectory (initial energy surge, plateau, accelerating decline). Burnout is qualitatively distinct from altruism decay: altruism decay represents declining willingness to contribute to defense, while burnout represents declining capacity to function at all.

Fled-stayed polarization. Social tension within organizations between employees who left Ukraine and those who stayed affected team cohesion and decision-making authority.

Work as psychological shelter. Several respondents described their organization as a psychologically safe space, sometimes the only one available. Continued work served a therapeutic function distinct from its economic function.

Guilt dynamics. Guilt (for leaving, for staying, for not doing enough, for profiting during wartime) operated as a persistent motivational force shaping organizational decisions.

Identity transformation. Some organizations underwent fundamental identity changes that the 11-bit cultural tag captures as group similarity but not as qualitative character transformation.

These patterns define the phenomena the model is not designed to explain. They are carried forward as documented scope boundaries and identify candidates for future model iterations that include intra-organizational structure.

D.6. Calibration Layer Details

Layer 1: Macro-Statistical Derivations

Each Layer 1 parameter was derived from aggregate Ukrainian statistics rather than applied as a direct lookup. This section documents the derivation methodology.

Effective tax rate (0.27). Ukrainian enterprises operate under multiple tax regimes depending on size, ownership form, and registration status. The simplified tax system (yedynyy podatok) applies rates of 2–5% of revenue for Groups 1–3, while the general system applies a 18% corporate income tax on profit plus a 1.5% military levy (introduced 2022). The effective rate of 0.27 was calculated as the weighted average of these statutory rates, using State Statistics Service data on the proportional distribution of enterprises across size categories and tax regimes (Ministry of Finance of Ukraine, 2024; Kyiv School of Economics, 2024; Bogdan, 2024). The model consolidates both systems into a single fiscal channel because it does not distinguish enterprise types by tax status.

Mobilization rate (25 units per recruitment event). Center for Strategic and International Studies (CSIS) force structure tracking reports approximately 130 brigade-equivalent formations by mid-2024 (Jones & McCabe, 2026), with total personnel estimated at 800,000–900,000 by Centre for Eastern Studies (OSW; Wilk & Żochowski, 2025). At a model-to-brigade ratio of approximately 1:1 (with 120–140 agents representing Ukraine's 130 brigade-equivalent formations), the recruitment rate of 25 units per mobilization event was set to reach this target within the documented timeline, accounting for the model's stochastic recruitment logic and attrition.

Infrastructure strike frequency (0.03 per tick). The World Bank Rapid Damage and Needs Assessments (RDNA3: World Bank et al., 2024; RDNA4: World Bank et al., 2025; RDNA5: World Bank Group et al., 2026) document cumulative infrastructure damage as a percentage of pre-invasion capital stock. The per-tick probability of 0.03 was calibrated to reproduce the documented damage trajectory over 300 ticks, with spatial concentration in the eastern front zone and periodic escalation matching documented strike patterns.

Initial civilian population (800). The State Statistics Service registry records approximately 320,000 active legal entities. At the model's 1:400 scale, this gives 800 initial civilian agents. The registry count includes enterprises of all sizes; the model represents each as a unitary agent regardless of size, with size-dependent properties (vision range, initial money) assigned from separate distributions.

Layer 2: Survey-Derived Parameters

Five parameters were committed from survey response distributions. The survey items, response distributions, and calibration mapping for each parameter are documented in Appendix B (Survey Instrument, Results, and Mechanism Mapping). This section summarizes the derivation logic.

The safety threshold (0.35) was derived by comparing self-reported safety assessments (Q12) between relocators and non-relocators (Q18), normalized to the model's [0,1] safety scale and adjusted for the habituation effect documented in the interviews. The partner memory decay time (35 ticks, approximately 105 days) was set from the median partnership recovery duration reported in Q27. The initial planning horizon (0.38) was calculated as a weighted midpoint from the Q16 distribution (51.4% shortened, 40% unchanged, 5.8% lengthened). The permanent partner loss fraction (0.143) was set directly from the Q27 finding that 14.3% of respondents reported partnerships that never recovered. The cultural compatibility weight (0.35) was set from Q28, reflecting the finding that cultural similarity operates as a threshold filter rather than a dominant selection criterion: only 8.6% ranked shared values as the top criterion, while 34.3% said no single factor dominated.

The survey also provided initial distributions for four agent-level properties: risk tolerance N(0.60, 0.30) from Q13, organizational hierarchy N(0.63, 0.20) from Q14, military friendliness Beta(4.0, 2.1) from Q35, and a planning horizon mixture from Q16 (53% from U(0.15, 0.40), 41% from U(0.40, 0.60), 6% from U(0.60, 0.80)). The initial comply/evade split was set at 86/14 from Q31, with an 80/20 adjustment applied as a robustness check.

Layer 3: Latin Hypercube Sampling

Latin Hypercube Sampling (LHS) is a statistical sampling method that divides each parameter's range into equal-probability intervals and draws exactly one sample from each interval, ensuring that the full range of every parameter is represented in the design (McKay, Beckman, & Conover, 1979). The maximin variant additionally maximizes the minimum distance between sample points, preventing clustering in the parameter space. LHS achieves better coverage of a high-dimensional space than random sampling with the same number of points, making it suitable for the six operational parameters that have no direct empirical anchor.

The design used 80 sample points across 18 dimensions (the nine Layer 1–2 parameters were held fixed), with 30 replications per point, producing 2,400 runs. Each run was measured against 21 validation targets. Row 50 was selected as the best design point, achieving the lowest sum of distances across 17 of 21 targets. Six parameters were committed from this row: civ-birth-mutation-rate (0.028), civilian-operate-revenue-rate (0.789), civilian-comply-revenue-rate (0.265), civilian-evade-revenue-rate (0.640), wf-migration-outflow-rate (0.272), and wf-transit-return-rate (0.097).

The three trust parameters (trust-trade-volume-weight, trust-decay-rate, trust-swift-culture-weight) were not committed at this layer despite being included in the LHS design. The sensitivity analysis had identified them as entangled with both economic and network outputs, and the LHS results showed that no single trust configuration satisfied both the economic and network validation targets simultaneously. These parameters were carried forward to Layer 4 for joint optimization.

D.7. BehaviorSearch Optimization: Methods and Cross-Method Comparison

Method Description

BehaviorSearch (Stonedahl & Wilensky, 2010) is an open-source software tool bundled with NetLogo that automates nonlinear numerical optimization in a model's parameter space. The user specifies which parameters to search, their ranges, and a fitness measure that quantifies how well the model's output matches desired behavior. BehaviorSearch then searches the parameter space to minimize (or maximize) the fitness measure, using one of several available algorithms. The tool supports numerical (discrete and continuous), boolean, and categorical parameters, and provides multi-threaded parallel execution for multi-core machines (Stonedahl & Wilensky, 2010).

BehaviorSearch offers several search algorithms because different strategies may be more efficient for different fitness landscapes. The four algorithms used in this calibration are described below.

The genetic algorithm (GA) maintains a population of candidate parameter sets (here: population 50). In each generation, candidates are evaluated by running the model, selected based on fitness (tournament selection with size 3), recombined through crossover (rate 0.7), and mutated (rate 0.05). Gray binary chromosome encoding was used to prevent Hamming cliff artifacts, where adjacent parameter values map to distant binary representations. GAs are effective at escaping local optima through population diversity but require many evaluations.

Simulated annealing begins with a single candidate and makes random perturbations. If a perturbation improves fitness, it is accepted. If it worsens fitness, it is accepted with a probability that decreases over time (the "cooling schedule"). This allows the search to escape local optima early and converge as the temperature falls.

Stochastic hill climbing begins with a single candidate and accepts only perturbations that improve fitness. It converges quickly but is susceptible to local optima.

Random search evaluates randomly generated parameter sets. It serves as a baseline: any algorithm that performs worse than random search is not adding value.

Search Configuration

Thirteen parameters remained after the LHS commitment: ten operational parameters controlling agent-level decision dynamics (government spending floor, bankruptcy probability, operating costs, planning horizon rates, diaspora loss, attrition, and three decision weights) and the three trust parameters. The fitness function was the sum of squared normalized band errors across 20 active calibration targets (21 total, with V3.4 military deaths excluded due to a reporter-metric mismatch). A fitness of zero would indicate that all targets fall within their acceptance bands simultaneously. Each method used approximately

2,500 evaluations with 3 replications per evaluation, and each method's best candidate was rechecked with 15 replications to reduce stochastic noise.

Cross-Method Comparison

Table D.5 reports the parameter values committed by each of the four BehaviorSearch optimization methods, allowing direct cross-method comparison of converged solutions.

Table D.5. Winning configurations from four BehaviorSearch methods

Parameter	Description	Genetic Algorithm	Random	Hill Climber	Simulated Annealing	Interpretation
gov-spending-floor	Min. government spending	0.15	0.45	0.20	0.40	Divergent: two regimes
civ-death-probability-rate	Bankruptcy death probability	0.08	0.09	0.10	0.07	Convergent
civilian-op-cost-rate	Operating cost fraction	0.11	0.13	0.09	0.08	Convergent
adaptive-planning-increase	Planning recovery rate	0.004	0.001	0.004	0.001	Moderate divergence
adaptive-planning-decrease	Planning contraction rate	0.015	0.025	0.005	0.020	Poorly constrained
wf-return-diaspora-loss-rate	Permanent diaspora loss	0.010	0.011	0.014	0.020	Moderate convergence
civilian-attrition-rate	Background org. death rate	0.04	0.01	0.03	0.04	Moderate divergence
w-comply-culture	Cultural weight in compliance	1.20	1.20	1.40	1.00	Convergent
w-comply-hierarchy	Hierarchy weight in compliance	0.40	0.30	0.90	1.00	Divergent
w-evade-risk	Risk weight in evasion	0.50	0.50	0.20	0.70	Moderate divergence

Parameter	Description	Genetic Algorithm	Random	Hill Climber	Simulated Annealing	Interpretation
trust-trade-volume-weight	Trust effect on trade volume	0.25	0.85	0.20	0.45	Strongly divergent
trust-decay-rate	Trust erosion between trades	0.002	0.024	0.002	0.044	Strongly divergent
trust-swift-culture-weight	Cultural basis of swift trust	0.90	0.75	0.55	0.20	Divergent
Rechecked fitness	–	1.826	2.079	2.135	2.217	All within factor of 1.2

D.8. Committed Parameter Set

Table D.6 presents the complete committed parameter set across all four calibration layers. This is the model's final calibration: the parameter values locked in before the model is used for computational experiments.

