# DISINFLATION IN CLOSED AND SMALL OPEN ECONOMIES*

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**Abstract**

This paper examines the cost of disinflation as measured by the sacrifice ratio and the central bank loss function in closed and small open economies. We show that the sacrifice ratio is slightly higher in the small open economy if monetary policy in both economies follow identical Taylor rules. However, if monetary policies follow optimized simple rules the sacrifice ratio becomes slightly lower in the small open economy. The cost in terms of the central bank loss is higher in the small open economy irrespective of monetary policies. Imperfect central bank credibility changes the results quantitatively, but not qualitatively. Finally, in both economies, the optimal implementation horizon is approximately two quarters in advance and approximately four quarters if central bank credibility is imperfect.

**Keywords**: Disinflation, small open economy, new Keynesian model, imperfect credibility, implementation.

**JEL classification**: E31, E5, F41.

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# 1. Introduction

Many emerging and developing countries have seen a remarkable decrease in inflation over the last 30-40 years. In many cases, inflation has fallen to 5% or lower.[1] However, periods of disinflation are often associated with short-term output losses. In this paper we examine the cost of a further reduction of inflation to the 2% level prevalent in many advanced economies. Ascari and Ropele (2004, 2012a, 2012b, and 2013) have shown that estimates of the sacrifice ratio – the percentage of output the economy has to give up for each percentage point reduction in long-run inflation – in a new Keynesian model can be in line with empirical estimates. However, they note that the empirical estimates can vary considerably depending on the country, the historical episode, and the econometric method.

The papers by Ascari and Ropele study the cost of disinflation in a closed economy.[2] We extend this analysis to a small open economy to account for exchange rate effects. In general, disinflation episodes in a small open economy are associated with higher real interest rates that lead to an appreciation of the real exchange rate. This has two effects. First, it affects prices through the exchange rate pass-through channel, which may facilitate the transition of inflation to a lower target since it puts downward pressure on prices. Second, households switch consumption towards imported goods when the exchange rate appreciates, which has a negative effect on net exports and output. We quantify how those effects impact the cost of disinflation in a small open economy compared to a closed economy. Moreover, studying the cost of disinflation in an open economy in a theoretical framework is also of interest because the empirical literature shows conflicting results. For example, Ball (1994) finds no correlation between openness and the sacrifice ratio, whereas Mazumder (2014) finds that increased openness is associated with lower sacrifice ratios.

Any successful disinflation policy relies on the central bank's credibility and the chosen implementation strategies. In an open economy, there is an additional channel through which the central bank's credibility can affect the cost of disinflation, i.e., through the uncovered interest rate parity condition. We quantify the effect of this channel. Ascari and Ropele (2013) study implementation strategies in which the central bank reduces its inflation target quickly initially and then more slowly. We extend their work by examining two other strategies: an increased rate of reduction whereby the target is reduced slowly initially and then more quickly, as well as a linear rate of reduction whereby the target is reduced at an equal rate each period. We show the optimal speed of reduction in all three scenarios and the optimal implementation horizon.

The standard Taylor rule can be a poor guide for monetary policy in periods of structural change, such as disinflation periods. To account for this, we extend the assumptions in the papers by Ascari and Ropele and assume that monetary policy follows an *optimized simple disinflation rule* instead of a Taylor rule. By this we mean a Taylor-type rule that is optimized

[1] See World Bank (2019).
[2] See also Collard et. al. (2012) and Fève et al. (2014).

given a quadratic loss function where the central bank puts a weight on stabilizing the output gap, in addition to stabilizing inflation around the target.[3]

The cost of disinflation is quantified in a standard new Keynesian model where price stickiness is the key friction, i.e., firms adjust prices infrequently according to the Calvo mechanism (see Calvo (1983) and Galí (2008)). The small open economy follows Adolfson et al. (2007) and Galí and Monacelli (2005). In this set up, importing firms set prices in local currency and adjust them infrequently according to the Calvo mechanism, which gives rise to imperfect exchange rate pass-through. Central bank credibility is modelled as in Ascari and Ropele (2013). Households and firms do not instantly revise their expectations to the new inflation target. Inflation expectations are instead gradually adjusted by putting a weight on the old inflation target. Two measures of the cost of disinflation are reported: the sacrifice ratio and the central bank's loss function. In addition to the output loss, the latter also measures deviations of inflation from the new target.

In all scenarios, inflation is reduced from 5% to 2%. The sacrifice ratio is slightly higher in the small open economy than in the closed economy – 0.83% compared to 0.73% – when central bank credibility is perfect and monetary policies in both economies follow identical Taylor rules. The sacrifice ratio is also slightly higher when central bank credibility is imperfect, but if credibility is low the sacrifice ratio converges to the closed economy. On the other hand, if monetary policies in both economies follow optimized simple disinflation rules, the sacrifice ratio is slightly lower in the small open economy. If central bank credibility is perfect, the sacrifice ratio is about 0.1 percentage points (pp) lower and if credibility is imperfect, the sacrifice ratio is about 0.3 pp lower. One reason for the lack of consensus on the effects of openness in the empirical literature may therefore be that the studies have not successfully controlled for the effects of different monetary policies.

In terms of the central bank loss function, the cost of disinflation is higher in the small open economy both when monetary policies follow identical Taylor rules and optimal simple disinflation rules. Moreover, the loss is higher both when central bank credibility is perfect and imperfect. According to our estimates, the loss can be between 3.5% and 29% higher in the small open economy, depending on the assumptions of monetary policy and central bank credibility.

The optimized simple disinflation rules are quantitatively different from the Taylor rule. In general, optimized rules react more aggressively to deviations of inflation from the new target. During episodes of disinflation, the central bank needs to exert more effort to anchor inflation expectations at the new target. Moreover, monetary policy in the small open economy reacts much more aggressively both to deviations of inflation from the target and to the output gap than in the closed economy. A notable feature is also that the weight on the real exchange rate gap in the Taylor rule is zero. Imperfect credibility implies even more active monetary policies with larger reaction coefficients on both inflation deviations from the target and the

[3] See Svensson (2000) for a discussion of the central bank's loss function.

output gap. When credibility is imperfect, monetary policy must work harder to anchor inflation expectations than when credibility is perfect.

To minimize the sacrifice ratio, monetary policy should reduce the inflation target at an increasing pace. If the target is implemented two years in advance, the sacrifice ratio is close to zero in both economies. On the other hand, in order to minimize the central bank loss function, monetary policy should implement the new target at a decreasing rate of reduction. The optimal implementation horizon is about two quarters in advance in both economies, but if central bank credibility is imperfect the optimal implementation horizon is prolonged to about four quarters. This strategy minimizes the loss in both economies, but to a larger extent in the small open economy.

This paper is organized as follows. In the next section we present the economic environment and calibration of the parameters in the model. In section 3, we report the cost of disinflation when the monetary policies in both economies follow identical Taylor rules, while in section 4 we report the cost when monetary policies follow optimized simple disinflation rules. Section 5 outlines the results of a sensitivity analysis of the disinflation cost with respect to imperfect credibility. Section 6 shows how different implementation strategies affect the cost of disinflation. Finally, section 7 concludes.

## 2. A small open economy

We assume the world economy is made up of a small open economy and a foreign economy, i.e., the rest of the world.

## 2.1. Households

The economy is comprised of a large number of households. Each household has preferences, $\mathcal{U}$, over a composite consumption index $C$ and hours worked $N$ according to

$$\mathcal{U} = \sum_{t=0}^{\infty} \beta^t U(C_t, N_t), \qquad (1)$$

where t denotes a time period, $U(\cdot)$ the period utility function, and $\beta > 1$ the households discount factor. The period utility function has the following functional form:

$$U(C_t, N_t) = \ln C_t - \frac{N_t^{(1+1/\varphi)}}{1 + 1/\varphi}, \qquad (2)$$

where $\varphi$ denotes the Frisch elasticity of labour supply, i.e., the substitution effect of a change in the wage rate on labour supply.

