

Open-Economy Inflation Targeting

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Abstract

The paper examines inflation targeting in a small open economy with forward-looking aggregate supply and demand with microfoundations, and with stylized realistic lags in the different monetary-policy transmission channels. The paper compares strict and flexible targeting of CPI and domestic inflation, and inflation-targeting reaction functions and the Taylor rule. Flexible CPI-inflation targeting does not limit the variability of CPI inflation but also the variability of the output gap and the real exchange rate. Negative productivity supply shocks and positive demand shocks have similar effects on inflation and the output gap, and induce similar monetary policy responses.

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“Why does the Bank make things so complicated? Why doesn’t it just follow the Taylor rule?” [Interruption by a distinguished macro economist at an American university, when the author was presenting Bank of Sweden’s approach to inflation targeting.]

1 Introduction

During the 1990’s, several countries (New Zealand, Canada, U.K., Sweden, Finland, Australia and Spain) have shifted to a new monetary policy regime, inflation targeting. This regime is characterized by (1) an explicit quantitative inflation target, either an interval or a point target, where the center of the interval or the point target currently varies across countries from 1.5 to 2.5 percent per year, (2) an operating procedure that can be described as “inflation-forecast targeting”, namely the use of an internal conditional inflation forecast as an intermediate target variable, and (3) a high degree of transparency and accountability.¹

The operating procedure can be described as inflation-forecast targeting in the following sense: The central bank’s internal conditional inflation forecast (conditional upon current information, a specific instrument path, the bank’s structural model(s), and judgemental adjustments of model forecasts with the use of extra-model information) is used as an intermediate target variable. An instrument path is selected which results in a conditional inflation forecast in line with a(n explicit or implicit) target for the inflation forecast (for instance, at a particular horizon, the forecast for inflation equals, or is sufficiently close to, the quantitative inflation target). This instrument path then constitutes the basis for the current instrument setting.

Inflation-targeting regimes are also characterized by a high degree of transparency and accountability. Inflation-targeting central banks regularly issue “Inflation Reports,” explaining and motivating their policy to the general public. In New Zealand, the Reserve Bank Governor’s performance is being evaluated, and his job is potentially at risk, if inflation exceeds 3 percent per year or falls below 0. In the U.K., the Chancellor of Exchequer recently announced that, if inflation deviates more than 1 percentage point from the inflation target of 2.5 percent, the Governor of the Bank of England shall explain in an open letter why the divergence has occurred and what steps the Bank will take to deal with it.

As argued in Svensson [34], inflation targeting can be interpreted as the announcement and assignment of a relatively specific loss function to be minimized by the central bank. The

¹ See, for instance, Leiderman and Svensson [19], Haldane [17], [18], Mayes and Riches [20], McCallum [21], Svensson [31], Freedman [15], and Bernanke and Mishkin [5].

operating procedure, inflation-forecast targeting, can be interpreted as a way of ensuring that first-order conditions for a minimum of the loss function are approximately fulfilled. The high degree of transparency and accountability, especially the published Inflation Reports, can be interpreted as a way for outside observers of verifying that the first-order conditions are fulfilled. As shown in Faust and Svensson [14], more transparency makes the central bank’s reputation more sensitive to the bank’s actions and increases the cost of deviation from the announced policy. Thus, the high degree of transparency increases the incentives for the central bank to minimize the assigned loss function. This means that inflation targeting is a strong commitment to an optimizing policy relative to the assigned loss function (it is argued in Svensson [34] that it is a stronger commitment than any other monetary policy regime so far). Therefore, inflation targeting can be very well modeled as the minimization of a given loss function, as will be done in this paper.