Table D.6. Committed parameter set: four calibration layers

Layer	Parameter	Description	Value	Source
1	gov-tax-rate	Effective tax rate	0.27	Ministry of Finance (derived)
1	gov-recruit-rate	Military units mobilized	25	CSIS (Jones & McCabe, 2026; rescaled)
1	base-disaster-rate	Infrastructure strike frequency	0.03	World Bank RDNA3–5 (derived)
1	civ-init-target-count	Initial civilian organizations	800	State Statistics Service (1:400 scale)
2	civilian-safety-threshold-base	Safety level triggering relocation	0.35	Survey Q12, Q18 (derived)
2	memory-decay-time	Partner memory half-life (ticks)	35	Survey Q27 (converted)
2	initial-planning-horizon	Starting planning horizon [0,1]	0.38	Survey Q16 (weighted midpoint)
2	permanent-partner-loss-fraction	Share of links permanently lost	0.143	Survey Q27 (direct)

Layer	Parameter	Description	Value	Source
2	seek-compat-culture-weight	Cultural similarity in partner choice	0.35	Survey Q28 (derived)
3	civ-birth-mutation-rate	Cultural tag mutation at birth	0.028	LHS row 50
3	civilian-operate-revenue-rate	Revenue per unit output	0.789	LHS row 50
3	civilian-comply-revenue-rate	Revenue from compliance	0.265	LHS row 50
3	civilian-evade-revenue-rate	Revenue from evasion	0.640	LHS row 50
3	wf-migration-outflow-rate	Workforce displacement rate	0.272	LHS row 50
3	wf-transit-return-rate	Displaced workforce return rate	0.097	LHS row 50
4	gov-spending-floor	Minimum government spending	0.15	BehaviorSearch GA
4	civ-death-probability-rate	Bankruptcy death probability	0.08	BehaviorSearch GA
4	civilian-op-cost-rate	Operating cost fraction	0.11	BehaviorSearch GA
4	adaptive-planning-increase	Planning horizon recovery rate	0.004	BehaviorSearch GA
4	adaptive-planning-decrease	Planning horizon contraction rate	0.015	BehaviorSearch GA
4	wf-return-diaspora-loss-rate	Permanent diaspora loss rate	0.01	BehaviorSearch GA
4	civilian-attrition-rate	Background organizational attrition	0.04	BehaviorSearch GA
4	w-comply-culture	Cultural weight in comply decision	1.20	BehaviorSearch GA
4	w-comply-hierarchy	Hierarchy weight in comply decision	0.40	BehaviorSearch GA
4	w-evade-risk	Risk tolerance weight in evade decision	0.50	BehaviorSearch GA
4	trust-trade-volume-weight	Trust effect on trade volume	0.25	BehaviorSearch GA (joint)

Layer	Parameter	Description	Value	Source
4	trust-decay-rate	Trust erosion between trades	0.002	BehaviorSearch GA (joint)
4	trust-swift-culture-weight	Cultural basis of swift trust	0.90	BehaviorSearch GA (joint)

The committed set satisfies 17 of 21 LHS targets and achieves a BehaviorSearch fitness of 1.826. The table lists 28 parameters whose values were committed through the four-layer calibration process. The remaining 10 of the model's 38 parameters (see Table D.8 for the full inventory) retain their default values as specified in the ODD protocol. These include parameters whose default values are structural constants (e.g., grid dimensions, initial spatial distributions) rather than behavioral parameters subject to calibration.

D.9. Validation Targets

The calibration was constrained by 21 validation targets drawn from all eight experimental domains (V1–V8). Each target specifies an acceptance band for a model reporter at a particular tick, derived from empirical data. The temporal mapping follows the ODD specification: one tick represents approximately three days, with 300 ticks spanning the first 2.5 years of the full-scale invasion (February 2022 through approximately August 2024).

Three factors determine a band's width. Temporal imprecision (the tick-to-date mapping is approximate, ±15 days) means that a data point documented for a specific date may fall within a range of model ticks. Cross-source disagreement (multiple sources providing different estimates for the same quantity) causes the band to span the range of plausible values. The absence of direct external data affects the network structure targets (V8), which are derived from the LHS calibration ensemble rather than empirical observation.

The 21 validation targets reported here are the subset of the model's 43 pattern-oriented validation criteria that were used as fitness anchors during calibration. The remaining 22 criteria are reserved for post-calibration validation in Chapter 5 and were not used to constrain the parameter search. The full set of 43 criteria across all eight validation domains (V1–V8) is reported in Chapter 5, Table 5.4.

Table D.7 lists the validation targets used to anchor calibration: each row specifies an experiment, the model reporter, the target tick, the acceptance interval, and the empirical source.

Table D.7. Validation targets for empirical calibration

Experiment	Reporter	Tick	Low	High	Empirical Source
V1	pct-civilians-relocating	21	1	20	15% displaced by late April 2022 (IOM)
V1	fled-workforce-pool (ratio)	50	0.03	0.15	Peak displacement wave; late July 2022
V1	fled-workforce-pool (ratio)	200	0.01	0.08	Partial returns; pool persists (October 2023)
V1	total-workforce (ratio)	300	0.60	0.90	Permanent workforce deficit (August 2024)
V1	total-workforce (ratio)	400	0.55	0.90	Late-war level (~June 2025)
V2	count-civilians (ratio)	80	0.55	0.85	30% org closure by October 2022 (Opendatabot)
V2	count-civilians (ratio)	300	0.10	0.70	Long-run survival rate (August 2024)
V3	count-militaries	110	100	200	130 brigades after mobilization (Jones & McCabe, 2026)
V3	total-mil-people	200	2,000	4,800	~907K personnel at 1:189 scale (Jones & McCabe, 2026; Wilk & Żochowski, 2025)
V3	total-military-deaths	300	200	600	Corrected proportional target (August 2024)
V4	gov-treasury (ratio)	30	0.05	0.80	Fiscal collapse, late May 2022 (Ministry of Finance of Ukraine, 2024)
V4	gov-treasury (ratio)	160	0.20	2.00	Fiscal recovery onset June 2023

Experiment	Reporter	Tick	Low	High	Empirical Source
V4	gov-treasury (ratio)	200	0.50	5.00	Revenue recovery; 24.7% growth (Bogdan, 2024)
V4	pct-civilians-complying	200	40	95	Survey Q31: 86% comply (October 2023)
V4	pct-civilians-complying	400	30	95	Sustained late-war compliance (June 2025)
V7	cultural-diversity (ratio)	200	0.20	0.80	Identity convergence: 60%–94% Ukrainian Hrushetskyi, 2024; Sociological Group "Rating", 2025)
V7	pct-long-horizon	200	5	60	NBU BAEI recovery to 49.4 (October 2023)
V7	pct-long-horizon	400	5	70	Continued planning recovery (June 2025)
V8	count-trade-links-total	80	100	500	Peak network formation (LHS ensemble mean = 261)
V8	count-trade-links-total	300	30	300	Network with permanent deficit (LHS ensemble mean = 112)
V8	count-supply-links-total	200	200	1,500	Supply network maturation (LHS ensemble mean = 500–700)

Three tiers classify how directly the model reporter corresponds to the empirical measure. Tier 1 indicates the same quantity measured in the same unit. Tier 2 indicates proportional scaling or temporal interpolation. Tier 3 indicates qualitative or model-derived correspondence. Tier 1 criteria pass at 83% (10 of 12), Tier 2 at 44% (4 of 9), and Tier 3 at 55% (6 of 11), indicating that the model reproduces empirical patterns most reliably where the measurement correspondence is most direct.

D.10. Morris Elementary Effects Screening

Method

The Morris method (Morris, 1991) is a global sensitivity analysis technique designed to identify which parameters most influence a model's output and whether their effects are additive or interactive. It achieves this at a computational cost far lower than variance-based methods (such as Sobol indices), making it practical for models with large parameter spaces and long run times.

The method works by constructing trajectories through the parameter space. Each trajectory is a sequence of points in which exactly one parameter changes at each step, while all others remain fixed. The parameter space is first discretized into p levels (here p=10), creating a grid. A trajectory begins at a randomly chosen grid point. At each subsequent step, one parameter is increased or decreased by a fixed increment $\Delta = p / [2(p-1)]$, and the model is run at the new point. The difference in model output between the two points, divided by Δ, is the elementary effect (EE) for that parameter at that location in the parameter space. Because each trajectory visits a different region of the space, the elementary effects for the same parameter vary across trajectories, and the pattern of that variation is the method's diagnostic power.

After collecting elementary effects from r trajectories (here r=20), each parameter is summarized by two statistics. The mean of the absolute elementary effects (μ) indicates the parameter's average influence on the output, regardless of direction. The standard deviation of the elementary effects (σ) indicates how much the parameter's influence varies depending on the values of other parameters. When σ is small relative to μ, the parameter has a consistent, additive effect. When σ exceeds μ, the parameter's effect is interactive: it depends strongly on what other parameters are doing. The σ/μ ratio is the primary diagnostic for distinguishing additive from interactive parameters.

The original Morris (1991) design selected trajectories randomly, which can leave regions of the parameter space undersampled. The enhanced design of Campolongo, Cariboni, and Saltelli (2007) addresses this by generating a large pool of candidate trajectories (here: 1,000) and selecting a subset of r trajectories that maximizes their spread across the parameter space, measured by the sum of pairwise Euclidean distances between trajectory starting points. This produces more uniform coverage without increasing the number of model runs.

The implementation used the companion R scripts developed by Thiele, Kurth, and Grimm (2014) for NetLogo models, which automate the design matrix generation, BehaviorSpace experiment file creation, and post-processing of elementary effects. Each of the 19,500 runs (20 trajectories × 39 points per trajectory × 25 replicates per design point) was measured on 52 model reporters at four ticks (80, 160, 300, 400), producing 208 output measures per run. Each trajectory consists of one starting point plus 38 successive one-at-a-time perturbations of the 38 parameters, producing $k + 1 = 39$ design points per trajectory; the design used $p = 4$ levels with grid jump $\Delta = 2$.

Parameter Selection

All 38 model parameters were included in the Morris screening. The purpose of the screening was to determine which parameters are influential and which are negligible, so excluding any parameter in advance would presuppose the answer. The parameter ranges were set to span the full plausible range for each parameter, informed by the empirical evidence from Layers 1-2 where available and by exploratory runs where not.

D.11. Results

Table D.8 presents the complete ranking of all 38 parameters. Parameters are ranked by aggregate mean absolute elementary effect (μ^*) across all 208 output measures. The Tier column classifies each parameter by its origin: T1 = interface slider (user-adjustable in the NetLogo interface), T2 = hardcoded parameter (set in setup procedures), T3 = parameter added in the V0.80 trust, network, and MCR architecture revision. The Interactive column reports the number of output measures (out of 208) for which $\sigma > \mu^*$.

Table D.8. Complete Morris elementary effects parameter ranking (38 parameters, 208 output measures)

#	Parameter	Description	Tier	μ*	σ	Int.
1	trust-trade-volume-weight	Trust-volume trade scaling	T3	659.49	780.85	193/208
2	wf-transit-return-rate	Diaspora return rate	T2	603.31	719.93	193/208
3	civilian-safety-threshold-base	Relocation safety threshold	T2	600.00	695.43	192/208
4	government-strength	Institutional capacity	T1	562.98	713.41	192/208
5	split-threshold	Organisation splitting age	T1	555.83	693.32	191/208
6	long-tie-keep-count	Preserved distant partners	T3	547.57	669.94	193/208
7	planning-recovery-ceiling	Long-horizon population cap	T3	544.68	627.29	195/208
8	adaptive-altruism-distress-count	Altruism activation threshold	T2	542.30	674.37	193/208
9	hub-degree-threshold	Hub coordinator threshold	T3	535.94	722.96	194/208
10	trust-decay-rate	Trust inactivity decay	T3	532.54	641.87	193/208
11	civilian-evade-revenue-rate	Evasion revenue fraction	T2	531.55	636.00	191/208
12	trust-swift-culture-weight	Cultural swift-trust weight	T3	524.51	598.66	192/208
13	wf-migration-outflow-rate	Displacement outflow rate	T2	523.62	641.59	193/208
14	mil-coordinate-blend-rate	Military coordination blending	T2	519.22	669.52	193/208
15	long-tie-trade-discount	Distance trade penalty	T3	511.08	640.85	192/208
16	seek-compat-culture-weight	Partner cultural preference	T2	507.75	640.86	191/208
17	civ-birth-mutation-rate	Cultural tag mutation	T2	507.06	633.35	193/208
18	trust-habitual-threshold	Habitual trust threshold	T3	504.32	634.88	193/208