The consumption aggregator is defined according to a composite consumption index defined by:

$$C_t = \left[(1-\alpha)^{\frac{1}{\eta}}\left(C_{H,t}\right)^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}}\left(C_{F,t}\right)^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}, \tag{3}$$

where $C_H$ denotes an index of consumption of domestic goods (H for Home), CF an index of consumption of foreign goods (F for Foreign), $\alpha \in [0,1]$ the degree of trade openness ($(1-\alpha)$ can also be interpreted as a measure of home bias in preferences), and $\eta > 1$ measures the elasticity of substitution between domestic and foreign goods. The closed economy is one in which the degree of openness is zero, i.e., $\alpha = 0$. The indices of consumption of domestic goods and of consumption of foreign goods are defined as follows:

$$C_{H,t} = \left(\int_0^1 C_{H,t}(i)^{\frac{\epsilon-1}{\epsilon}} di\right)^{\frac{\epsilon}{\epsilon-1}}, \tag{4}$$

$$C_{F,t} = \left(\int_0^1 C_{F,t}(i)^{\frac{\epsilon-1}{\epsilon}} di\right)^{\frac{\epsilon}{\epsilon-1}} \tag{5}$$

where $\epsilon > 1$ is the elasticity of substitution between domestic goods and the elasticity of substitution between foreign goods. Households minimize the total expenditure required to purchase a given amount of consumption, $\tilde{C}$; formally:

$$\min_{C_{H,t}, C_{F,t}} P_{H,t}C_{H,t} + P_{F,t}C_{F,t}\,, \qquad s.t.\, C_t = \tilde{C}, \tag{6}$$

where $P_H$ is the price of one unit of the home good and $P_F$ is the price of one unit of the foreign good, measured in the domestic currency. The first order conditions are given by:

$$C_{H,t} = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t, \tag{7}$$

$$C_{F,t} = \alpha\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} C_t, \tag{8}$$

where $P$ denotes the price of a consumption basket (CPI – the consumer price index), expressed in units of domestic currency:

$$\mathrm{P_t} = \left[(1-\alpha)\left(P_{H,t}\right)^{1-\eta} + \alpha\left(P_{F,t}\right)^{1-\eta}\right]^{\frac{1}{1-\eta}}. \tag{9}$$

Solving households' minimization problem for a given amount of domestically produced goods, $\tilde{C}_H$, and imported goods, $\tilde{C}_F$ , yields:

$$C_{H,t}(i) = (1-\alpha)\left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\epsilon}\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t, \tag{10}$$

$$C_{F,t}(i) = \alpha\left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\epsilon}\left(\frac{P_{F,t}}{F_t}\right)^{-\eta} C_t. \tag{11}$$

By symmetry, foreign demand for domestically produced goods is:

$$C_{H,t}^{W}(i) = \alpha\left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\epsilon}\left(\frac{P_{H,t}}{S_t P_t^W}\right)^{-\eta} Y_t^W, \tag{12}$$

The households' intertemporal budget constraint at t can be written as:

$$\begin{aligned} P_t C_t + B_t + S_t B_t^W &= \\ = B_{t-1}(1+R_{t-1}) + S_t B_{t-1}^W (1+R_{t-1}^w)\Phi_{t-1} &+ \\ +W_t N_t + D_{H,t} + D_{F,t} - T_t&, \end{aligned} \tag{13}$$

where $B$ denotes the stock of nominal bonds denominated in domestic currency, $B^W$ the stock of nominal bonds (or net foreign assets) denominated in foreign currency, $S$ the nominal exchange rate defined as the price of foreign currency in terms of domestic currency, $W$ the nominal wage rate, $R$ and $R^W$ are the nominal interest rates on domestic and foreign bonds, respectively, and $\Phi$ is a risk premium. Finally, $D_H$ and $D_F$ denote profits from owning the equity of firms and importing firms, while $T$ represents lump-sum transfers.

The risk premium depends negatively on net foreign assets:

$$\Phi_t = \exp\{-\phi_\Gamma(NBA_T - \overline{NFA})\}, \tag{14}$$

where $NFA$ denotes net foreign assets and $\overline{NFA}$ the steady state of the net foreign assets. In addition to add realism, the risk premium induce stationarity in the net asset position.

The first order conditions of the households' intertemporal maximization problem can be summarized by the following three conditions:

$$\frac{W_t}{P_t} = -\frac{U_{N,t}}{U_{C,t}}, \tag{15}$$

$$1 + R_t = (1+r_t)\mathbb{E}[\Pi_{t+1}], \tag{16}$$

$$\frac{1+R_t}{1+R_t^W} = \mathbb{E}\left[\frac{S_{t+1}}{S_t}\right]\Phi_t, \tag{17}$$

where $\Pi_{t+1} = \frac{P_{t+1}}{P_t}$ denotes gross inflation in period $t+1$, while $r_t$ is the real interest rate defined as follows:

$$1 + r_t = \frac{1}{\beta}\mathbb{E}\left[\frac{U_{C,t}}{U_{C,t+1}}\right], \tag{18}$$

The first condition (12) gives the familiar result that the real wage is the negative of the marginal rate of substitution between labor supply and consumption. The next condition (13) is the so-called Fisher equation, which says that the nominal interest rate equals the real interest rate times expected inflation. The last condition (14) is the nominal uncovered interest rate parity condition, according to which the domestic nominal interest rate equals foreign interest rates times the expected depreciation of the exchange rate.

## 2.2. Firms

There is a continuum of firms indexed by $i \in [0,1]$. Each firm produces a differentiated good, using a constant return to scale production where labor is the input factor:

$$Y_t(i) = N_t(i), \tag{19}$$

where $Y$ denotes output. Note that we have normalized the technology level, which is equal to all firms, at one.

Following Calvo (1983), each firm can reset prices in any period with a constant probability $1 - \theta_H$. A firm that does not re-optimize its price in period $t$ indexes its price to inflation in the previous period according to the following rule:

$$P_{H,t}(i) = P_{H,t-1}(i)\left(\frac{P_{H,t-1}}{P_{H,t-2}}\right). \tag{20}$$

A firm that re-optimizes its price, $P_H^*(i)$, maximizes profits while the price remains effective:

$$\max_{P_{H,t}^*(i)} \mathbb{E}\left[\sum_{k=0}^{\infty} \theta_H^k \Lambda_{\mathrm{t+k}}\left[P_{H,t+k}^*(i)Y_{t+k}(i) - (1+\tau)W_{t+k}Y_{t+k}(i)\right]\right], \tag{21}$$

where $\Lambda_{\mathrm{t+k}} = \beta\left(U_{C,t+k}P_t\right)/\left(U_{C,t}P_{t+k}\right)$ denotes the one-period stochastic discount factor and $\tau$ a subsidy set to eliminate the steady state distortion implied by imperfect competition.

The maximization is subject to the following demand constraint:

$$Y_t(i) = C_{H,t}(i) + C_{H,t}^W(i), \tag{22}$$

where $C_H(i)$, and $C_H^W(i)$ are defined by equations (8) and (10), respectively.

The first order condition of the firms' maximization problem is given by the following condition:

$$\begin{aligned} &\mathbb{E}\left[\sum_{k=0}^{\infty} \theta_H^k \Lambda_{\mathrm{t,t+k}} Y_{t+k}(i) P_{H,t}^* \left(\frac{P_{H,t+k-1}}{P_{H,t+k-2}}\right)\right] = \\ &= \mathbb{E}\left[\sum_{k=0}^{\infty} \theta_H^k \Lambda_{\mathrm{t,t+k}} Y_{t+k}(i) \frac{\varepsilon}{\varepsilon-1}(1+\tau) W_{t+k}\right]. \end{aligned} \tag{23}$$

The aggregate domestic price is a weighted average of prices set by firms that re-optimize and by those that do not re-optimize:

$$\left(P_{H,t}\right)^{1-\epsilon} = (1-\theta_H)\left(P_{H,t}^*\right)^{1-\epsilon} + \theta_H \left(P_{H,t-1}\left(\frac{P_{H,t-1}}{P_{H,t-2}}\right)\right)^{1-\epsilon} \tag{24}$$

## 2.3. Importing firm

There is a continuum of importing firms that acquire a homogeneous foreign good on the international market. The price of this good in domestic currency is $S_t P_t^*$. The importing firms rebrand the good and sell it to domestic households under monopolistic competition. An important feature of the model is the assumption of imperfect exchange rate pass-through. Empirical evidence suggests that changes in nominal exchange rates affect import prices only gradually. There is therefore incomplete pass-through of exchange rate changes to import prices in the short run, i.e., that changes in the nominal exchange rate affect import prices only gradually, while in the long-run pass-through is complete. A common explanation of the gradual exchange rate pass-through is that import prices are sticky. Price setting of import prices are therefore subject to Calvo price setting. Import prices that are not reset in period $t$ are updated to the price from the last period.