The above operating procedure implies that all relevant information is used for conducting monetary policy. It also implies that there is no explicit instrument rule, that is, the current instrument setting is not a prescribed explicit function of current information. Nevertheless, the procedure results in an endogenous reaction function, which expresses the instrument as a function of the relevant information. The reaction function will, in general, not be a Taylor-type rule (where a Taylor-type rule denotes a reaction function rule that is a linear function of current inflation and the output gap only)² except in the special case when current inflation and output are sufficient statistics for the state of the economy. Typically, it will depend on much more information; indeed, on anything affecting the central bank’s conditional inflation forecast. Especially for an open economy, the reaction function will also depend on foreign variables, for instance foreign inflation and output and interest rates, since these have domestic effects.³

All real-world inflation-targeting economies are quite open economies with free capital mobility, where shocks originating in the rest of the world are important, and where the exchange rate plays a prominent role in the transmission mechanism of monetary policy. Nevertheless,

² For the Taylor rule, cf. [37], the instrument is a short nominal interest rate and its deviation from a long-run mean equals the sum of 1.5 times the deviation of current inflation from an inflation target and 0.5 times the percentage deviation of current output from the natural output level.

³ Furthermore, the reaction function is generally not only a function of the gap between the inflation forecast, the intermediate target variable, and the inflation target. In the literature, “targeting” and “intermediate targets” are frequently associated with a particular *information restriction* for the reaction function, namely that the instrument must only depend on the gap between the intermediate target variable and the target level (and lags of this gap). (See, for instance, Bryant, Hooper and Mann [8] and McCallum and Nelson [22].)

I find this information restriction rather unwarranted. In this paper, “targeting variable x ” (as in Rogoff [27], Walsh [40], Svensson [31] and [32], Cecchetti [10], and Rudebusch and Svensson [29], and as discussed in more detail in Svensson [34]) used in the sense of “*setting a target* for variable x ”. Thus, “having an intermediate target” means “using all relevant information to bring the intermediate target variable in line with the target.”

most previous formal work on inflation targeting deals with closed economies (including my own in [31] and [32]).⁴ The main purpose of this paper is to extend the formal analysis of inflation targeting to a small open economy where the exchange rate and the shocks from the rest of the world are important for conducting monetary policy. Another purpose is to incorporate recent advances in the modelling of forward-looking aggregate supply and demand. Most of the previous work on inflation targeting has used simple representations of aggregate supply and demand which more or less disregard forward-looking aspects.⁵

Including the exchange rate in the discussion of inflation targeting has several important consequences. *First*, the exchange rate allows additional channels for the transmission of monetary policy. In a closed economy, standard transmission channels include an aggregate demand channel and an expectations channel. With the aggregate demand channel, monetary policy affects aggregate demand, with a lag, via its effect on the short real interest rate (and possibly on the availability of credit). Aggregate demand then affects inflation, with another lag, via an aggregate supply equation (a Phillips curve). The expectations channel allows monetary policy to affect inflation expectations which, in turn, affect inflation, with a lag, via wage and price setting behavior.

In an open economy, the real exchange rate will affect the relative price between domestic and foreign goods, which, in turn, will affect both domestic and foreign demand for domestic goods, and hence contribute to the aggregate-demand channel for the transmission of monetary policy. There is also a *direct* exchange rate channel for the transmission of monetary policy to inflation, in that the exchange rate affects domestic currency prices of imported final goods, which enter the consumer price index (CPI) and hence CPI inflation. Typically, the lag of this direct exchange rate channel is considered to be shorter than that of the aggregate demand channel. Hence, by inducing exchange rate movements, monetary policy can affect CPI inflation with a shorter lag. Finally, there is an additional exchange rate channel to inflation: The exchange rate will affect the domestic currency prices of imported intermediate inputs. Eventually, it will also affect nominal wages via the effect of the CPI on wage-setting. In both cases, it will affect the cost of domestically produced goods, and hence domestic inflation (inflation in the prices of domestically produced goods).

Second, as an asset price, the exchange rate is inherently a forward-looking and expectations-

⁴ For formal work that deals with open-economy aspects of inflation targeting, see, for instance, Blake and Westaway [7], Nadal-De Simone, Dennis and Redward [23] and Persson and Tabellini [25]. Persson and Tabellini [25] (footnote 14) briefly discuss targeting of CPI inflation vs. domestic inflation.

⁵ A notable exception is Bernanke and Woodford [6]. See also Svensson [32], section 7.

determined variable. This contributes to making forward-looking behavior and the role of expectations essential in monetary policy.

Third, some foreign disturbances will be transmitted through the exchange rate, for instance, changes in foreign inflation, foreign interest rates and foreign investors' foreign-exchange risk premium. Disturbances to foreign demand for domestic goods will directly affect aggregate demand for domestic goods.