#	Parameter	Description	Tier	μ*	σ	Int.
19	mcr-crisis-safety-threshold	Crisis militarisation threshold	T3	503.58	605.75	193/208
20	initial-planning-horizon	Initial planning horizon	T1	501.79	636.65	192/208
21	gov-tax-rate	Effective tax rate	T1	499.87	631.43	191/208
22	mcr-crisis-increase	Crisis militarisation rate	T3	496.46	622.12	193/208
23	memory-decay-time	Partnership memory decay	T1	493.72	579.01	192/208
24	mil-support-gov-hierarchy-rate	Military hierarchy drift	T2	492.17	627.31	192/208
25	rear-strike-share	Rear strike targeting	T2	487.43	570.16	193/208
26	adaptive-planning-decrease	Horizon contraction rate	T2	486.29	680.55	194/208
27	subsidy-bias	Cultural subsidy bias	T1	485.50	642.03	189/208
28	civilian-operate-revenue-rate	Operations revenue fraction	T2	478.95	556.21	193/208
29	trust-swift-base	Baseline swift trust	T3	473.28	610.00	192/208
30	base-disaster-rate	Strike frequency rate	T2	467.01	615.75	194/208
31	gov-recruit-rate	Military recruitment rate	T2	455.20	582.78	192/208
32	planning-mod-safety-crisis	Safety crisis threshold	T2	454.03	550.05	191/208
33	hub-broker-rate	Hub brokerage rate	T3	452.13	545.19	192/208
34	min-front-deployment	Minimum front rotation	T3	439.88	561.23	191/208
35	civilian-comply-revenue-rate	Compliance revenue fraction	T2	429.33	557.16	195/208
36	initial-altruism	Initial altruism level	T1	427.21	537.16	190/208
37	civ-init-target-count	Initial civilian count	T1	399.23	512.27	192/208
38	trust-increment-rate	Trust per-trade gain	T3	391.08	467.29	189/208

Note: μ = mean absolute elementary effect aggregated across 208 output measures. σ = standard deviation of elementary effects. Int. = number of output measures (out of 208) where σ > μ, indicating interactive behavior.

The full ranking shows a flat influence distribution. The μ range from the highest (659 for trust-trade-volume-weight) to the lowest (391 for trust-increment-rate) spans less than a factor of two. There is no natural break point that separates "influential" from "negligible" parameters. All 38 exhibit $\sigma > \mu$ on the majority of outputs, confirming pervasive parameter interactions throughout the model.

The Tier distribution in the top 10 is notable: five of the ten most influential parameters are T3 (trust, network, and MCR architecture), added in the V0.80 revision. This indicates that the trust and network subsystems, which are among the model's more original contributions, are also among its most consequential for model behavior.

D.12. Stability Check

Table D.9 presents the Spearman rank-correlation coefficients comparing the top-10 parameter ranking obtained from $r = 3$ trajectories against the full $r = 20$ trajectories, for each of the 208 output measures (52 reporters at 4 ticks). A coefficient of $\rho >= 0.8$ is considered stable, indicating that the parameter ranking would not change materially with additional trajectories.

Only 1 of 208 output measures met the stability threshold: total-trades at t160 ($\rho = 0.818$). The remaining 207 were unstable. Many correlation coefficients are near zero, and a substantial number are negative, meaning the top-10 parameter ranking actually reversed between the $r = 3$ and $r = 20$ subsets. Negative correlations are stronger evidence for interactions than mere instability: they indicate that the relative importance of parameters shifts qualitatively depending on which region of the parameter space is sampled.

Two output reporters deserve specific attention. pct-civilians-defending and pct-civilians-mutual-aid return $\rho = 0.000$ at all four ticks. This is consistent with the $\mu = 0$ finding in Table D.8: these reporters produce zero variation under any parameter combination in the screening space. The activation chain for defending and mutual-aid intentions, which runs from the altruism threshold through the MCR gating condition to the behavioral output, is never triggered. This is a structural limitation rather than a parameter issue.

The near-universal instability does not invalidate the screening. The qualitative conclusion that all parameters interact with all others is itself robust, and the aggregate ranking in Table D.8 is based on the full r = 20 trajectories. The recommendation to increase to r = 30 for future studies is noted but does not affect the present analysis, which proceeds to OFAT local sensitivity for the top-ranked parameters.

Table D.9. Morris stability check: Spearman rank-correlation between r = 3 and r = 20 trajectory rankings (208 output measures)

Output Reporter	**Tick**	**Spearman ρ**	**Stable?**
avg-altruism	t80	-0.248	No
avg-altruism	t160	-0.188	No
avg-altruism	t300	-0.042	No
avg-altruism	t400	-0.212	No
avg-civilian-money	t80	0.455	No
avg-civilian-money	t160	0.685	No
avg-civilian-money	t300	-0.333	No
avg-civilian-money	t400	-0.176	No
avg-coordination-degree	t80	-0.321	No
avg-coordination-degree	t160	-0.600	No
avg-coordination-degree	t300	0.139	No
avg-coordination-degree	t400	0.588	No
avg-mcr-civilians	t80	0.127	No
avg-mcr-civilians	t160	0.188	No
avg-mcr-civilians	t300	-0.164	No
avg-mcr-civilians	t400	-0.176	No
avg-mil-money	t80	0.467	No
avg-mil-money	t160	0.152	No
avg-mil-money	t300	0.139	No
avg-mil-money	t400	0.103	No
avg-planning-horizon	t80	-0.055	No

Output Reporter	Tick	Spearman ρ	Stable?
avg-planning-horizon	t160	0.055	No
avg-planning-horizon	t300	-0.042	No
avg-planning-horizon	t400	0.418	No
avg-safety-front	t80	-0.418	No
avg-safety-front	t160	0.285	No
avg-safety-front	t300	-0.188	No
avg-safety-front	t400	0.212	No
avg-safety-landscape	t80	-0.164	No
avg-safety-landscape	t160	0.297	No
avg-safety-landscape	t300	-0.079	No
avg-safety-landscape	t400	-0.042	No
avg-safety-rear	t80	-0.006	No
avg-safety-rear	t160	0.212	No
avg-safety-rear	t300	-0.055	No
avg-safety-rear	t400	0.406	No
avg-social-capital-proxy	t80	0.030	No
avg-social-capital-proxy	t160	-0.018	No
avg-social-capital-proxy	t300	-0.188	No
avg-social-capital-proxy	t400	0.236	No
avg-trade-degree	t80	0.200	No
avg-trade-degree	t160	-0.394	No
avg-trade-degree	t300	-0.673	No
avg-trade-degree	t400	-0.224	No
avg-trust-level	t80	0.018	No
avg-trust-level	t160	0.406	No
avg-trust-level	t300	0.285	No
avg-trust-level	t400	-0.103	No
bridging-link-count	t80	0.176	No
bridging-link-count	t160	0.115	No

Output Reporter	Tick	Spearman ρ	Stable?
bridging-link-count	t300	-0.358	No
bridging-link-count	t400	0.115	No
civilians-in-front	t80	0.273	No
civilians-in-front	t160	-0.245	No
civilians-in-front	t300	-0.085	No
civilians-in-front	t400	0.170	No
civilians-in-middle	t80	0.394	No
civilians-in-middle	t160	-0.030	No
civilians-in-middle	t300	0.467	No
civilians-in-middle	t400	0.067	No
civilians-in-rear	t80	0.201	No
civilians-in-rear	t160	0.030	No
civilians-in-rear	t300	0.200	No
civilians-in-rear	t400	0.067	No
count-civilians	t80	-0.042	No
count-civilians	t160	-0.212	No
count-civilians	t300	-0.134	No
count-civilians	t400	0.224	No
count-hub-coordinators	t80	0.000	No
count-hub-coordinators	t160	-0.218	No
count-hub-coordinators	t300	-0.218	No
count-hub-coordinators	t400	0.000	No
count-long-ties	t80	-0.164	No
count-long-ties	t160	-0.309	No
count-long-ties	t300	0.236	No
count-long-ties	t400	-0.345	No
count-militaries	t80	0.685	No
count-militaries	t160	0.248	No
count-militaries	t300	-0.152	No

Output Reporter	Tick	Spearman ρ	Stable?
count-militaries	t400	0.188	No
count-supply-links-total	t80	0.300	No
count-supply-links-total	t160	-0.430	No
count-supply-links-total	t300	0.115	No
count-supply-links-total	t400	-0.358	No
count-trade-links-total	t80	0.309	No
count-trade-links-total	t160	0.261	No
count-trade-links-total	t300	-0.018	No
count-trade-links-total	t400	-0.236	No
cross-group-trade-fraction	t80	-0.018	No
cross-group-trade-fraction	t160	0.612	No
cross-group-trade-fraction	t300	0.709	No
cross-group-trade-fraction	t400	0.285	No
cultural-diversity	t80	0.067	No
cultural-diversity	t160	-0.103	No
cultural-diversity	t300	-0.309	No
cultural-diversity	t400	0.224	No
fled-workforce-pool	t80	0.576	No
fled-workforce-pool	t160	-0.030	No
fled-workforce-pool	t300	0.212	No
fled-workforce-pool	t400	-0.055	No
giant-component-fraction	t80	0.442	No
giant-component-fraction	t160	-0.236	No
giant-component-fraction	t300	-0.139	No

Output Reporter	Tick	Spearman ρ	Stable?
giant-component-fraction	t400	0.309	No
gov-treasury	t80	0.418	No
gov-treasury	t160	0.030	No
gov-treasury	t300	0.115	No
gov-treasury	t400	0.515	No
jungle-index	t80	-0.115	No
jungle-index	t160	0.261	No
jungle-index	t300	-0.200	No
jungle-index	t400	-0.079	No
mean-civilian-output	t80	-0.200	No
mean-civilian-output	t160	-0.018	No
mean-civilian-output	t300	0.273	No
mean-civilian-output	t400	0.079	No
nw-clustering-coefficient	t80	-0.030	No
nw-clustering-coefficient	t160	-0.600	No
nw-clustering-coefficient	t300	-0.418	No
nw-clustering-coefficient	t400	0.042	No
pct-civilians-complying	t80	-0.006	No
pct-civilians-complying	t160	-0.055	No
pct-civilians-complying	t300	0.321	No
pct-civilians-complying	t400	0.491	No
pct-civilians-defending	t80	0.000	No
pct-civilians-defending	t160	0.000	No
pct-civilians-defending	t300	0.000	No
pct-civilians-defending	t400	0.000	No
pct-civilians-evading	t80	0.442	No

Output Reporter	Tick	Spearman ρ	Stable?
pct-civilians-evading	t160	-0.139	No
pct-civilians-evading	t300	0.564	No
pct-civilians-evading	t400	-0.345	No
pct-civilians-mutual-aid	t80	0.000	No
pct-civilians-mutual-aid	t160	0.000	No
pct-civilians-mutual-aid	t300	0.000	No
pct-civilians-mutual-aid	t400	0.000	No
pct-civilians-operating	t80	0.479	No
pct-civilians-operating	t160	0.139	No
pct-civilians-operating	t300	0.333	No
pct-civilians-operating	t400	0.564	No
pct-civilians-relocating	t80	-0.055	No
pct-civilians-relocating	t160	-0.115	No
pct-civilians-relocating	t300	0.188	No
pct-civilians-relocating	t400	-0.236	No
pct-civilians-seeking	t80	0.648	No
pct-civilians-seeking	t160	-0.309	No
pct-civilians-seeking	t300	-0.321	No
pct-civilians-seeking	t400	0.030	No
pct-civilians-supporting	t80	0.172	No
pct-civilians-supporting	t160	0.000	No
pct-civilians-supporting	t300	-0.126	No
pct-civilians-supporting	t400	0.487	No
pct-domain-expanded	t80	-0.261	No
pct-domain-expanded	t160	-0.297	No
pct-domain-expanded	t300	0.467	No
pct-domain-expanded	t400	0.042	No
pct-long-horizon	t80	0.000	No
pct-long-horizon	t160	0.200	No