Prices that are not reset in period $t$ are indexed to inflation in the previous period according to the following:

$$P_{F,t}(i) = P_{F,t-1}(i)\left(\frac{P_{F,t-1}}{P_{F,t-2}}\right). \tag{25}$$

With constant probability $1-\theta_F$ importing firms optimally revise their price in period $t$ and solve the following profit maximization problem:

$$\max_{P^*_{F,t}(i)} \mathbb{E}\left[\sum_{k=0}^{\infty} \theta_F^k \Lambda_{\mathrm{t+k}}\left[P^*_{F,t+k}(i) C_{F,t+k}(i) - (1+\tau) S_{t+k} P^W_{t+k} C_{F,t+k}(i)\right]\right]. \quad (26)$$

The maximization is subject to a foreign demand function $C_F(i)$ defined by equation (9). The first order condition is given by:

$$\begin{aligned} &\mathbb{E}\left[\sum_{k=0}^{\infty} \theta_H^k \Lambda_{\mathrm{t,t+k}} C_{F,t+k}(i) P^*_{H,t}\left(\frac{P_{H,t+k-1}}{P_{H,t+k-2}}\right)\right] = \\ &= \mathbb{E}\left[\sum_{k=0}^{\infty} \theta_H^k \Lambda_{\mathrm{t,t+k}} C_{F,t+k}(i) \frac{\varepsilon}{\varepsilon - 1}(1+\tau) S_{t+k} P^W_{t+k}\right]. \end{aligned} \quad (27)$$

The aggregate import price is a weighted average of prices set by importing firms that re-optimize and by those that do not re-optimize:

$$\left(P_{F,t}\right)^{1-\epsilon} = (1-\theta_F)\left(P^*_{F,t}\right)^{1-\epsilon} + \theta_F\left(P_{F,t-1}\left(\frac{P_{F,t-1}}{P_{F,t-2}}\right)\right)^{1-\epsilon} \quad (28)$$

## 2.4. Monetary Policy

Monetary policy follows a standard Taylor rule (see Taylor (1993)). According to this rule, the policy rate depends on deviations of inflation from its target (inflation gap), the output gap, and the long-term interest rate,

$$\frac{1+R_t}{1+\bar{R}} = \left(\frac{\Pi_t}{\bar{\Pi}}\right)^{\rho_\pi}\left(\frac{Y}{\bar{Y}}\right)^{\rho_Y}, \quad (29)$$

where parameters $\rho_\pi$ and $\rho_Y$ show the amount by which the policy rate reacts to deviations of inflation from the target and the output gap, respectively. Following Taylor (1993), we set $\rho_\pi = 1.5$ and $\rho_Y = 0.5/4$.

The Taylor rule is widely used as a benchmark rule since it describes monetary policy relatively well under normal circumstances. Another reason is that it has been shown in economic models to provide good guidance on how monetary policy should be conducted under different assumptions of the functioning of the economy. That is true even though the optimal monetary policy is complex and depends on several different factors. The Taylor rule may, however, not be a useful guideline under all circumstances, for example, when introducing a new inflation target. We therefore calculate optimized simple disinflation rules for the small open economy and the closed economy. We restrict attention to optimized rules of the following functional form:

$$\frac{1+R_t}{1+\bar{R}} = \left(\frac{\Pi_t}{\overline{\Pi}}\right)^{\rho_\pi} \left(\frac{Y}{\bar{\bar{Y}}}\right)^{\rho_Y} \left(\frac{Q}{\bar{\bar{Q}}}\right)^{\rho_Q}, \tag{30}$$

where $Q$ is the real exchange rate and $\rho_Q$ states by how much the policy rate reacts to the real exchange rate gap.

We search for the optimized parameter vector $\rho = [\rho_\pi, \rho_Y, \rho_Q]$ that during the transition to the new inflation target solves

$$\tilde{\rho} = \arg\left\{\max_{\rho} \mathcal{L}\right\}, \tag{31}$$

where $\mathcal{L}$ denotes the central bank's loss function which takes into account both inflation deviations from the target and the output gap.[4] The central bank loss function is further discussed in section 2.8.

## 2.5. Imperfect credibility

Many studies explain the cost of disinflation by an imperfect credibility channel (see Goodfriend and King (2005), Erceg and Levin (2003), Gibbs and Kulish (2015)). The assumption is that households do not instantly revise their expectations to the new inflation target, but gradually adjust expectations by putting a greater weight on the old inflation target. Price indexation to previous inflation, as in the Calvo price-setting framework, can to a certain extent be viewed as a reduced-form substitute for imperfect credibility, since it adds a backward-looking component to the Phillips curve (see Ascari and Ropele (2013)). We follow Ascari and Ropele (2013) and Goodfriend and King (2005) and assume that agents adjust their expectations $\widetilde{\mathbb{E}}_t(\Pi_{t+1})$ in a forward-looking manner with probability$\left(1-\omega_t^{cred}\right)$ and with respect to the old inflation target with probability $\omega_t^{cred}$,

$$\widetilde{\mathbb{E}}_t(\Pi_{t+1}) = \left(1-\omega_t^{cred}\right)\mathbb{E}_t(\Pi_{t+1}) + \ \omega_t^{cred}\, \overline{\Pi}^{old}\ . \tag{32}$$

The variable $\omega_t^{cred} \in [0,1]$ determines the credibility of the policy. When $\omega_t^{cred} = 0$ there is full credibility, while $\omega_t^{cred} = 1$ implies zero credibility.

When a central bank announces a new lower inflation target, agents are not fully convinced of the central bank's commitment to the new target. If the central bank remains committed to the new target, its credibility grows towards full credibility. We model this by introducing an AR(1) process for $\omega_t^{cred}$,

$$\omega_t^{cred} = \rho^{cred}\, \omega_{t-1}^{cred}, \tag{33}$$

[4] Technically, we simulate the model for different values of $\rho_\pi, \rho_Y, \rho_Q$ and calculate corresponding loss functions. We test the following parameter values: $\rho_\pi = [1 : 0.1 : 25]$, $\rho_Y = [0 : 0.1 : 15]$, and for the small open economy $\rho_Q = [0 : 0.1 : 5]$. In order to avoid corner solutions, we choose the smallest parameters so that the corresponding loss does not exceed the minimum loss by 0.5%.

where $\rho^{cred}$ is a persistence parameter that shows how fast the central bank achieves full credibility. For the benchmark simulation under imperfect credibility, this parameter is set to 0.7 as in Ascari and Ropele (2013). Formally, the formation of inflation expectations in the Phillips curve, Fisher equation, and the uncovered interest rate parity condition are changed to $\widetilde{\mathbb{E}}_t(\Pi_{t+1})$. Hence, in a small open economy there is an additional channel through which imperfect credibility can affect the cost of disinflation, i.e., through the uncovered interest rate parity condition.

## 2.6. Market clearing, trade, and net foreign assets

There are five markets in the model that require market clearing: the labor market, domestic and foreign bond markets, and the markets for domestically produced and imported goods.

Domestic currency bonds cannot be traded in the international financial market and their net supply is zero, i.e., $B_t = 0$.

Market clearing in the labor market requires that

$$N_t = \int_0^1 N_t(i)di. \tag{34}$$

Market clearing in the market for domestically produced goods requires that for any producing firm the production is either consumed domestically or exported:

$$Y_t(i) = C_{H,t}(i) + C_{H,t}^W(i). \tag{35}$$

An economy-wide goods-market clearing condition is achieved by integrating over the continuum of goods and plugging in demand and production functions for individual goods:

$$\begin{gathered} \int_0^1 N_t(i)di = \int_0^1 \left(C_{H,t}(i) + C_{H,t}^W(i)\right) di \qquad \Leftrightarrow \\ N_t = \left[(1-\alpha)C_t + \alpha Q_t^{\eta} Y_t^W\right]\Delta_{H,t}, \end{gathered} \tag{36}$$

where $\Delta_{H,t} = \int_0^1 \left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\epsilon} \left(\frac{P_{H,t}}{P_t}\right)^{-\eta} di$ denotes price dispersion across firms.

We define nominal income and output to close the model. Nominal household income consists of labor earnings plus profits from producers and importing firms. Nominal output in domestic output units $P_H Y$ equals nominal income and, hence, nominal sales, and, in turn, equals nominal consumption minus imports plus exports, as follows:

$$P_{H,t}Y_t = W_t N_t + D_{H,t} + D_{F,t} = P_t(C_t + X_t - M_t). \tag{37}$$

The real exchange rate $Q$ is defined as:

$$Q_t = S_t \frac{P_t^W}{P_t}. \tag{38}$$

Real exports $X$ and real imports $M$ are then given by:

$$X_t = \alpha \left(\frac{P_{H,t}}{P_t}\right)^{1-\eta} Q_t^\eta Y_t^W, \tag{39}$$

$$M_t = \alpha Q_t \Delta_{F,t} C_t, \tag{40}$$

where $\Delta_{F,t} = \int_0^1 \left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\epsilon} \left(\frac{P_{F,t}}{P_t}\right)^{-\eta} di$ is a measure of price dispersion across importing firms.

Net foreign assets are defined as the stock of foreign bonds in domestic currency $NFA_t = S_t B_t^W$. Using the households' budget constraint and the expression for aggregate nominal income, and assuming that domestic bonds are in zero net supply, we can derive the law of motion for net foreign assets:

$$NFA_t = NFA_{t-1} \frac{S_t}{S_{t-1}} (1 + R_{t-1}^W) \Phi_{t-1} + P_t(X_t - M_t). \tag{41}$$

## 2.7. Stationarity and equilibrium

Finally, the model needs to be stationary to be solved. Therefore, we scale the nominal variables $P_H$, $P_F$, $W$, and $NFA$ by dividing them with the consumer price index $P$. In addition, domestic foreign consumer price indices are replaced with the corresponding stationary inflation rates $\Pi_t \equiv P_t/P_{t-1}$ and $\Pi_t^W \equiv P_t^W/P_{t-1}^W$. Lastly, we replace the nominal exchange rate $S$ with the stationary real exchange rate $Q$.