Thus, this paper will attempt to construct a small open-economy model, with particular emphasis on the exchange rate channels in monetary policy, in order to model the effect on the equilibrium of domestic and foreign disturbances and the appropriate monetary-policy response to these disturbances under inflation targeting.

Several particular issues will be discussed. *First*, all inflation-targeting countries have chosen to target CPI inflation, or some measure of underlying inflation that excludes some components from the CPI, for instance, costs of credit services. None of them has chosen only to target domestic inflation (either inflation in the domestic component of the CPI, or GDP inflation). One difference between CPI inflation and domestic inflation is that the direct exchange rate channel is more prominent in the former case. I will try to characterize the differences between these two targeting cases.

Second, under strict inflation targeting (when stabilizing inflation around the inflation target is the only objective for monetary policy; the terminology follows Svensson [32]) the direct exchange rate channel offers a potentially effective inflation stabilization at a relatively short horizon. Such ambitious inflation targeting may require considerable activism in monetary policy (activism in the sense of frequent adjustments of the monetary policy instrument), with the possibility of considerable variability in macro variables other than inflation. In contrast, flexible inflation targeting (when there are additional objectives for monetary policy, for instance output stabilization), may allow less activism and possibly less variability in macro variables other than inflation. Consequently, I will attempt to characterize the differences between strict and flexible inflation targeting.

Third, I will try to characterize the appropriate monetary policy response to domestic and foreign shocks, and especially the appropriate response to exchange rate movements, under different forms of inflation targeting. In this context, the Taylor rule offers a focal point for discussing reaction functions, and is, in practice, increasingly used as a reference point in practical monetary policy discussions. Consequently, I will compare the reaction functions arising under

inflation targeting in an open economy to the Taylor rule, particularly in order to judge what guidance the Taylor rule provides in a small open economy.

The results of my study indicate that strict CPI-inflation targeting indeed implies a vigorous use of the direct exchange rate channel for stabilizing CPI inflation at a short horizon. This results in considerable variability of the real exchange rate and other variables. In contrast, flexible CPI-inflation targeting ends up stabilizing CPI-inflation at a longer horizon, and thereby also stabilizes real exchange rates and other variables to a significant extent. In comparison with the Taylor rule, the reaction functions under inflation targeting in an open economy responds to more information than does the Taylor rule. In particular, the reaction function for CPI-inflation targeting deviates substantially from the Taylor rule, with significant direct responses to foreign disturbances. With regard to the monetary-policy response to different shocks, counter to conventional wisdom, the optimal responses to positive demand shocks and negative supply shocks are very similar.

Section 2 presents the model, section 3 compares the different cases of targeting, and section 4 presents the conclusions. The working paper version of this paper, Svensson [35] contains further technical details.

2 The model

Comparing and discussing targeting of CPI inflation and domestic inflation, as well as strict and flexible inflation targeting, requires a flexible model allowing a variety of loss functions for the central bank. I consider the case of a small rather than a large open economy, which is also the actual situation for most economies with inflation targeting.⁶

Lags and imperfect control of inflation are crucial aspects of monetary policy, which should be explicitly taken into account in formal models of inflation targeting, as emphasized in Svensson [31]. As discussed in the Introduction above, the exchange rate introduces additional channels for monetary policy, with different lags. Finally, forward-looking expectations are crucial for exchange rate determination and may be important for aggregate supply and aggregate demand.⁷ Thus, these seem to be the minimum building blocks that must be incorporated in order to discuss inflation targeting in an open economy.

⁶ Strictly speaking, the economy is small in the world asset market and in the market for foreign goods, but not in the world market for its output.

⁷ Ball [4] follows a different strategy, when incorporating exchange rates in an open-economy model of inflation targeting. He retains the backward-looking model presented in Svensson [31] and used in Ball [3], and adds an equation for the exchange rate. In order to retain the backward-looking nature of the model, the exchange rate equation lacks an expectation term and will then generally violate exchange rate parity and non-arbitrage.