Output Reporter	**Tick**	**Spearman ρ**	**Stable?**
pct-long-horizon	t300	0.200	No
pct-long-horizon	t400	0.200	No
pct-militarized-civilians	t80	0.139	No
pct-militarized-civilians	t160	0.455	No
pct-militarized-civilians	t300	0.285	No
pct-militarized-civilians	t400	0.042	No
pct-short-horizon	t80	-0.297	No
pct-short-horizon	t160	0.103	No
pct-short-horizon	t300	0.115	No
pct-short-horizon	t400	-0.176	No
threat-front-x	t80	0.285	No
threat-front-x	t160	0.055	No
threat-front-x	t300	0.297	No
threat-front-x	t400	-0.018	No
total-civilian-births	t80	0.370	No
total-civilian-births	t160	0.176	No
total-civilian-births	t300	-0.624	No
total-civilian-births	t400	0.067	No
total-civilian-deaths	t80	0.297	No
total-civilian-deaths	t160	0.333	No
total-civilian-deaths	t300	-0.188	No
total-civilian-deaths	t400	0.200	No
total-military-deaths	t80	-0.304	No
total-military-deaths	t160	0.055	No
total-military-deaths	t300	0.370	No
total-military-deaths	t400	0.176	No
total-money	t80	0.297	No
total-money	t160	-0.018	No
total-money	t300	0.248	No

Output Reporter	Tick	Spearman ρ	Stable?
total-money	t400	0.648	No
total-people	t80	0.018	No
total-people	t160	-0.467	No
total-people	t300	-0.115	No
total-people	t400	0.370	No
total-trades	t80	0.091	No
total-trades	t160	0.818	Yes
total-trades	t300	0.491	No
total-trades	t400	0.394	No
total-workforce	t80	0.636	No
total-workforce	t160	0.164	No
total-workforce	t300	-0.103	No
total-workforce	t400	-0.224	No
trade-component-count	t80	0.600	No
trade-component-count	t160	0.309	No
trade-component-count	t300	0.055	No
trade-component-count	t400	-0.006	No
workforce-utilization	t80	0.588	No
workforce-utilization	t160	0.721	No
workforce-utilization	t300	0.455	No
workforce-utilization	t400	0.091	No

Negative ρ values indicate that the top-10 parameter ranking reversed between the $r = 3$ and $r = 20$ subsets, reflecting high-order parameter interactions.

D.13. OFAT Domain Affinity Mapping

Method

One-factor-at-a-time (OFAT) analysis is a local sensitivity method that complements the Morris screening's global ranking. Morris asks "how influential is this parameter across the entire parameter space?" OFAT asks a different question: "what happens to each output domain when this specific parameter changes, with all other parameters held at their baseline values?"

For each selected parameter, OFAT holds all others at the committed baseline values (from Layers 1-2 of the calibration) and varies the focal parameter across its full range in equal steps. At each step, the model is run multiple times (here: 30 replications) to account for stochastic variation, and the mean output is recorded for every reporter. The result is a response curve for each parameter-reporter pair, showing the direction (positive or negative), shape (linear, threshold, saturating), and magnitude of the effect.

The key diagnostic from OFAT is domain affinity: whether a parameter's effects are confined to a single output domain (behavior, economy, spatial, network) or cross domain boundaries. Cross-domain effects indicate parameter entanglement. The "Primary Effect" statistic in Table D.10 reports the ratio of the maximum output change to the parameter change across the primary domain's reporters, providing a scale-free measure of sensitivity.

Parameter Selection

Sixteen parameters were selected for OFAT analysis from the Morris screening results. The selection included the eight most influential parameters by aggregate μ *(ranks 1-8 in Table D.8) and eight additional parameters from the upper half of the ranking (ranks 9-19, selected to ensure coverage of all mechanism types: trust, network, workforce, fiscal, and behavioral parameters). The lower-ranked parameters (ranks 20-38) were excluded because their aggregate μ* values were within the flat distribution range identified by the Morris screening.

Results

Each parameter was varied across 15 levels with 30 replications, producing 7,200 runs measured on 52 reporters at five ticks. Table D.10 maps each parameter to its primary and secondary output domains.

Table D.10. OFAT domain affinity: 16 parameters mapped to primary and secondary output domains

Parameter	Primary Domain	Secondary Domain	Primary Effect	Cross-Domain?
trust-trade-volume-weight	Behavior	Economy / Network	2.7-5.5	Yes
trust-decay-rate	Spatial	Behavior	1.4-2.9	Yes
trust-swift-culture-weight	Spatial / Behavior	Network	3.4-9.0	Yes
hub-degree-threshold	Behavior	Spatial	3.1-4.9	Yes
long-tie-keep-count	Economy / Behavior	Network	0.7-4.6	Yes
long-tie-trade-discount	Spatial / Behavior	Economy	4.1-4.3	Yes
planning-recovery-ceiling	Economy	Spatial	5.2	Yes
government-strength	Behavior / Economy	Spatial	1.6-8.3	Yes
split-threshold	Behavior	Economy	1.4-15.7	Moderate
civilian-safety-threshold-base	Spatial / Network	Economy	1.6-6.0	Yes
wf-transit-return-rate	Behavior	Spatial	2.0-33.3	Moderate
wf-migration-outflow-rate	Spatial	Economy	2.3-14.0	Moderate
civilian-evade-revenue-rate	Spatial	Economy	2.5-7.4	Yes
adaptive-altruism-distress-count	Behavior	Spatial	3.0-3.9	Moderate
mil-coordinate-blend-rate	Behavior	Spatial	1.3-24.1	Moderate
mcr-crisis-safety-threshold	Behavior	Economy	1.9-31.0	Low

Trust-network-economy entanglement

The domain mapping's central finding is that trust parameters are entangled with the network and economic domains. Trust-trade-volume-weight primarily affects behavioral outputs but has substantial secondary effects on both the economy and network structure. Trust-decay-rate and trust-swift-culture-weight cross spatial and behavioral domains. The network topology parameters (hub-degree-threshold, long-tie-keep-count) likewise show cross-domain effects. This entanglement means that trust parameters cannot be calibrated independently: changing a trust parameter to improve a behavioral outcome simultaneously shifts network structure and economic aggregates. The calibration architecture addresses this by moving trust parameters to Layer 4, where they are jointly optimized against behavioral, economic, and network validation targets.

Parameters with contained effects

Government-strength and split-threshold affect behavior and economy but do not substantially shift network structure. Workforce parameters (wf-transit-return-rate, wf-migration-outflow-rate) primarily affect spatial and economic outputs with moderate cross-domain spillover. Only mcr-crisis-safety-threshold shows low cross-domain influence, consistent with the structural isolation of the entire activation chain identified in the dead-reporter diagnostic: the altruism-through-MCR-to-defending/mutual-aid pathway operates independently of the model's other dynamics.

APPENDIX E

EXPERIMENTAL DESIGN DETAIL AND FULL RESULTS

This appendix documents the experimental designs, statistical procedures, and per-experiment results tables underlying the computational experiments reported in Chapter 6. The chapter presents the sociological findings; this appendix provides the methodological apparatus that an external reader would need to audit, replicate, or extend the experiments. Section E.1 presents the epistemological foundation for treating agent-based models as experimental instruments. Section E.2 describes the four-battery experimental program. Section E.3 documents the mechanism exploration design and results. Section E.4 provides per-experiment specifications and results for the eleven counterfactual experiments. Section E.5 documents the complex systems analysis. Section E.6 reports the robustness protocols and their outcomes. Section E.7 summarizes the statistical methods used throughout the program.

E.1. Epistemological Foundation for ABM Counterfactuals

Three traditions of causal reasoning converge on the claim that agent-based models can function as experimental instruments. The potential-outcomes framework (Rubin, 1974) defines a causal effect as the difference between what happened under one condition and what would have happened under another. The mechanism-based approach in analytical sociology (Hedström & Swedberg, 1998) defines it as the identification of generative processes connecting micro-level action to macro-level outcomes. Marshall and Galea (2015) and Casini and Manzo (2016) bridge these two traditions by arguing that agent-based models can produce counterfactual potential outcomes, provided that the mechanisms driving them are empirically grounded.

The bridge works because of a practical advantage. In observational research, the same entity cannot simultaneously experience and not experience a treatment. Agent-based models face no such constraint. The simulation can be run repeatedly under a baseline condition and then re-run with one parameter altered, producing paired outcome distributions whose difference is interpretable as a causal effect (Marshall & Galea, 2015). Unlike standard regression, this approach does not require isolating units from one another. In systems where organizations influence their neighbors through trade, displacement, and cultural contact, the interference between units is not a complication to be controlled away but part of what the model represents.

The capacity to generate counterfactuals does not by itself guarantee their validity. Casini and Manzo (2016) established three interlocking conditions under which agent-based models can produce valid causal counterfactuals, summarized in Table E.1.

Table E.1. Three pillars of counterfactual validity in agent-based models (after Casini & Manzo, 2016)

Methodological pillar	**Definition**	**Role in counterfactual analysis**
Theoretical realism	Agent attributes, cognitive rules, and interaction topologies must be derived from domain-specific micro-level theories and direct empirical evidence.	Ensures that counterfactual interventions manipulate meaningful, mechanistically sound behaviors rather than arbitrary mathematical variables.
Empirical validation	Emergent macro-level outcomes must be systematically confronted with quantified empirical patterns or established stylized facts.	Provides the baseline against which counterfactual deviations are measured; confirms the model captures the target system's endogenous dynamics.
Empirical calibration	Initial conditions, parameter spaces, and baseline agent states must be parameterized by real-world empirical micro-data.	Anchors the simulation in material reality, eliminating competing theoretical accounts and ensuring counterfactual trajectories branch from a historically accurate foundation.

The present model satisfies all three pillars. The agent decision rules draw on domain-specific theories: Bevzenko's (2022) crisis-agency framework for adaptive trait dynamics, the BDI architecture (Bourgais et al., 2020) for the cognitive decision cycle, Hammond and Axelrod's (2006) ethnocentrism model for cultural tag dynamics, and Lambert and Knemeyer's (2004) partnership formation model for trade and trust. These theories are implemented through established computational frameworks and confirmed through face validation against the interview and survey data. The model was calibrated through four layers of empirical evidence and validated against 43 criteria spanning eight domains, as reported in Chapter 5.

Four additional constraints shape the experimental design. The first is empirical embeddedness. Boero and Squazzoni (2005) distinguish case-based models, typifications, and theoretical abstractions. The present model occupies an intermediate position. Its baseline configuration is case-based, calibrated to the Ukrainian wartime context. The model uses 800 agents at a 1:400 mapping to active enterprises (State Statistics Service of Ukraine, 2024), an effective tax rate of 0.27 matching the aggregate tax-to-GDP ratio (Ministry of Finance of Ukraine, 2024; Kyiv School of Economics, 2024; Bogdan, 2024), military structure scaled to approximately 130 brigade-equivalents (Jones & McCabe, 2026; Wilk & Żochowski, 2025), and infrastructure damage following the World Bank RDNA3–5 assessments (World Bank et al., 2024, 2025; World Bank Group et al., 2026). The counterfactual presets explore mechanism spaces without direct empirical analogs. Mixing calibrated and theoretical experiments in a single study is acceptable provided the boundaries between them are clearly documented (Edmonds et al., 2019). Table E.3 marks which experiments branch from the calibrated baseline and which operate beyond it.