## 2.8. Calibration and measures of the cost of disinflation

To parametrize the benchmark model, we use standard values from the literature. The parameter values are summarized in Table 1.

**Table 1. Benchmark calibration**

| Parameter | Description | Value |
|---|---|---|
| $\alpha$ | Openness | 0.4 |
| $\beta$ | Discount factor | 1.02^(-0.25) |
| $\phi$ | Frisch elasticity | 2 |
| $\theta_H, \theta_F$ | Price stickiness – firms and importers | 0.75 (4 quarters) |
| $\eta$ | Domestic/imported goods subst. elast. | 6 |
| $1/\epsilon + 1$ | Price markup – firms and importers | 20% |
| $\rho_\pi$ | Taylor rule: weight on inflation | 1.5 |
| $\rho_Y$ | Taylor rule: weight on output | 0.5/4 |

The length of a time period is assumed to be one quarter. The discount factor $\beta$ is set to 0.9951, which implies an annual long-run real interest rate of 2%. The Frisch elasticity $\phi$ is set to 2. This is within the range of values (2-4) that macroeconomists often use to calibrate general equilibrium models (see Peterman (2016)). Evidence from Nakamura and Steinsson (2008) suggests that the median duration of price changes is 8 − 11 months. Hence, we assume the Calvo parameters $\theta_H$ and $\theta_F$ are both equal to 0.75, implying an average duration between price changes of four quarters. Price markups are set to 20% for both firms and importing firms (see Bayoumi, Laxton and Pesenti (2004)). Estimates of the elasticity of substitution between home and foreign goods are around 5 to 20 (see references in Obstfeld and Rogoff (2000) and others). Estimates using macro data are, however, lower (see Collard and Dellas (2002)). We therefore set the elasticity of substitution parameter $\eta$ at the lower range of the estimates from the micro data, i.e., to 6. The openness parameter $\alpha$ is set at 0.4, in line with the value suggested by Adolfson et al. (2007). Finally, the weight on inflation's deviation from the target $\rho_\pi$, is set at 1.5 and the weight on the output gap $\rho_Y$ is set at 0.125, following Taylor (1993).

The cost of disinflation is measured by the sacrifice ratio and the central bank loss function. The sacrifice ratio SR is defined as follows:

$$SR = -\frac{1}{\pi_{old} - \pi_T} \sum_{t=0}^{T} \frac{Y_t - \bar{Y}}{\bar{Y}}, \tag{42}$$

where $\pi_{old}$ denotes the initial or old inflation target, $\pi_T$ inflation at time of calculation $T$, and $\bar{Y}$ the steady state level of output in the low inflation regime.[5] The sacrifice ratio measures the percentage of output the economy has to give up for each percentage point reduction in long-run inflation. Note that the output loss is calculated as output deviations from steady state output in the low inflation regime.

The central bank's loss function accounts for the trade-off between reaching the new inflation target rapidly and mitigating a negative output gap. The loss function is defined as follows:

$$CBL = \sum_{t=0}^{\infty} \left[ (\pi_t - \bar{\pi})^2 + \left( \frac{Y_t - \bar{Y}}{\bar{Y}} \right)^2 \right]. \tag{43}$$

We also compute alternative central bank loss functions to check the robustness of our results; see the results in the appendix.

To solve for the transition path between the initial steady state and the new steady state, we stack the model's equilibrium conditions and solve the system of non-linear equations with a non-linear numerical solver.[6]

## 3. The cost of disinflation when monetary policy follows the Taylor rule

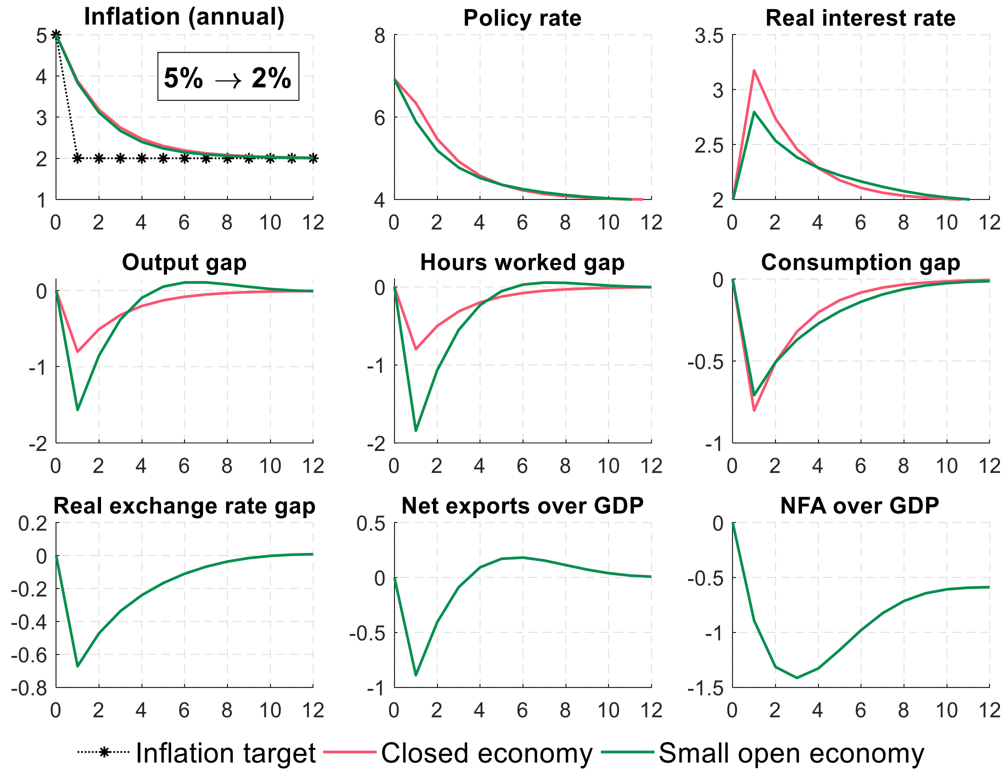
In our scenarios, the inflation target is lowered from 5% to 2%. A lowering of the inflation target by 3 pp is a reasonable scenario given the Calvo price-setting mechanism. For higher disinflation scenarios, state-dependent price-setting would be a more suitable framework.

Monetary policies follow identical Taylor rules in both economies in these scenarios (see equation (24). Figure 1 shows the transition paths for key variables in the small open economy (red line) and the closed economy (blue line).

[5] Ascari and Ropele (2013) set T to a number where the difference between actual inflation and the inflation target is very low. In our simulations, we explore different degrees of imperfect credibility and gradual implementation which can considerably extend the disinflation period. Therefore, given that we are interested in the short-term cost of disinflation, we set T = 12 (3 years).

[6] We use the numerical packages in Dynare to solve for the transition path.

**Figure 1. Disinflation under a standard Taylor rule and perfect credibility**




When a new and lower target is announced, households and firms start to revise their inflation expectations downwards. Actual inflation starts to fall and the central bank lowers the policy rate, but at a slower rate than the rate of disinflation. This leads to a rise in the real interest rate, which gives households an incentive to postpone consumption to later periods. Households consume less and therefore need to work less to finance their consumption. Moreover, the real wage falls (not shown in the diagrams), giving households an additional incentive to work less. There is no capital in this economy. Output is only a function of hours worked and therefore falls at the same rate as hours worked.

This basic story applies to both economies. But in the small open economy, there are additional effects from the real exchange rate and net exports. The increase in the real interest rate leads to an appreciation of the real exchange rate through the uncovered interest rate parity condition, since it is assumed that the foreign real interest rate is unaffected in all scenarios. This puts downward pressure on net exports and yields an additional reduction in output. There is thus a larger decrease in output in the small open economy. However, the transition path for inflation is similar in both economies. This suggests that the sacrifice ratio is higher in the small open economy. This is confirmed in Table 2, where it is shown that the sacrifice ratio is 0.83% in the small open economy and 0.73% in the closed economy.

