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RESEARCH OF THE POLISH LABOR FORCE MARKET WITH THE EFFECT OF WAR IN UKRAINE

The purpose of this research to investigate the Polish labor force under the influence of traditional permanent demographic and economic factors (such as population, wages, prices etc.) represented through Aging Chain model and Economic Factors models connected through labor force sector.

Two questions were in focus. First, how efficiently the labor force - salary - price chain works in the Polish economy. Second, to what extent the increase in the number of refugees with the beginning of a full-scale invasion of Ukraine affected the efficiency of the chain. The proposed model also shows how the behavior of factors is changing affected by certain variables.

The period in question for the research is 2010 –2022 years. Historical data was provided from official sources mostly from Główny Urząd Statystyczny (government statistics), OECD and World Bank. The research is grounded on literature about the System Dynamics approach to modeling similar problems (Sterman J., 2000) and economic theory, especially labor market modelling approach.

The basis for the entire model was Aging Chain, because, from economic theory, it is considered that changing age structure statistically has one of the largest effects on labor force participation, and in our case, no possible dramatic changes in economic factors can be fully explained by population issues.

From model behavior we can conclude that economic crises did not have a big impact on migration processes, and the spread of COVID-19 did not affect the increase in mortality. Russia's invasion of Ukraine in 2014 also did not change the demographic pattern, since most migration processes among the Ukrainian population were internal, in contrast to migration processes after the start of a full-scale invasion. The number of the labor force follows the downward trend of the

largest cohort of adults potentially involved in work, weighted by the labor force participation rate.

The correctness of the data display by the model was checked on this stage and further by means of comparison graphs with real historical data.

In the Labor Force Sector, can be observed stable trends in the growth of wages per person and GDP per capita. Considering the declining trends in the population in those years, this may indicate a high demand for workers and its stimulation by increased wages. The increase in GDP is associated both with a decrease in population and with an increase in labor productivity. In Wage and Price sub-model, the relationship between wages and the price index was investigated in details. Through the model we were able to follow the growth in DGP deflator, which represented Price Index, caused by eased monetary policy and a gradual reduction in interest rates over this decade until 2021 in Poland that was highly likely the reasons for the rise in inflation and, accordingly, the subsequent growth in GDP. Increasing in inflation also affected on real factors that were adjusted to it and respectively affected on wages.

Wage & Price Sub-Model Test were added to model to check the lever of inequality in the Labor Force Sector. The Theil Index and regulated elasticity converters that effected on wages and price index, were used in combination. Regulating each elasticity converters, we were able to achieve the lowest mean percentage error for wage and price index that are 3.27% and 1.44% respectively, minimizing the differ of our model from actual values.

Parameters sensitivity analysis was also provided in our research to determine how “sensitive” parameters of the model are to changes in the value of other parameters of the model. Model was the most sensitive to changes in labor force growth rate and nominal AD growth rate because both parameters have high correlation with other factors in the real economy system.

Using these models, we were able to explore the first question. To address the second question, a War Shock Scenario submodel was created. For the Basic Scenario we discarded migration processes and shocks from the war in Ukraine, focusing on the internal system; we added these shocks of a full-scale invasion into a War Shock

Scenario. Submodel interacts with other blocks through a converter that has two positions: the model reflects what happened to the economy of Poland with the beginning of a full-scale invasion of Ukraine; the model does not reflect the consequences. Accordingly, when the influence of refugees on the model is included, a chain of changes is started in all parameters, starting with the increased labor force.

Changes in age structure have large effect on labor force and, accordingly, economy. In general, the increase in the number of people who are part of the LF leads to an increase in the total number of people employed, who accordingly produce more products, increasing GDP, increasing demand and inflation in the country's economy. In Poland, despite the downward trends in previous years, thanks to the accession to the European Union, changes in monetary policy and greater involvement in international trade, it was possible to keep the economy on the rise.