The second is transportability. Murray et al. (2017) showed that agent-based models produce unbiased causal estimates when all inputs come from the target population, but biased ones when parameters are borrowed from elsewhere. All four calibration layers in the present model draw exclusively from Ukrainian sources: macro-data from the Ministry of Finance, State Statistics Service, CSIS, and World Bank; micro-data from a survey of 35 Ukrainian organizations; and two algorithmic search layers constrained by these empirical anchors. The counterfactual presets modify structural toggles while retaining population-level baseline risks, so they represent theoretical explorations rather than transferable predictions about other countries.

The third is counterfactual robustness. A valid counterfactual effect must hold across many runs, not depend on a single initial configuration (Bedau, 2003). The experimental program addresses this through replication (30–200 runs per condition), bootstrap confidence intervals, equifinality testing across 4,753 configuration pairs, and cross-experiment consistency checks. A dedicated robustness battery (R1–R11) applies parameter perturbation and noise injection on decision weights.

The fourth is the risk of overgeneralization. Edmonds et al. (2024) warn that models can give a false impression of broad applicability when they possess only analogical validity. The present model guards against this in two ways. The mechanism inventory traces each mechanism to its theoretical source and empirical status. The credibility assessment specifies the six domains where outputs can be trusted and the three where they cannot. Counterfactual results are interpreted as theoretical explorations, not as claims about alternative empirical realities (Windrum et al., 2007).

These four constraints intersect with three broader epistemological challenges that apply to all agent-based counterfactual analysis, summarized in Table E.2.

Table E.2. Epistemological challenges for ABM counterfactual analysis and proposed solutions

Challenge	**Definition**	**Proposed solution**
The uniqueness problem	Recorded history represents only one realization of a stochastic process, making it impossible to know whether observed events are typical or extreme.	Large Monte Carlo ensembles (30–200 replications per condition); match distributional signatures rather than single trajectories.
Non-ergodicity	Complex systems exhibit path dependence and lock-in, where minor initial variations lead to vastly different states.	Validate on distributional patterns (survival curves, size distributions); map the bifurcation space through phase diagrams and hysteresis tests (C1–C6).
Over-parameterization	High degrees of computational freedom allow the model to fit almost any data, stripping it of explanatory power.	Four-layer Werker–Brenner calibration; Morris sensitivity screening (all 38 parameters interactive); restrict the parameter space to zones replicating established facts.

E.2. Experimental Program and Battery Design

The experimental design follows a four-step logic reflecting the abductive reasoning at the core of the MBSSM framework (Vu et al., 2020). Step 1, mechanism exploration, treats the model as a structural hypothesis space. Five society presets are crossed with five binary mechanism toggles, producing 160 structural configurations, each evaluated against six empirical pattern filters. Step 2, counterfactual scenario analysis, uses the validated model to explore what-if questions grounded in the Ukrainian wartime experience and broader disaster sociology. Step 3, complex systems analysis, treats the model as a dynamical system and applies tools from critical transitions theory (Scheffer et al., 2009) and social-ecological resilience research (Holling, 2001; Walker et al., 2004). Step 4, robustness and confirmatory testing, subjects the preceding findings to formal checks.

The experiments measure outcomes through direct macro indicators organized into seven interpretive domains: population and survival, economy, networks and social structure, defense, institutions and behavior, adaptive traits and culture, and spatial infrastructure. Each experiment records the subset of indicators relevant to its hypotheses. Table E.3 summarizes the complete experimental program.

Table E.3. Experiment battery summary

Code	Name	Reps	Ticks	Conditions	Runs
Mechanism exploration					
S1	Structural toggle design	30	500	160	4,800
Counterfactual scenarios					
B1	Preset comparison	50	300	5	250
B2	Government collapse	50	300	3	150
B3	Volunteer activation	50	300	32	1,600
B4	Cultural dynamics	50	300	8	400
B5	Trait differentiation	50	300	1	50
B6	Migration anchoring	50	300	8	400
B7	War trajectories	50	300	5	250
B8	Cascading disruption	50	300	2	100

Code	Name	Reps	Ticks	Conditions	Runs
B9	Decentralization x gov. strength	50	300	6	300
B10	Behavioral permeability	50	300	9	450
B11	Requisition impact	50	300	3	150
Complex systems					
C1	Collapse boundaries	50	500	99	4,950
C2	Bimodality detection	200	500	5	1,000
C3	Early warning signals	100	500	1	100
C4	Network percolation	50	300	49	2,450
C5	Phase diagram	30	300	100	3,000
C6	Hysteresis	50	600	3	150
C7	Spatial early warning	–	–	–	(reuses C3)
Robustness					
R1–R10	Parameter perturbation	30	500	50	1,500
R11	Noise injection	30	500	4	120
				Total	**~22,200**

Table E.4 maps the model's twenty mechanisms to their theoretical sources and to the experiments that test them. This is a subset of the 27 interview-testable mechanisms documented in Appendix A and the 38 model rules documented in Appendix C. The remaining mechanisms operate as background scaffolding (computational infrastructure inherited from parent agent-based frameworks: trade dynamics, partnership memory, agent birth and death, taxation, spatial environment) rather than as experimental treatments, and are therefore not toggled or varied across the experimental conditions.

Table E.4. Mechanism inventory: theoretical source and experimental coverage

Mechanism	Source	Experiments
Spatial resource landscape	SugarScape	B7, C1, C5
Advancing threat front	SugarScape	B7, C3, C5, C6
Bilateral trade	SugarScape + SKIN	B4, B6, C4
Cultural tag transmission	Axelrod (1997)	B4, S1 toggle
Ethnocentric partner preference	Hammond and Axelrod (2006)	B4, B9
BDI intentional decision cycle	BEN; ASSOCC	B3, B5
Compliance and evasion	BEN; WorkSim	B2, B9

Mechanism	Source	Experiments
Structural trait drift	Epstein	B4, B9, R1–R10
Planning horizon contraction	Bevzenko (2022)	B5, C1, C2
Altruism activation	Bevzenko (2022)	B2, B3, C1, C6
Domain expansion	Novel	B3, B8
Priority shift trajectory	Novel	B5, B7
Network information diffusion	Watts and Strogatz (1998), Burt (2005)	B6, C4
Three-route trust model	Hung et al. (2004)	S1 toggle, R1–R10
Reputation diffusion	Hung et al. (2004)	S1 toggle
Hub brokering	Burt (2005)	S1 toggle, C4
Government fiscal cycle	WorkSim	B2, B9, C5
Relocation and displacement	Aldrich (2012)	B6, B7, C1, C6
Jungle/Zoo regime dynamics	Novel	B1, B3, B10
Crisis competitor cooperation	Ukrainian wartime evidence	B8

Transformational mechanisms are tested through structural toggle experiments (S1). Action-formation mechanisms are tested through dose-response counterfactual experiments. Feedback mechanisms are tested through phase-boundary mapping. Trust and reputation have the weakest direct empirical grounding, as their values lack empirical proxies; the toggle experiments determine whether these mechanisms are necessary for reproducing observed patterns.

E.3. Mechanism Exploration (S1)

E.3.1. Society Presets

Five society presets define the structural configurations. Each preset is applied after baseline initialization by modifying agent properties without altering the landscape or scenario schedule. The parameter modifications are listed in Table E.5.

Table E.5. Society preset parameter modifications

Parameter	Baseline	Total-defense	Decentralized	Centralized	Dual-economy
Hierarchy	calibrated N(0.63, 0.20)	calibrated	U(0.0, 0.2)	U(0.8, 1.0)	calibrated
Flexibility	calibrated	calibrated	U(0.8, 1.0)	U(0.0, 0.2)	calibrated

Parameter	Baseline	Total-defense	Decentralized	Centralized	Dual-economy
Tax rate	calibrated (0.27)	calibrated	calibrated x 0.30	0.40	calibrated
Mil-budget share	calibrated (0.50)	calibrated	calibrated x 0.30	calibrated	calibrated
Subsidy share	calibrated	calibrated	calibrated x 0.30	0.45	calibrated
Gov. treasury	calibrated	calibrated	calibrated x 0.10	calibrated	calibrated
Mil-friendliness	calibrated Beta(4.0, 2.1)	U(0.6, 0.9)	calibrated	calibrated	calibrated
Altruism boost	none	+0.1	none	none	none
Domain expanded	0%	30%	0%	0%	0%
Mil-civ-ratio (civilians)	0	0	0	0	U(0.1, 0.5)

Note. "Calibrated" refers to the values established through the four-layer calibration procedure reported in Chapter 5 and documented in Appendix D. U(a, b) denotes a uniform distribution. All presets apply identical modifications to both civilian and military agents for hierarchy and flexibility parameters. The government fiscal parameters (treasury, tax rate, budget share, subsidy share) are modified only in the decentralized and centralized presets.

Crossed with five transformational-mechanism toggles (cultural-transmission?, trust-enabled?, reputation-enabled?, hub-brokering-enabled?, long-ties-enabled?), the presets produce 5 x 2^5 = 160 experimental configurations, each run for 500 ticks with 30 replications.

E.3.2. Pattern Filter Specifications

Six empirical pattern filters evaluate each configuration.

P1 requires population survival: civilian organizations must remain above zero at tick 300 in at least 90% of replications.

P2 requires displacement timing consistent with the IOM Displacement Tracking Matrix data (International Organization for Migration, 2022, 2024, 2025): the peak relocation rate must occur during the rapid-advance phase (ticks 10–40).

P3 requires an economic shock and a partial recovery consistent with the wartime GDP trajectory documented by Bogdan (2024): total wealth must drop below 95% of its initial value and then recover by at least 5% above the trough.

P4 requires network disruption and rebuilding consistent with the partnership disruption documented in the calibration survey (Q26–Q27): the giant-component fraction must drop below 90% of its initial value and then stabilize.

P5 requires cultural convergence consistent with sociological data showing identity consolidation during the war (Hrushetskyi, 2024; Sociological Group "Rating", 2025): cultural diversity must decline over time. This filter applies only to configurations with cultural transmission enabled; configurations with it disabled cannot produce convergence by design and are not penalized.

P6 requires trait differentiation consistent with Bevzenko’s (2025) prediction that differential threat exposure produces divergent adaptive responses: the variance of planning horizons must increase over time.

E.3.3. Classification Framework

Configurations that fail three or more of the six filters are eliminated; those that pass at least four become candidate explanations. Surviving configurations are classified using a necessity-sufficiency framework. A mechanism is necessary if no configuration survives without it. It is sufficient if at least one configuration survives with that mechanism alone active and all others disabled. It is dispensable if configurations survive both with and without it. It is interactive if turning it on or off changes the survival rate, but the direction and size of the change depend on which other mechanisms are active.

E.3.4. Continuous Fitness Scoring

Each of the six empirical patterns is converted into a continuous score between 0 and 1. Population survival is scored as the proportion of replications with civilians above zero. Displacement timing is scored as the proportion peaking in the tick 10–40 window.

Economic shock-recovery and network disruption-recovery are scored as per-replication rates of drop-and-rebound. Cultural convergence is scored as normalized diversity decline. Trait differentiation is scored as the positive part of Kendall's tau for planning-horizon variance. The composite fitness is the mean of all available scores.

E.3.5. S1 Results

98 of 160 configurations survive the pattern filter battery. All five presets are represented among survivors, with decentralized showing the highest survival rate (30 of 32 configurations) and dual-economy the lowest (13 of 32). All 32 possible toggle combinations are represented among surviving configurations, indicating that no single mechanism combination is uniquely required. Table E.6 presents the mechanism classification results.