**Table 2. Sacrifice ratio and central bank loss under a standard Taylor rule, with perfect and imperfect credibility**

| | Sacrifice ratio | Central bank loss |
|---|---|---|
| | *Perfect credibility* | |
| Closed economy | 0.73% | 0.0% |
| Small open economy | 0.83% | 25.2% |
| | *Imperfect credibility* | |
| Closed economy | 1.09% | 0.0% [157%] |
| Small open economy | 1.15% | 3.5% [166%] |

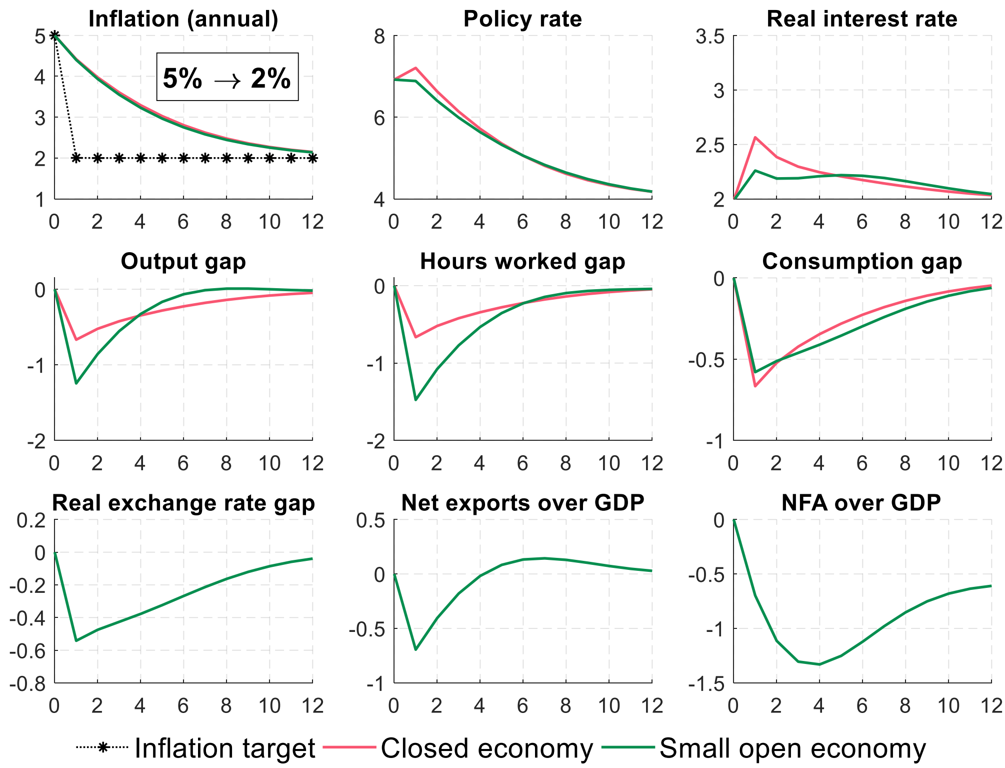
Note: Losses normalized to the closed economy under perfect and imperfect credibility; numbers in brackets represent losses normalized to the closed economy under perfect credibility.

Central bank credibility is an important factor in disinflation episodes. Inflation adjusts more slowly when a central bank's credibility is low. This has two counteracting effects on the real interest rate. On one hand, the initial increase becomes weaker, but on the other hand, the increase is prolonged. The output loss is lower initially but remains higher for longer. Depending on which effect dominates, the sacrifice ratio can increase or decrease. In the small open economy, low credibility has an additional impact through the uncovered interest parity condition. The real exchange rate appreciates less initially due to a lower real interest rate, but the appreciation continues for longer. Figure 2 shows the transition paths for key variables when central bank credibility is low at the benchmark case ρ cred = 0.7.

The sacrifice ratio is higher in both economies when credibility is imperfect, suggesting that the effect of a more persistent increase in the real interest rate dominates (see Table 2). The sacrifice ratio increases to 1.15% in the small open economy and to 1.09% in the closed economy.

The cost of disinflation in terms of the central bank loss function is higher in the small open economy both when credibility is perfect and imperfect. The loss is about 25% higher when central bank credibility is perfect and about 3.5% higher when credibility is imperfect.

**Figure 2. Disinflation under a standard Taylor rule and imperfect credibility**




## 4. The cost of disinflation under optimized simple disinflation rules

The Taylor rule is often a good description of monetary policy in normal times, but in periods of structural changes, like during a disinflation episode, it can be a poor guide. To account for this, monetary policy follows a simple rule where the reaction coefficients are optimized given the disinflation path, which is called the optimized simple disinflation rule. The monetary policy rule can thus be different in the closed and the small open economy in these scenarios.

Consider first a case where central bank credibility is perfect. In the small open economy, the optimized reaction coefficients become 6.6 on the inflation gap and 2.1 on the output gap, while the coefficient on the real exchange rate gap is zero (see Table 3).

Compared to the Taylor rule, monetary policy reacts stronger on both the inflation and output gaps. This illustrates that in a disinflation scenario it is optimal to focus on anchoring inflation expectations at the new target by putting a high weight on inflation. But by doing so, monetary policy implicitly puts a relatively lower weight on the output gap. To optimally account for the trade-off between stabilizing the inflation gap and the output gap, the reaction coefficient on the output gap also becomes higher than in the Taylor rule. By following the optimized rule, the sacrifice ratio decreases from 0.83% to 0.77%. In the closed economy, the optimized reaction coefficients become 2 on the inflation gap and zero on the output gap. The sacrifice ratio increases to 0.91% from 0.73% under a Taylor rule. The optimized rule puts zero weight on the output gap, which makes the output loss larger and the sacrifice ratio higher. The sacrifice ratio is thus lower in the small open economy (0.77%) compared to the closed economy (0.91%).

**Table 3. Sacrifice ratio and central bank loss under optimized simple disinflation rules, with perfect and imperfect credibility**

| | $\rho_\pi$ | $\rho_Y$ | $\rho_Q$ | **SR** | **CBL** |
|---|---|---|---|---|---|
| | | | *Perfect credibility* | | |
| Closed economy | 2.0 | 0.0 | – | 0.91% | 0% |
| Small open economy | 6.6 | 2.1 | 0.0 | 0.77% | 29% |
| | | | *Imperfect credibility* | | |
| Closed economy | 7.8 | 1.3 | – | 1.77% | 0% [96%] |
| Small open economy | 13.4 | 4.1 | 0.0 | 1.41% | 23% [141%] |

Note: Losses normalized to the closed economy under perfect and imperfect credibility; numbers in brackets represent losses normalized to the closed economy under perfect credibility.

Figure 3 illustrates the transition path of some key variables when monetary policies follow the optimized simple disinflation rules. The output and inflation paths are similar in both economies, while monetary policy differs substantially. Monetary policy is more counteractive in the closed economy where the policy rate is hiked initially. In the small open economy, monetary policy is less aggressive to prevent output losses due to an excessive appreciation of the exchange rate.

Imperfect credibility prolongs the disinflation period. To anchor inflation expectations, monetary policy needs to put an even higher weight on the inflation gap. The reaction coefficient on the inflation gap increases to 13.4 in the small open economy and to 7.8 in the closed economy (see Table 3). The weight on the output gap is also higher: 4.1 in the small open economy and 1.3 in the closed economy. The sacrifice ratio increases to 1.41% in the small open economy and to 1.77% in the closed economy. When monetary policy follows optimized simple rules, the sacrifice ratio is lower in the small open economy irrespective of the credibility of the central bank.

**Figure 3. Disinflation under optimized simple disinflation rules and perfect credibility**

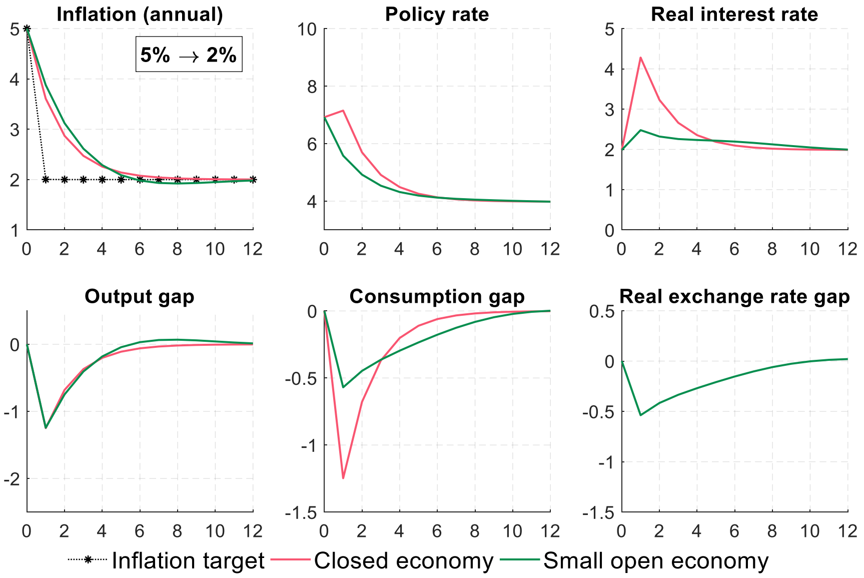



Figure 4 plots the transition paths when monetary policies follow optimized simple rules and central bank credibility is imperfect. The policy rates are initially increased in both economies, but the increase in the closed economy is much more noticeable. The transition paths of output and inflation are nearly the same, indicating that an appropriate monetary policy in the two economies can generate a similar central bank loss. But this is achieved through higher real interest rates, in particular in the closed economy, where the real interest rate increases to slightly more than 4%.