The labor force – wages – prices channel works well in Poland, especially after joining the European Union at the beginning of the 2000-s. It is proving its effectiveness after increase in labor force in 2022-2023 because of the full-scale invasion into Ukraine. In 2022, Poland accepted many refugees and allowed them to work legally. It led to expanding of the Polish labor force. In the future, this may lead to saturation of the labor market, a decrease in wages per person, and an increase in demand for goods. From the model we can also see that prices and wages move together in a common trend. The decrease in the number of potential labor force led to higher wages as an incentive and to attract "new brains" instead of those who immigrated to other countries.

Lets consider evolutionary computing in economics and its applications. In an era of rapid technological development, innovations in computational methods provide new perspectives for solving complex problems in various fields. In this context, evolutionary computing is becoming an important tool in economic science. The ability to adapt and find optimal solutions in complex, changing environments gives these methods a significant advantage. We will review the basic principles of evolutionary computing, its role in solving economic problems, and the possibilities of applying it to optimize and improve economic processes. Studying this topic will

allow us to better understand the potential of these methods in building a more efficient and adaptive economy.

Evolutionary computing is a term that refers to several optimization methods that are united by the fact that they all use the concept of evolution of objects in a system. From the point of view of system theory, evolution is the process of system adaptation through changes in its parameters under the influence of external conditions. Therefore, evolutionary computing can be interpreted as a development of the methods of adaptive systems theory [1].

The development of evolutionary computing in the field of economics took place in several stages. Initially, they were applied in the field of optimization, where they were able to solve problems with complex functional dependence. With the development of technology, evolutionary computing was applied in economic research to model market behavior, analyze financial data, and optimize investment portfolios.

Nowadays, evolutionary algorithms are used to predict market trends, optimize financial management strategies, and find optimal solutions in complex economic models. Due to their ability to adapt to changes in the environment and effectively search for the best solutions under uncertainty, these methods (genetic algorithms, evolutionary strategies, genetic programming, differential evolution methods, evolutionary computing for portfolio optimization, financial market forecasting) are becoming increasingly important for analyzing and managing economic processes.

Technological progress also contributes to the development of evolutionary computing, allowing it to be applied to large amounts of data and complex computational tasks, which is important for the modern economy.

The basic principles of evolutionary computing in economics are the use of evolutionary algorithms [2] to solve economic problems. The main principles include working with a "population" of strategies (models, solutions), each of which is a potential solution to the problem, and selecting the best solutions based on the criteria of efficiency or suitability for solving a particular economic problem. Evolutionary algorithms generate new strategies or solutions by randomly changing or combining the characteristics of existing ones, evaluate the suitability of each solution to obtain

the appropriate result, and adapt systems to the possibility of changes in the initial data.

Another important element of evolutionary computing is genetic algorithms (the "founding father" of genetic algorithms is John Holland, whose book Adaptation in Natural and Artificial Systems is a fundamental research in this area), which are complex computational tools based on the principles of natural evolution and used to solve economic problems. They are able to quickly find optimal or near-optimal solutions to complex, multimodal, and nonlinear problems, which is an advantage in solving economic problems. A genetic algorithm is a heuristic search algorithm used to solve optimization and modeling problems by randomly selecting, combining, and modifying the parameters sought using mechanisms that resemble biological evolution. Their main advantages are a relatively high speed of finding a satisfactory solution under certain conditions and a unique way of working: by implementing the mechanisms of crossing, selection, mutation, and other genetic operators, the algorithm will search through the next "generations" of solutions until it finds the optimal result or exhausts a certain amount of time or cycles allotted for its operation [3].

The main characteristic of genetic algorithms in economics is that they can effectively solve optimization problems in conditions of complexity and multidimensionality, for example, investment portfolio optimization, price forecasting, production planning, etc. Their versatility makes it possible to apply them to a wide range of economic tasks, from resource management and forecasting to optimization of production processes to marketing strategies. Genetic algorithms can quickly adapt to changes in the initial data or problem conditions, which is an important condition for solving economic problems, and can find optimal or near-optimal solutions in cases where other optimization methods may get stuck in local minima or maxima.