Table E.6. S1 mechanism classification

Mechanism	Configs ON	Survive ON	Rate ON	Configs OFF	Survive OFF	Rate OFF	Classification
Cultural transmission	80	54	67.5%	80	44	55.0%	Sufficient
Trust	80	46	57.5%	80	52	65.0%	Sufficient
Reputation	80	52	65.0%	80	46	57.5%	Sufficient
Hub brokering	80	45	56.2%	80	53	66.2%	Sufficient
Long ties	80	46	57.5%	80	52	65.0%	Sufficient

Note. All five mechanisms are classified as Sufficient: configurations survive with each mechanism enabled alone. No mechanism is Necessary (no mechanism is required for survival across all presets). All mechanisms are Dispensable (configurations survive both with and without each). All are Interactive (survival rates vary depending on which other mechanisms are active).

The continuous fitness analysis confirms the binary classification pattern: no individual mechanism produces a large effect on composite fitness. Table E.7 presents the pooled mechanism effects.

Table E.7. S1 pooled mechanism effects on continuous composite fitness

Mechanism	Mean ON	Mean OFF	Diff	W	p	Cliff's delta	Effect size
Cultural transmission	0.446	0.436	+0.010	3,723	0.075	0.163	small

Mechanism	Mean ON	Mean OFF	Diff	W	p	Cliff's delta	Effect size
Trust	0.440	0.443	-0.003	3,284	0.777	0.026	negligible
Reputation	0.441	0.441	-0.000	3,107	0.752	-0.029	negligible
Hub brokering	0.441	0.441	-0.001	3,396	0.506	0.061	negligible
Long ties	0.443	0.439	+0.004	3,333	0.651	0.042	negligible

Note. Cultural transmission shows a marginally significant positive contribution ($p = 0.075$, small effect). All other mechanisms show negligible effects at the pooled level. The explanation is functional interchangeability: the system adapts through whichever self-organizational pathways are available.

E.4. Counterfactual Experiment Specifications (B1–B11)

Each subsection below follows a uniform structure: design (conditions, replications, ticks, parameter values), statistical procedure, results (tables with effect sizes, p-values, cell means), and interpretive notes.

E.4.1. B1: Preset Comparison

Design. Five societal presets (baseline, total-defense, decentralized, centralized, dual-economy), 50 replications each (250 runs total), 300 ticks per run. Each preset configures a different balance between the organizational and self-organizational pathways. Preset parameter values are documented in Table E.5.

Statistical procedure. Pairwise Wilcoxon rank-sum tests between all preset pairs (10 comparisons per metric) at tick 300. Cliff's delta effect sizes for each pair.

Results. Table E.8 presents selected pairwise comparisons on population (count.civilians). The centralized preset produces large-effect-size differences against every other preset. The decentralized preset shows large advantages over all presets except total-defense.

Table E.8. B1: Pairwise Cliff's delta effect sizes at tick 300 (count.civilians)

group1	group2	delta	magnitude	p
baseline	centralized	0.933	large	1.2 x 10^-15
baseline	decentralized	-1.000	large	7.0 x 10^-18
baseline	dual-economy	-0.377	medium	0.001

group1	group2	delta	magnitude	p
baseline	total-defense	-0.014	negligible	0.907
centralized	decentralized	-1.000	large	1.0 x 10^-17
centralized	dual-economy	-0.998	large	1.2 x 10^-17
centralized	total-defense	-0.913	large	5.2 x 10^-15
decentralized	dual-economy	1.000	large	7.0 x 10^-18
decentralized	total-defense	0.998	large	7.9 x 10^-18
dual-economy	total-defense	0.367	medium	0.002

Note. All comparisons involving centralized show large effect sizes (delta >= 0.91) on population. Baseline and total-defense are statistically indistinguishable on population (delta = -0.014, negligible). The pattern repeats on total.money: centralized produces delta >= 0.99 against all other presets; decentralized outperforms all others with large effects.

E.4.2. B2: Government Collapse

Design. Three conditions, 50 replications each (150 runs total), 300 ticks per run: baseline (government active throughout), temporary collapse (government disabled at tick 0, restored at tick 50), and permanent collapse (government disabled at tick 0, never restored). The conditions are implemented through the gov-collapse-until-tick parameter set to 0, 50, and 500 respectively.

Statistical procedure. Pairwise Wilcoxon rank-sum tests at tick 300 between each collapse condition and baseline. Cliff's delta effect sizes.

Results. Table E.9 presents pairwise comparisons at tick 300.

Table E.9. B2: Government collapse pairwise comparisons at tick 300

Metric	Comparison	delta	Magnitude	p	Verdict
count.civilians	0 vs 50	0.260	small	0.025	Supported
count.civilians	0 vs 500	-0.997	large	8.9 x 10^-18	Supported
count.civilians	50 vs 500	-0.994	large	1.1 x 10^-17	Supported
total.money	0 vs 50	0.320	small	0.006	Supported
total.money	0 vs 500	-0.882	large	3.0 x 10^-14	Supported
total.money	50 vs 500	-0.923	large	1.8 x 10^-15	Supported
gov.treasury	0 vs 50	0.155	small	0.182	Inconclusive
gov.treasury	0 vs 500	-0.998	large	8.5 x 10^-18	Supported
avg.altruism	0 vs 50	-0.353	medium	0.002	Supported

Metric	Comparison	delta	Magnitude	p	Verdict
avg.altruism	0 vs 500	-0.898	large	1.1 x 10^-14	Supported
avg.altruism	50 vs 500	-0.770	large	3.4 x 10^-11	Supported
pct.domain.expanded	0 vs 50	0.235	small	0.043	Supported
pct.domain.expanded	0 vs 500	0.729	large	3.5 x 10^-10	Supported
pct.domain.expanded	50 vs 500	0.504	large	1.4 x 10^-5	Supported

Note. Temporary collapse (condition 50) shows small effects against baseline on population and economy but a medium effect on altruism (delta = -0.353), indicating that temporary institutional failure activates the volunteer mechanism and the activation partially persists. Permanent collapse (condition 500) produces large effects across all indicators. Domain expansion is higher under both collapse conditions, consistent with the substitution hypothesis.

E.4.3. B3: Volunteer Activation

Design. Factorial design: 4 (initial altruism: 0.1, 0.3, 0.5, 0.7) x 4 (government strength: 0.0, 0.25, 0.5, 1.0) x 2 (mobilization: on/off) = 32 conditions, 50 replications each (1,600 runs total), 300 ticks per run.

Statistical procedure. Kruskal-Wallis tests to identify which factor dominates each outcome metric. Table E.10 presents the results.

Table E.10. B3: Kruskal-Wallis test results by factor

Metric	Factor	chi-sq	df	p
pct.domain.expanded	initial.altruism	1421.0	3	8.2 x 10^-308
pct.domain.expanded	government.strength	58.3	3	1.4 x 10^-12
pct.domain.expanded	mobilization.enabled	0.02	1	0.899
count.civilians	initial.altruism	7.4	3	0.059
count.civilians	government.strength	1304.2	3	1.8 x 10^-282
count.civilians	mobilization.enabled	2.7	1	0.103
total.money	initial.altruism	39.7	3	1.2 x 10^-8
total.money	government.strength	1180.7	3	1.1 x 10^-255
total.money	mobilization.enabled	2.1	1	0.147
count.militaries	government.strength	930.4	3	2.3 x 10^-201
count.militaries	mobilization.enabled	205.7	1	1.2 x 10^-46
total.mil.people	government.strength	920.4	3	3.3 x 10^-199
total.mil.people	mobilization.enabled	332.0	1	3.6 x 10^-74

Note. Initial altruism dominates domain expansion (chi-sq = 1421, p < 10^-307). Government strength dominates population survival and economic output. Mobilization toggle affects only military metrics; it has no significant effect on civilian outcomes.

Table E.11 presents the domain expansion cell means (%), with mobilization on and off combined, showing the sharp nonlinear threshold between altruism 0.3 and 0.5.

Table E.11. B3: Domain expansion cell means (%) by altruism and government strength

Altruism	Gov = 0.0	Gov = 0.25	Gov = 0.5	Gov = 1.0
0.1	0.0	0.0	0.0	0.0
0.3	0.1	0.1	0.2	0.0
0.5	83.3	81.0	77.8	57.8
0.7	98.2	97.8	93.2	75.5

Note. Values are averaged across mobilization on/off conditions. The threshold between altruism 0.3 and 0.5 is sharp and nonlinear. The substitution effect is visible at the right: at altruism 0.5, domain expansion under full government (Gov = 1.0) drops by 25.5 percentage points compared to no government (Gov = 0.0). At altruism 0.7, the suppression effect weakens to 22.7 percentage points.

E.4.4. B4: Cultural Dynamics

Design. Factorial design: 2 (cultural transmission: on/off) x 4 (subsidy bias: 0, 2, 4, 8) = 8 conditions, 50 replications each (400 runs total), 300 ticks per run.

Statistical procedure. Two-way analysis using Kruskal-Wallis tests for each factor on each outcome metric.

Results. Cultural transmission dominates all five tested metrics. Table E.12 presents the Kruskal-Wallis results.

Table E.12. B4: Kruskal-Wallis test results by factor

Metric	Factor	chi-sq	p
cultural.diversity	cultural.transmission	275.8	6.2 x 10^-62
cultural.diversity	subsidy.bias	8.5	0.037
count.civilians	cultural.transmission	100.8	1.0 x 10^-23
count.civilians	subsidy.bias	37.1	4.3 x 10^-8

Metric	Factor	chi-sq	p
total.money	cultural.transmission	55.0	1.2 x 10^-13
total.money	subsidy.bias	36.5	5.9 x 10^-8
avg.altruism	cultural.transmission	265.5	1.1 x 10^-59
avg.altruism	subsidy.bias	8.6	0.036
avg.planning.horizon	cultural.transmission	20.2	6.9 x 10^-6
avg.planning.horizon	subsidy.bias	13.6	0.003

Note. Cultural transmission produces chi-squared values one to two orders of magnitude larger than subsidy bias on cultural diversity and altruism. Subsidy bias reaches significance for population and economic metrics but with much smaller effect sizes, indicating that fiscal incentives operate through a different pathway than cultural dynamics.

E.4.5. B5: Trait Differentiation

Design. Single condition (baseline preset), 50 replications (50 runs), 300 ticks. Three spatial zones are tracked: front (patches within threat range), middle, and rear. Planning horizon variance and front-rear gap are recorded at each tick.

Statistical procedure. Kendall's tau trend test on the front-rear planning horizon gap over ticks 1–300.

Results. Kendall's tau = -0.944, $p < 0.001$ for planning horizon. The front-rear gap narrows monotonically. Altruism shows the same pattern (tau = -0.944, $p < 0.001$). Displacement mixing dominates spatial selection: as organizations flee the front zone and resettle, they carry their crisis-adapted traits with them, homogenizing the trait distribution across the landscape.

E.4.6. B6: Migration Anchoring

Design. Factorial design: 2 (memory decay time: short/long) x 2 (long ties: off/on) x 2 (hub brokering: off/on) = 8 conditions, 50 replications each (400 runs total), 300 ticks per run.

Statistical procedure. Three-way Kruskal-Wallis tests for each factor on nine outcome metrics.

Results. Table E.13 presents the main effects on trade degree and other key metrics.