**Figure 4. Disinflation under optimized simple disinflation rules and imperfect credibility**

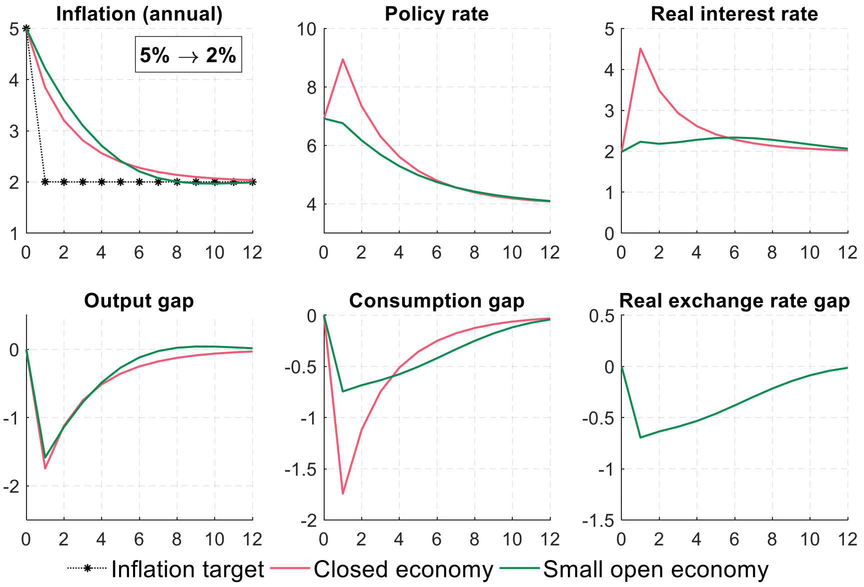
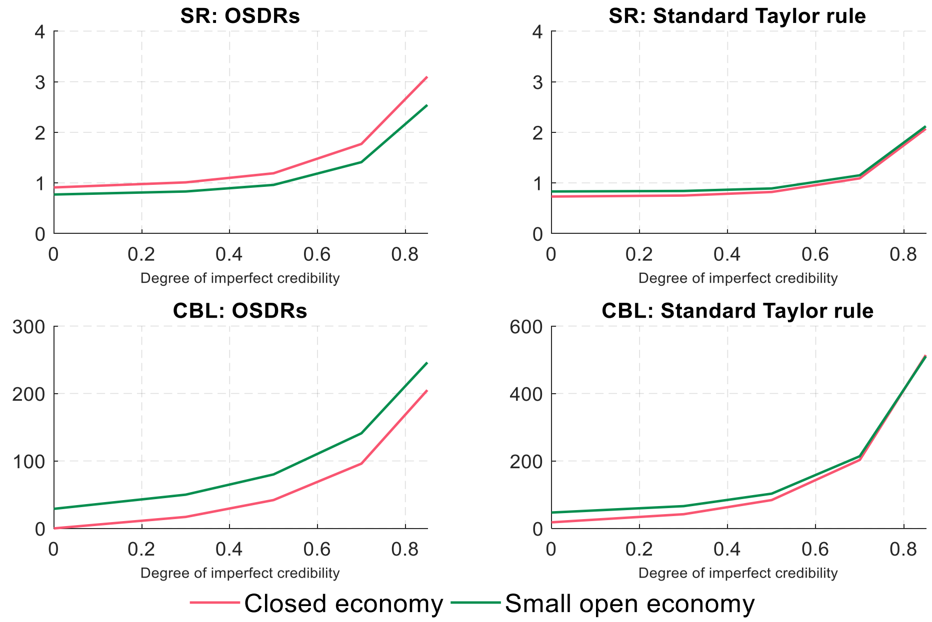


Table 3 also reports the cost of disinflation in terms of the central bank loss function. Under perfect credibility, the loss is 29% higher in the small open economy and 23% higher under imperfect credibility. To summarize, when monetary policies follow optimized simple disinflation rules, the cost of disinflation as measured by the sacrifice ratio is lower in the small open economy, but it is higher in the small open economy when measured by the central bank's loss function.

## 5. Sensitivity analysis with respect to central bank credibility

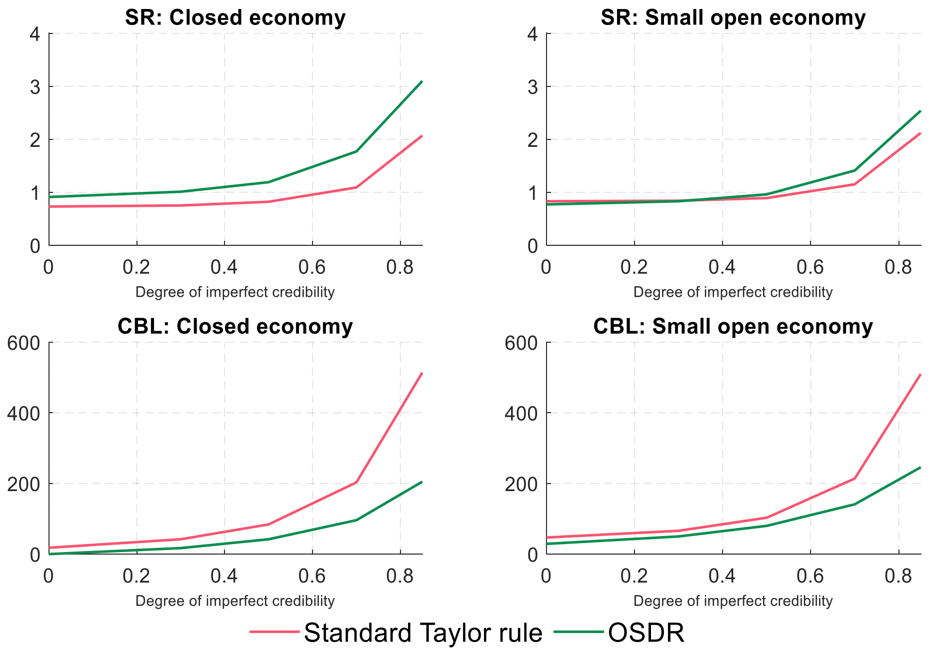
The central bank's credibility is quantitatively important in determining the cost of disinflation. Figure 5 shows the sacrifice ratio and the central bank loss for different levels of central bank credibility, i.e., when the parameter ρ cred is varied from 0 (perfect credibility) to 0.85 (low credibility). The effects are highly non-linear for both measures. They are nearly constant for levels of imperfect credibility up to approximately ρ cred = 0.6 irrespective of monetary policy rules. When credibility is more imperfect, the cost of disinflation increases rapidly. For high values of imperfect credibility, the sacrifice ratio in the small open economy converges towards the closed economy when monetary policy follows the Taylor rule. When monetary policy follows optimized simple disinflation rules, the sacrifice ratio is lower in the small open economy for all values of credibility while the central bank loss is higher.

**Figure 5. Sacrifice ratio and central bank loss given different degrees of imperfect credibility in the closed economy and the small open economy**



Following a Taylor rule is particularly costly in terms of the central bank's loss function when imperfect credibility is high (see Figure 6). The central bank can significantly reduce the loss by following optimized simple disinflation rules. If imperfect credibility is high, monetary policy should put a greater weight on inflation deviations from the new target to anchor households' and firms' inflation expectations at the new target. The optimized simple rules put a higher weight on stabilizing the inflation gap than the Taylor rule. The weight on the output gap is therefore relatively higher in the Taylor rule and the sacrifice ratio is lower. For all degrees of central bank credibility, the Taylor rule is better to follow to minimize the sacrifice ratio.

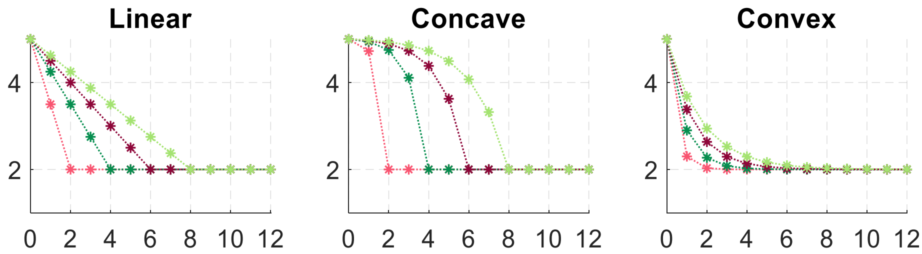
**Figure 6. Sacrifice ratio and central bank loss at different degrees of imperfect credibility. Comparing the standard Taylor rule and OSDRs**