Evolutionary computing widely uses an evolutionary strategy (a heuristic optimization method in the section of evolutionary algorithms based on adaptation and evolution. The method was developed in 1964 by German scientist Ingo RehenFberg and further developed by Hans-Paul Schweffel) is an optimization

method based on the ideas of biological evolution to find optimal solutions to complex economic problems. This approach imitates natural selection and evolution in its work, which makes it useful and effective for solving various economic problems.

Main features and peculiarities of evolutionary strategies in economics:

- Search for optimality: evolutionary strategies look for optimal or acceptable solutions in conditions where there may be many options for solving a problem.

- Modeling of evolutionary processes: this approach mimics natural selection, mutation, and other processes that promote adaptation and change.

- Genetic operations: evolutionary strategies use genetic operations, such as selection, mutation, to maintain and change strategies.

- Adaptability: they can quickly adapt to changing conditions and dynamic environments, making them effective in solving economic problems.

- Applications: they are used to solve various economic problems, such as investment portfolio optimization, price forecasting, adaptive management, and others.

Evolutionary computing is widely used in optimizing portfolio management, which is a key aspect of the financial sector. Portfolio optimization [4] is the allocation of assets or investments between different financial instruments in order to maximize profitability at a certain level of risk. The application of evolutionary computing [5] in this area is to create algorithms that search for the optimal allocation of assets for investment. They are based on the modeling of natural selection and evolution, which allows finding effective portfolio management strategies under uncertainty and changing market conditions. Thanks to evolutionary algorithms, portfolio management provides risk and return optimization, diversification management (using evolutionary computations, you can find the optimal combination of investments that reduces the overall risk of the portfolio by allocating resources between different asset classes), and adaptive management (evolutionary strategies allow you to change the portfolio in response to changes in market conditions and the economic environment).

Evolutionary computing in economics has found its niche in financial market forecasting [6], and its use makes it possible to identify and analyze trends, risks, and potential opportunities. These computations are based on the simulation of evolutionary processes in nature, such as selection, mutation, and recombination, which makes it possible to create optimal models for analyzing financial markets. The main aspects of evolutionary computing in this area include the creation of predictive models, optimization of trading strategies, forecasting price dynamics, creation of intelligent decision support systems, and forecasting supply and demand.

Evolutionary computing is widely used in optimizing business processes and solving logistics problems in the economy. They can help optimize delivery routes, plan transportation, and allocate resources to minimize time and money, and can be used to optimize inventory levels, taking into account factors such as demand, delivery time, costs, and storage conditions. Evolutionary algorithms help manage business processes in terms of choosing strategies and optimizing decisions in real time, optimize work schedules, distribute tasks and resources among staff, taking into account business constraints and requirements, help analyze data and find optimal pricing strategies, taking into account the demand for goods and services.

In turn, the use of evolutionary computing in economics is also accompanied by certain limitations, including execution time (especially when working with large data sets or complex models), local maxima (in complex optimization functions, evolutionary methods can get stuck in local maxima without finding optimal solutions), and the choice of an optimal algorithm (different tasks require the selection of a suitable evolutionary algorithm, which requires a deep understanding of their principles and features).

Economic research conducted with the help of evolutionary computing can pursue one of two main goals: the first is a constructive explanation of macro phenomena, and the second is the development of new economic mechanisms, in turn, the research conducted is classified into four main categories: empirical understanding, normative understanding, methodological progress, as well as qualitative understanding and theory creation [7].

Also, when considering this topic, we cannot ignore the rapid development of artificial intelligence (AI) and its connection with evolutionary computing. It affects this industry by providing new methods and techniques that allow improving and adapting algorithms to optimize and predict various economic processes. AI is used to improve evolutionary strategies, through deep learning and neural networks, leading to more accurate and efficient models. Its impact lies in the development of this field, making the processes of optimizing economic systems more efficient and adaptive to changes.

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