Table E.13. B6: Kruskal-Wallis main effects

Metric	Factor	chi-sq	p	Direction
avg.trade.degree	memory.decay.time	0.13	0.723	–
avg.trade.degree	long.ties.enabled	5.18	0.023	positive
avg.trade.degree	hub.brokering.enabled	0.07	0.790	–
count.civilians	long.ties.enabled	5.53	0.019	positive
total.money	long.ties.enabled	4.47	0.035	positive
trade.component.count	long.ties.enabled	4.97	0.026	positive
count.long.ties	long.ties.enabled	–	1.2 x 10^-12	positive

Note. Long ties show the only significant main effect among the three network mechanisms. Memory decay time and hub brokering produce no significant effects on any of the nine metrics tested (all p > 0.07). Pairwise tests for long ties: trade degree delta = -0.342 (medium), count.civilians delta = -0.353 (medium), total.money delta = -0.318 (small).

E.4.7. B7: War Trajectories

Design. Five war scenarios, 50 replications each (250 runs), 300 ticks. Each scenario implements a distinct warfare timeline through a custom scenario-schedule data structure:

1. Default Ukraine scenario: the calibrated nine-phase timeline.
2. Rapid collapse: high-intensity advance (intensity 0.8 for 50 ticks, then 0.4 for 50 ticks), government at 5% capacity.
3. Prolonged grinding: low-intensity sustained advance (intensity 0.15 for 100 ticks, then 0.10 for 100 ticks), government at 20%.
4. Successful early defense: brief advance (30 ticks), then retreat and stabilization, government rising to 60%.
5. Frozen conflict: brief advance (30 ticks at intensity 0.3), then indefinite hold, government at 40%.

Results. Frozen conflict produces the best outcomes. Among active combat scenarios, intensity and duration damage different domains independently. The full pairwise Cliff's delta table contains 50 comparisons across six metrics (10 pairs x 5 metrics plus trade degree), reported in Table E.14 for selected key comparisons.

Table E.14. B7: Selected pairwise Cliff's delta values at tick 300

Comparison	Metric	delta	Magnitude
frozen vs default	count.civilians	0.908	large
frozen vs rapid-collapse	count.civilians	0.972	large
frozen vs prolonged-grind	count.civilians	0.919	large
rapid-collapse vs default	count.civilians	-0.375	medium
prolonged-grind vs default	count.civilians	-0.069	negligible
rapid-collapse vs prolonged-grind	total.money	0.259	small

Note. Rapid collapse kills more organizations (delta = -0.375 vs default) but concentrates wealth among survivors. Prolonged attrition steadily erodes the population at a rate indistinguishable from the default on population but diverges on cultural diversity.

E.4.8. B8: Cascading Disruption

Design. Two conditions (baseline disaster frequency 0.03, doubled disaster frequency 0.06), 50 replications each (100 runs), 300 ticks per run.

Results. Doubled disaster frequency significantly increases front-zone infrastructure damage (delta = -0.680, large, $p < 0.001$). No significant effects on population (delta = -0.006, negligible, $p = 0.982$), economy (delta = 0.182, small, $p = 0.305$), or domain expansion (delta = -0.042, negligible, $p = 0.820$). Trade network density is marginally affected (delta = -0.166, small, $p = 0.350$). The Pescaroli and Alexander (2016) cascading framework is not supported at the tested intensity.

E.4.9. B9: Decentralization x Government Strength

Design. Factorial design: 2 (preset: decentralized, centralized) x 3 (government strength: 0.20, 0.50, 0.80) = 6 conditions, 50 replications each (300 runs total), 300 ticks per run. Government strength is held fixed throughout the simulation (gov-strength-fixed? = true).

Results. The decentralization advantage is absolute: delta = -1.00 on population at every government strength level, indicating perfect separation between the two presets. The decentralized preset produces approximately 360 surviving organizations at all three levels. The centralized preset collapses from approximately 210 survivors at government strength

0.20 to approximately 20 at government strength 0.80. The advantage does not weaken as institutional capacity increases.

E.4.10. B10: Behavioral Permeability

Design. Factorial design: 3 (MCR civilian cap: 0.0, 0.3, 0.7) x 3 (MCR crisis-increase rate: 0.0, 0.01, 0.03) = 9 conditions, 50 replications each (450 runs total), 300 ticks per run.

Results. Table E.15 presents the jungle index by cell.

Table E.15. B10: Jungle index at tick 300 by MCR civilian cap and crisis-increase rate

MCR cap	Crisis = 0.0	Crisis = 0.01	Crisis = 0.03
0.0	0.000	0.000	0.000
0.3	0.143	0.136	0.143
0.7	0.133	0.144	0.137

Note. Civilian cap dominates the jungle index: at cap = 0, the index is zero regardless of crisis intensity; at cap >= 0.3, it jumps to approximately 0.14 and shows no further increase. Crisis-increase rate has no significant effect on any metric, indicating that civilian military participation is governed by institutional permission (cap) rather than crisis pressure.

E.4.11. B11: Requisition Impact

Design. Three conditions (requisition rate: 0%, 10%, 20%), 50 replications each (150 runs), 300 ticks per run.

Results. Of 33 pairwise comparisons across 11 metrics, 22 produce negligible effect sizes (delta < 0.147), 8 produce small effects, and 3 produce medium or inconclusive effects. No significant economic damage is detected at tested intensities. The 0% vs 20% comparison on population shows a small effect (delta = 0.312, p = 0.031), but this is the only comparison reaching significance on a core outcome metric.

E.5. Complex Systems Analysis (C1–C7)

Experiment IDs C1 through C7 in this section refer to complex-systems analyses (collapse boundaries, bimodality, early warning signals, network percolation, phase diagram, hysteresis, and spatial early warning, respectively). These should not be confused with the codebook mechanism codes C1 (Planning horizon contraction) and C2 (Altruism activation) defined in Appendix A, Table A.1, which retain their meaning throughout the dissertation. Context disambiguates throughout this section: experiment IDs appear with the prefix "experiment" or in design-specification headings, while mechanism codes appear in causal-pathway discussions and cross-references to Appendix A.

E.5.1. C1: Collapse Boundaries

Design. Five parameters swept through approximately 20 values each, 50 replications per value (4,950 runs total), 500 ticks. Parameters were selected from Morris sensitivity screening to represent different pathways to collapse: civilian attrition rate (0.01–0.50), military attrition rate (0.01–0.50), government strength (0.10–1.00), base vision range (0.5–5.0), and memory decay time (5–50 ticks).

Statistical procedure. Logistic regression of extinction probability (proportion of replications with zero civilians at tick 500) against parameter value. The inflection point of the logistic curve identifies the threshold.

Results. Table E.16 presents the tipping-point results.

Table E.16. C1: Extinction thresholds

Parameter	Threshold	Logistic AIC
Civilian attrition rate	No threshold	230.9
Military attrition rate	0.327	1109.5
Government strength	0.830	723.8
Base vision range	2.187	401.4
Memory decay time	No threshold	525.0

Note. Three parameters show clear thresholds; two show no sharp transition. The system's vulnerability is concentrated in military protection (attrition rate 0.327), institutional overextraction (government strength 0.830), and network connectivity (vision range 2.187). Civilian attrition rate and memory decay time show gradual degradation without a clear tipping point.

E.5.2. C2: Bimodality Detection

Design. Hartigan's dip test applied to final-tick distributions of five metrics across five presets (25 tests), 200 replications per preset (1,000 runs total), 500 ticks.

Results. Only two combinations show significant bimodality, both under the centralized preset: trade degree (dip = 0.071, $p < 10^{-6}$) and total money (dip = 0.042, p = 0.013). All 23 remaining combinations produce single-peaked distributions (all $p > 0.27$). Suppressing self-organizational pathways does not merely reduce average performance: it makes the system structurally fragile, capable of bifurcation between distinct outcome states.

E.5.3. C3/C7: Early-Warning Signals

Design. Civilian attrition rate gradually increased from 0.04 to 0.27 over 500 ticks (implemented via attrition-ramp-rate), 100 replications. Four indicators tracked in rolling 50-tick windows: temporal autocorrelation of population, variance of population, spatial autocorrelation of safety (Moran's I), and economic output variance.

Results. 16 of 100 replications collapsed. Table E.17 presents Kendall's tau trend test results for each indicator, separately for collapsing and surviving replications.

Table E.17. C3/C7: Kendall's tau trend coefficients for early-warning indicators

Indicator	**tau (collapsing)**	**tau (surviving)**	**Gap**
Spatial autocorrelation (Moran's I)	0.395	0.192	0.203
Spatial variance	0.335	0.181	0.154
Temporal autocorrelation (AR1)	0.055	-0.027	0.082
Economic variance	-0.083	-0.118	0.035

Note. Spatial indicators outperform temporal and economic indicators, consistent with Dakos et al. (2010). Moran's I shows the largest gap (0.203) between collapsing and surviving trajectories. The result supports the transfer of ecological early-warning diagnostics to social-organizational systems.

E.5.4. C4: Network Percolation

Design. Three connectivity parameters swept: memory decay time (7 values, 5–50 ticks), base vision range (7 values, 0.5–5.0), and hub degree threshold (7 values, 3–15). Total: 49 conditions x 50 replications = 2,450 runs, 300 ticks. Threshold detection uses the same logistic regression method as C1.

Results. Table E.18 presents the percolation thresholds.

Table E.18. C4: Network percolation thresholds

Parameter	Threshold
Memory decay time	15.26 ticks
Base vision range	2.0 patches
Hub degree threshold	8

Note. The vision range threshold (2.0) aligns approximately with the C1 population tipping point (2.187), suggesting a causal pathway from network fragmentation to population collapse. When organizations cannot perceive potential partners beyond two patches, the trade network fragments and organizations die from economic isolation.

E.5.5. C5: Phase Diagram

Design. 10 x 10 grid: government strength (0.0–1.0, step approximately 0.11) x threat intensity (0.0–2.0, step approximately 0.22). 30 replications per cell (3,000 runs total), 300 ticks.

Regime classification criteria. Each cell is classified by its tick-300 outcomes averaged across replications: Collapsed if extinction probability > 50% or population ratio < 6% of initial; Stressed if extinction probability > 10% or population ratio < 20%; Degraded if population ratio < 40%; Viable otherwise.

Results. The 100 cells classify as: 7 Viable, 41 Stressed, 38 Degraded, 14 Collapsed. The Viable cells cluster at low government strength (0.0–0.11) and low-to-moderate threat intensity, forming a narrow band. At zero government strength, all cells are Degraded. At high government strength (>= 0.75), cells shift from Stressed to Collapsed as threat increases. The main driver of regime classification is government strength, not threat intensity.

E.5.6. C6: Hysteresis

Design. Three scenarios, 50 replications each (150 runs), 600 ticks. Shock-and-recovery: invasion phase (ticks 0–30), holding and retreat (ticks 30–200), peace (ticks 200–600), government starting at 10% and rising to 50%. No-war: 600 ticks of stability, government at 50% throughout. Permanent occupation: invasion and sustained holding, government at 10% rising to 25%.

Statistical procedure. Kruskal-Wallis omnibus tests followed by pairwise Wilcoxon rank-sum tests at tick 600 between shock-and-recovery and no-war.

Results. Table E.19 presents the hysteresis gap quantification.