## 6. Different implementation strategies

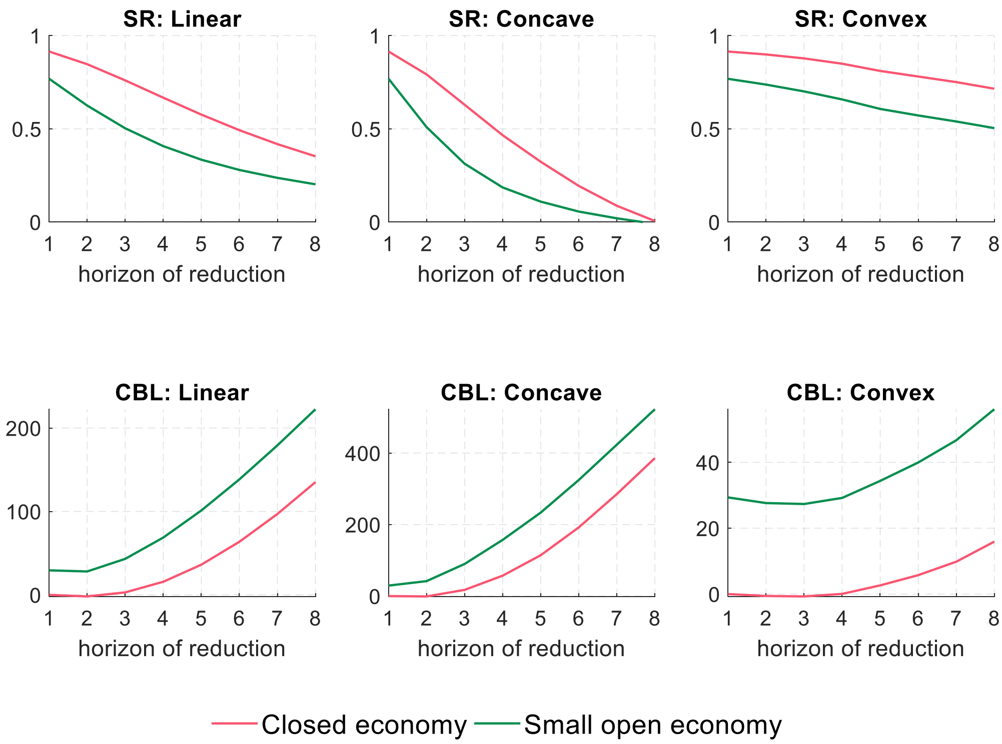
A new lower inflation target is gradually implemented over a number of periods. This can lead to less output loss and a lower sacrifice ratio when prices are sticky (see Taylor (1983)). But a rapid reduction of the inflation target can affect inflation expectations and enhance the credibility of the new target. Ascari and Ropele (2013) evaluate these trade-offs and show that gradualism mitigates the sacrifice ratio in a closed economy. They study an implementation strategy where the central bank reduces the target quickly initially and then more slowly. Another implementation strategy is where the central bank reduces the target slowly initially and then more quickly. We examine the following three implementation strategies in the closed and small open economies: (i) a decreasing (convex) rate of reduction, which reduces the target quickly initially and then more slowly; (ii) an increasing (concave) rate of reduction, which reduces the target slowly initially and then more quickly; and (iii) a linear rate of reduction, which reduces the target equally each period. The implementation strategies are shown in Figure 7.

**Figure 7. Different communication and implementation strategies**




Consider first the perfect credibility case. Figure 8 shows the sacrifice ratio and the central bank loss for the three implementation strategies and announcement horizons from one to eight quarters in advance. Disinflation is costlier in the small open economy in terms of the central bank loss and less costly in terms of the sacrifice ratio, which is in line with our earlier results.

**Figure 8. Sacrifice ratio and central bank loss for different communication and implementation strategies under OSDRs and perfect credibility**

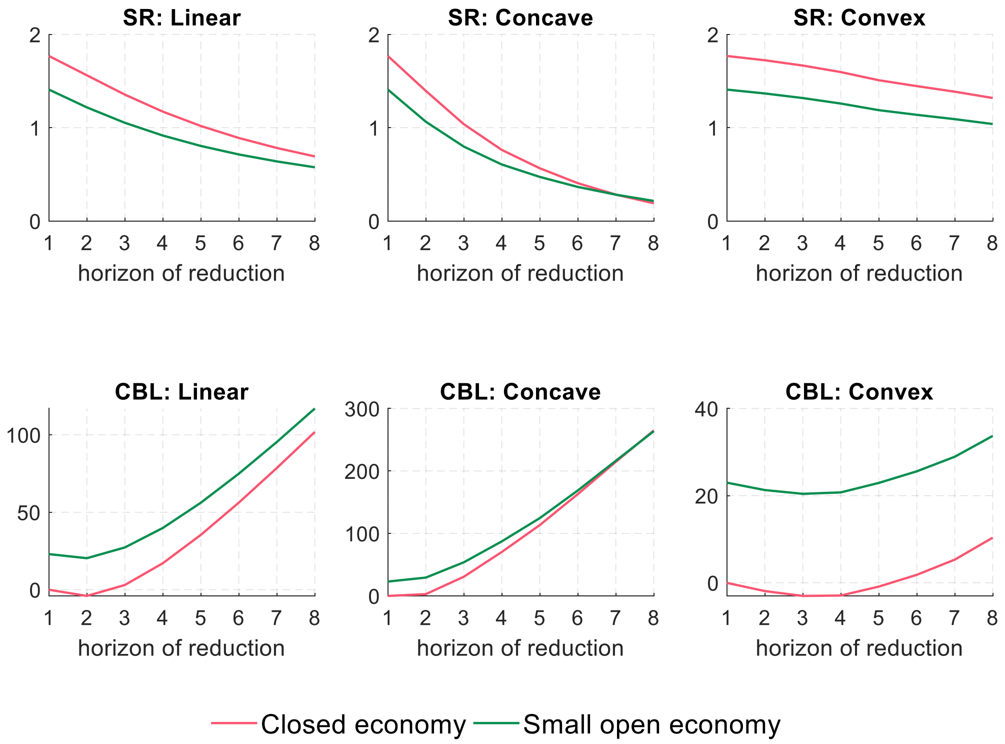


To minimize the central bank loss, the central bank should implement a decreasing (convex) rate of reduction in both economies. The optimal implementation horizon is about two quarters in advance. An increasing (concave) rate of reduction is the costliest strategy. It prolongs the anchoring of inflation expectations at the new level and the transition path of inflation to the new lower target. This is costly in terms of the central bank loss function. As expected, the central bank loss in the linear implementation strategy lies in between the convex and concave strategies.

An increasing (concave) rate of reduction of the target is optimal to minimize the sacrifice ratio. Initially this strategy reduces inflation more slowly towards the new target, which leads to a reduction of the real interest rate. There is a short-term boom before output falls below its long-run level after about a year. By following the linear strategy, the output gap is close to zero during the transition. This implies a small cost of disinflation given that the central bank's loss function is quadratic.

Imperfect credibility does not change the results qualitatively, but quantitatively the results are different. A more sluggish adjustment of inflation to its new target imposes additional costs in terms of the loss function, but a decreasing rate of reduction is still optimal in both economies (see Figure 9).

**Figure 9. Sacrifice ratio and central bank loss for different communication and implementation strategies under OSDRs and imperfect credibility**



The optimal implementation horizon is prolonged to about four quarters in advance. To minimize the sacrifice ratio, an increasing rate of reduction is also optimal with imperfect credibility. The sacrifice ratio is not reduced to zero, as with perfect credibility, when implementing the new target two years in advance. Instead, it falls to less than 0.5% in both economies.

Figure 10 illustrates the transition paths of inflation, the output gap, and the real interest rate under alternative strategies of gradual implementation over eight quarters. In all scenarios, the central bank follows OSDRs for immediate implementation. A linear reduction of the target results in a prolonged, modest recession. A concave reduction creates a small boom at the start and postpones a sharp drop in output. A convex reduction is similar to the immediate implementation as is generates an initial drop in output, but it is smaller. In a closed economy, inflation adjusts to the new target faster than in a small open economy. Under imperfect credibility, inflation becomes more slow-moving while the real economy suffers more (see Figure 11).

**Figure 10. Gradual disinflation under OSDRs and perfect credibility**

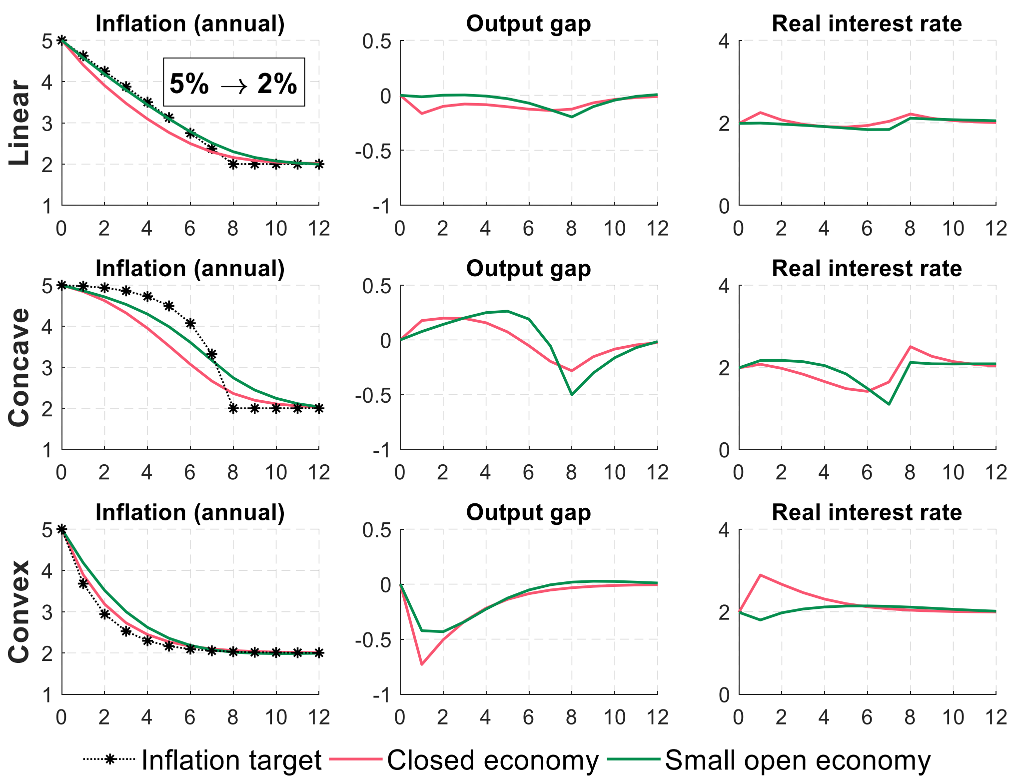
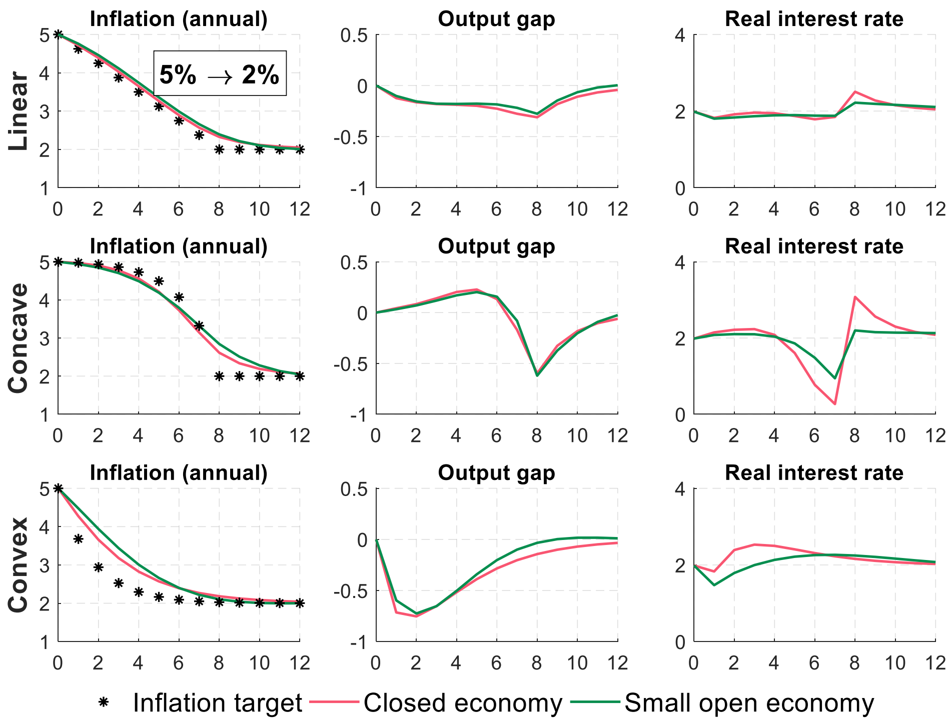


**Figure 11. Gradual disinflation under OSDRs and imperfect credibility**




## 7. Concluding remarks

In many emerging and developing countries, inflation is now near or below 5%. Many of these countries are open or small open economies. We have examined the cost of reducing inflation to the level of many advanced economies (2%). The sacrifice ratio in the small open economy is slightly higher than in a closed economy when monetary policy in both economies follows identical Taylor rules. But if monetary policies follow optimized simple disinflation rules, the sacrifice ratio is slightly lower in the small open economy. However, in terms of the central bank loss function, the cost of disinflation is higher in the small open economy irrespective of monetary policies. We have also shown that imperfect central bank credibility and different implementation strategies change these results quantitatively, but not qualitatively.

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# Appendix

According to Woodford (2003), a welfare-maximizing central bank should be assigned only a small weight to measures of economic activity in its objective. We therefore also consider loss functions with different weights on output stabilization:

$$CBL_2 = \sum_{t=0}^{\infty}\left[(\pi_t - \bar{\pi})^2 + 0.5\left(\frac{Y_t - \bar{Y}}{\bar{Y}}\right)^2\right], \tag{A1}$$

$$CBL_3 = \sum_{t=0}^{\infty}\left[(\pi_t - \bar{\pi})^2 + 1.5\left(\frac{Y_t - \bar{Y}}{\bar{Y}}\right)^2\right], \tag{A2}$$

A quadratic loss function punishes large deviations from the long-run values and they are often used in analyses where the steady state is constant over time. In our scenarios, the changes in the long-term inflation rate decrease. This implies initially large deviations from the target, which in the model and in practice cannot be affected by monetary policy. The central bank may therefore put a lower weight on the initial inflation deviations. A way to capture these considerations is to specify the loss function in terms of absolute values, which is also in line with how the sacrifice ratio is calculated. We consider three absolute value loss functions with similar weights as the quadratic loss functions:

$$CBL_4 = \sum_{t=0}^{\infty}\left[|\pi_t - \bar{\pi}| + \left|\frac{Y_t - \bar{Y}}{\bar{Y}}\right|\right], \tag{A3}$$

$$CBL_5 = \sum_{t=0}^{\infty}\left[|\pi_t - \bar{\pi}| + 0.5\left|\frac{Y_t - \bar{Y}}{\bar{Y}}\right|\right], \tag{A4}$$

$$CBL_6 = \sum_{t=0}^{\infty}\left[|\pi_t - \bar{\pi}| + 1.5\left|\frac{Y_t - \bar{Y}}{\bar{Y}}\right|\right], \tag{A5}$$

Table A1 reports the results of optimization according to alternative loss functions. Our results do not change quantitatively.

**Table A1. Optimized simple disinflation rules for alternative central bank loss functions**

| | $\mathbf{CBL_1}$ | $\mathbf{CBL_2}$ | $\mathbf{CBL_3}$ | $\mathbf{CBL_4}$ | $\mathbf{CBL_5}$ | $\mathbf{CBL_6}$ |
|---|---|---|---|---|---|---|
| **Closed economy: Perfect credibility** | | | | | | |
| CBL | 0 | 0 | 0 | 0 | 0 | 0 |
| SR | 0.91 | 1.07 | 0.88 | 1.30 | 1.63 | 1.05 |
| $\rho_\pi$ | 2 | 3.2 | 1.8 | 6.6 | 22.8 | 3 |
| $\rho_Y$ | 0 | 0 | 0 | 0 | 0 | 0 |
| **Closed economy: Imperfect credibility** $(\boldsymbol{\omega}^{\mathbf{cred}} = \mathbf{0.7})$ | | | | | | |
| CBL | 96% | 90% | 100% | 78% | 75% | 82% |
| SR | 1.77 | 2.04 | 1.62 | 2.51 | 2.87 | 2.17 |
| $\rho_\pi$ | 7.8 | 9 | 6.8 | 10 | 23.4 | 6 |
| $\rho_Y$ | 1.3 | 0.8 | 1.5 | 0 | 0 | 0.1 |
| **Small open economy: Perfect credibility** | | | | | | |
| CBL | 29% | 42% | 24% | 46% | 82% | 29% |
| SR | 0.77 | 0.91 | 0.70 | 0.83 | 1.16 | 0.67 |
| $\rho_\pi$ | 6.6 | 8.6 | 5.6 | 2.6 | 3.4 | 2.4 |
| $\rho_Y$ | 2.1 | 1.8 | 2.2 | 0.5 | 0.2 | 0.8 |
| $\rho_Q$ | 0 | 0 | 0 | 0 | 0 | 0 |
| **Small open economy: Imperfect credibility** $(\boldsymbol{\omega}^{\mathbf{cred}} = \mathbf{0.7})$ | | | | | | |
| CBL | 141% | 158% | 133% | 119% | 162% | 97% |
| SR | 1.41 | 1.66 | 1.27 | 1.60 | 2.23 | 1.29 |
| $\rho_\pi$ | 13.4 | 15.4 | 12 | 7.2 | 11 | 7 |
| $\rho_Y$ | 4.1 | 3.1 | 4.7 | 1.4 | 0.8 | 2.4 |
| $\rho_Q$ | 0 | 0 | 0 | 0 | 0 | 0 |

Note: Losses normalized to closed economy under perfect credibility for each type of central bank loss function.