Table E.19. C6: Hysteresis gap at tick 600 (shock-recovery vs no-war)

Metric	Mean (shock)	Mean (no-war)	Gap (%)	p	Hysteresis?
Total money	627,134	278,520	+125.2%	1.4 x 10^-6	Yes
Cultural diversity	0.486	0.560	-13.2%	0.018	Yes
Population	160.8	115.6	+39.1%	0.052	No
Planning horizon	0.658	0.637	+3.4%	0.053	No
Altruism	0.358	0.406	-11.8%	0.058	No

Note. Two metrics show statistically significant hysteresis. The shock-recovery society ends with 125% more money than the no-war society but 13.2% less cultural diversity. Population, planning horizon, and altruism show gaps in the expected directions but do not reach significance at alpha = 0.05. The economic overshoot reflects both the crisis-driven adaptation effect and the difference in government extraction levels between scenarios (shock-recovery operates at initially lower government strength). Cultural diversity falls during war and does not recover during 400 ticks of peace, consistent with the interpretation that solidarity capital is consumed during adaptation and is not replenished.

E.6. Robustness Protocols (R1–R11)

E.6.1. R1–R10: Parameter Perturbation

Design. Ten calibrated parameters perturbed at five levels: -20%, -10%, baseline, +10%, +20%. 30 replications per condition (1,500 runs total), 500 ticks. Table E.20 lists the parameters and their perturbation ranges.

Table E.20. R1–R10: Parameter perturbation specification

ID	Parameter	Calibrated	Description	-20%	+20%
R1	initial.altruism	0.50	Altruism level	0.40	0.60
R2	government.strength	0.10	Institutional capacity	0.08	0.12
R3	civilian.attrition.rate	0.04	Civilian death rate	0.032	0.048
R4	military.attrition.rate	0.04	Military death rate	0.032	0.048
R5	memory.decay.time	20	Partner memory (ticks)	16	24
R6	base.vision.range	3.0	Perception range (patches)	2.4	3.6
R7	hub.degree.threshold	5	Hub brokering threshold	4	6
R8	mcr.civilian.cap	0.70	Max civilian militarization	0.56	0.84

ID	Parameter	Calibrated	Description	-20%	+20%
R9	mcr.crisis.increase	0.01	Crisis MCR increase rate	0.008	0.012
R10	mil.requisition.take.rate	0.10	Military requisition rate	0.08	0.12

Results. Overall, 241 of 300 perturbed conditions (80.3%) fall within the baseline 95% confidence interval. Table E.21 presents the per-parameter robustness rates.

Table E.21. R1–R10: Percentage of conditions within baseline CI by parameter

Parameter	Within CI (of 30)	Rate
R1: initial.altruism	20	66.7%
R2: government.strength	21	70.0%
R3: civilian.attrition.rate	27	90.0%
R4: military.attrition.rate	28	93.3%
R5: memory.decay.time	25	83.3%
R6: base.vision.range	16	53.3%
R7: hub.degree.threshold	26	86.7%
R8: mcr.civilian.cap	25	83.3%
R9: mcr.crisis.increase	27	90.0%
R10: mil.requisition.take.rate	26	86.7%

Note. Base vision range is the least robust parameter (53.3%), consistent with the C1/C4 finding that vision range sits near a tipping point. Military attrition rate is the most robust (93.3%). Initial altruism and government strength show moderate sensitivity (66.7% and 70.0%), reflecting that these parameters directly govern the institutional paradox threshold.

E.6.2. R11: Noise Injection

Design. Gaussian noise added to seven civilian intention-scoring weights at three non-baseline intensity levels (sigma = 0.05, 0.10, 0.20), 30 replications per level (90 non-baseline runs plus baseline), 500 ticks.

Results. 9 of 18 noisy conditions (50.0%) remain within the baseline 95% confidence interval, compared with 80.3% for systematic parameter perturbation. At sigma = 0.05, 4 of 6 metrics are within CI. At sigma = 0.10, 3 of 6 are within CI. At sigma = 0.20, 2 of 6 are within CI. The intention-scoring weights carry more structural information than their calibrated values suggest: perturbing the balance between competing behavioral strategies produces larger deviations than systematic parameter shifts. Qualitative behavior persists under noise; quantitative outputs shift outside baseline precision bands.

E.6.3. Bootstrap Precision

Mean absolute confidence interval widths at tick 300 for the six tracked metrics are presented in Table E.22. The relative CI widths (expressed as a percentage of the metric mean) range from 2.3% (planning horizon) to 40.9% (trade degree). Five of six metrics fall below 17%. Trade degree shows high stochastic variability in network formation, but the remaining metrics are estimated with sufficient precision for the mechanism classification.

Table E.22. Bootstrap precision at tick 300 (98 surviving configurations)

Metric	**Mean CI width**	**Max CI width**
Planning horizon	0.014	0.029
Cultural diversity	0.069	0.166
Population	33.3	71.8
Total money	85,070	143,129
Domain expansion	3.5	15.4
Trade degree	0.116	0.370

E.6.4. Equifinality

4,753 configuration pairs tested for statistical distinguishability across six metrics using Wilcoxon rank-sum tests at alpha = 0.05 with Bonferroni correction. Overall, 31.3% of pairs produce indistinguishable outputs. Table E.23 presents per-metric equifinality rates.

Table E.23. Per-metric equifinality rates

Metric	**Pairs**	**Equifinal**	**Rate**
Population	4,753	942	19.8%
Total money	4,753	1,096	23.1%
Domain expansion	4,753	1,354	28.5%
Cultural diversity	4,753	1,470	30.9%
Trade degree	4,753	1,834	38.6%
Planning horizon	4,753	2,231	46.9%

Note. Population and total money are the most discriminating metrics. Planning horizon shows the highest equifinality (46.9%), indicating that this trait settles into a narrow range regardless of which mechanisms are active.

E.6.5. Cross-Experiment Consistency

Four mechanisms are testable in both the S1 toggle design and the B-series counterfactual experiments. Table E.24 presents the comparison.

Table E.24. Cross-experiment consistency: S1 vs B-series

Mechanism	S1 survival (on)	S1 survival (off)	B-series test	Consistent?
Cultural transmission	67.5%	55.0%	B4: significant (p = 6.2 x 10^-62)	Yes
Trust	57.5%	65.0%	B6: null (p = 0.73)	No
Hub brokering	56.2%	66.2%	B6: null (p = 0.79)	No
Long ties	57.5%	65.0%	B6: null (p = 0.41)	No

Note. Only cultural transmission shows agreement between S1 and B-series. The three network mechanisms produce different estimates depending on which other mechanisms are active, reflecting their interaction-dependent nature.

E.6.6. Robustness Summary

Table E.25 summarizes the robustness program: each row gives the test name, what it checks, the observed result, and the verdict on whether the corresponding finding is robust.

Table E.25. Robustness test summary

Test	What it checks	Result	Verdict
Bootstrap precision	Are 30 replications enough?	CI width < 17% for 5/6 metrics	Adequate
Equifinality	Do different configs produce same outputs?	31.3% indistinguishable	Good discrimination
Structural diversity	Do survivors span toggle space?	32/32 combinations represented	Good diversity
Cross-experiment consistency	Do S1 and B-series agree?	1/4 mechanisms consistent	Partial
Parameter perturbation (R1–R10)	Stable under +/-20%?	80.3% within baseline CI	Robust
Noise injection (R11)	Robust to random perturbation?	50% within baseline CI	Moderate

E.7. Statistical Methods

All counterfactual comparisons use Wilcoxon rank-sum tests at tick 300 (or tick 500/600 where specified) with Cliff's delta effect sizes classified as negligible (delta < 0.147), small (0.147–0.330), medium (0.330–0.474), or large (delta > 0.474). For factorial designs, Kruskal-Wallis tests identify which factor dominates each outcome. Bootstrap confidence intervals use 10,000 resamples (reduced to 2,000 for the full 98-configuration grid in the robustness analysis). Kendall's tau is used for trend detection in adaptive traits (B5) and early-warning signals (C3/C7). Hartigan's dip test is used for bimodality detection (C2). Moran's I is used for spatial autocorrelation in early-warning signals (C3/C7). Logistic regression is used for tipping-point detection in collapse boundaries (C1) and network percolation (C4). Bonferroni correction is applied for multiple comparisons in equifinality testing. All analyses were conducted in R using the stats, boot, and diptest packages.

APPENDIX F

LIST OF THE PUBLICATIONS ON THE TOPIC OF THE DISSERTATION

List of scientific publications in which the primary research results of the dissertation are published:

1. Serdyuk, A. (2023). Organizational adaptation to a disruption caused by the full-scale russian invasion of Ukraine. NaUKMA Research Papers. Sociology, 6, 39–49. https://doi.org/10.18523/2617-9067.2023.6.39-49
2. Serdyuk, A. (2025). Choosing validation methods for agent-based models: A practical framework. NaUKMA Research Papers. Sociology, 8, 4–15. https://doi.org/10.18523/2617-9067.2025.8.4-15
3. Serdyuk, A. (2026). Choosing agent-based modelling as a method of social research: Practical recommendations. Ukrainian Society, 1(96), 43–60. https://doi.org/10.15407/socium2026.01.043

List of scientific publications confirming dissemination of the dissertation findings:

1. Serdyuk, A. (2025). Validation strategies for agent-based models in social science: Insights from modeling of migration caused by the full-scale russian invasion of Ukraine. In *Russian war against Ukraine: Transformations of social institutions and practices: Proceedings of the academic and practical conference* (pp. 182–187). National University of Kyiv-Mohyla Academy. https://ekmair.ukma.edu.ua/handle/123456789/36677

2. Serdyuk, A. (2025). Agent-based simulating of Ukrainian universities adaptation to a full-scale russian invasion. In *Proceedings of the XV International Scientific and Practical Conference "Sociology, social work and social security: Regulation of social problems"* (pp. 68–73). https://doi.org/10.5281/zenodo.15635368

3. Serdyuk, A. (2025). Policy responses and organizational adaptation of Ukrainian universities during the full-scale russian invasion: An agent-based approach. In T. Nahorniak & I. Zaichenko (Eds.), *Interdisciplinary expertise for the recovery and development of Ukraine: Proceedings of the International Scientific and Practical Conference* (pp. 216–221). National University of Kyiv-Mohyla Academy. https://doi.org/10.5281/zenodo.16421646

List of other conferences and events confirming dissemination of the dissertation findings:

1. Serdyuk, A. (2025, February 28). *Agent-based modeling of social processes: The case of migration caused by the war* [Conference presentation]. Student and Postgraduate Academic Conference of the Department of Sociology of NaUKMA "Ukrainian society and the challenges of the russian–Ukrainian war," National University of Kyiv-Mohyla Academy, Kyiv, Ukraine.
2. Serdyuk, A. (2025, May 10). *Agent-based model of the universities' adaptation to the full-scale russian invasion of Ukraine* [Online conference presentation]. Sesiunea Națională de Comunicări Științifice "Ecouri din Social 2025," Babeș-Bolyai University, Cluj-Napoca, Romania.
3. Serdyuk, A. (2025, August 29). *Beyond economic factors: Agent-based modeling of Ukrainian refugee decision-making* [Online conference presentation]. Social Simulation Conference 2025: Social simulation in a socio-technical context – Embracing societies' complexities. Delft University of Technology, Delft, The Netherlands.
4. Serdyuk, A. (2025, November 10). *Agent-based modeling of Ukraine's organizations' response to the full-scale russian invasion of Ukraine* [Online conference presentation]. XVIII All-Ukrainian Academic Conference "Sociology and modern social transformations," Faculty of Sociology, Taras Shevchenko National University of Kyiv, Kyiv, Ukraine.

5. Serdyuk, A. (2026, January 24). *Relocate, merge, or go online? Agent-based modeling of Ukrainian university adaptation during war* [Online conference presentation]. International Graduate Student Symposium "New Perspectives in Ukrainian Studies: Transnational, Transcultural, and Translocal Insights," Centre for European and Eurasian Studies, Munk School of Global Affairs and Public Policy, University of Toronto, Toronto, Canada.

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