2.1 A simple model of a small open economy

The model has an aggregate supply equation (Phillips curve) of the form

$$\pi_{t+2} = \alpha_\pi \pi_{t+1} + (1 - \alpha_\pi) \pi_{t+3|t} + \alpha_y [y_{t+2|t} + \beta_y (y_{t+1} - y_{t+1|t})] + \alpha_q q_{t+2|t} + \varepsilon_{t+2}. \quad (2.1)$$

Here, for any variable x , $x_{t+\tau|t}$ denotes $E_t x_{t+\tau}$, that is, the rational expectation of $x_{t+\tau}$ in period $t+\tau$, conditional on the information available in period t . Furthermore, π_t denotes domestic (log gross) inflation in period t . Domestic inflation is measured as the deviation of log gross domestic inflation from a constant mean, which equals the constant inflation target. Since the central bank's loss function to be specified assumes that any output target is equal to the natural output level, there will be no average inflation bias (deviation of average inflation from the inflation target). Hence, average inflation will coincide with the constant inflation target. The variable y_t is the output gap, defined as

$$y_t \equiv y_t^d - y_t^n, \quad (2.2)$$

where y_t^d is (log) aggregate demand and y_t^n is the (log) natural output level. The latter is assumed to be exogenous and stochastic and follows

$$y_{t+1}^n = \gamma_y^n y_t^n + \eta_{t+1}^n, \quad (2.3)$$

where the coefficient γ_y^n fulfills $0 \leq \gamma_y^n < 1$ and η_{t+1}^n is a serially uncorrelated zero-mean shock to the natural output level (a “productivity” shock). The variable q_t is the (log) real exchange rate, defined as

$$q_t \equiv s_t + p_t^* - p_t, \quad (2.4)$$

where p_t is the (log) price level of domestic(ally produced) goods, p_t^* the (log) foreign price level (measured as deviations from appropriate constant trends), and s_t denotes the (log) exchange rate (measured as the deviation from a constant trend, the difference between the domestic inflation target and the mean of foreign inflation; the real exchange rate will be stationary in equilibrium).⁸ The term ε_{t+2} is a zero-mean i.i.d. inflation shock (a “cost-push” shock). Thus, we have two distinct “supply” shocks, namely a productivity shock and a cost-push shock. The coefficients α_π , α_y , β_y and α_q are constant and positive; furthermore α_π and β_y are smaller than unity.

This supply function is derived in Svensson [35], from the first-order condition of an optimization problem and hence, with some microfoundations. Aside from the open-economy aspects,

⁸ Since there are no nontraded goods, the real exchange rate also constitutes the terms of trade.

this function is similar to the aggregate supply function given in Svensson [32], section 7, although the more rigorous derivation here (along the lines of Woodford [42] and Rotemberg and Woodford [28]) has resulted in a somewhat different dating of the variables on the right side in (2.1). Inflation depends on lagged inflation and previous expectations of the output gap and future inflation. It is similar to a Calvo-type [9] Phillips curve in that inflation depends upon expectations of future inflation. It is similar to the Fuhrer and Moore [16] Phillips curve in that inflation depends on both lagged inflation and expected future inflation. However, it is assumed that domestic inflation is predetermined two periods in advance, in order to have a two-period lag in the effect of monetary policy on domestic inflation (and hence a longer lag than for the output gap, see below). The term including $q_{t+2|t}$ in (2.1) represents the effect of expected costs of imported intermediate inputs (or resulting wage compensation).

Let ω be the share of imported goods in the CPI.⁹ Then CPI inflation, π_t^c , fulfills¹⁰

$$\pi_t^c = (1 - \omega)\pi_t + \omega\pi_t^f = \pi_t + \omega(q_t - q_{t-1}). \quad (2.5)$$

Here π_t^f denotes domestic-currency inflation of imported foreign goods, which fulfills

$$\pi_t^f = p_t^f - p_{t-1}^f = \pi_t^* + s_t - s_{t-1} = \pi_t + q_t - q_{t-1},$$

where

$$p_t^f = p_t^* + s_t \quad (2.6)$$

is the (log) domestic-currency price of imported foreign goods, and $\pi_t^* = p_t^* - p_{t-1}^*$ is foreign inflation. That is, I assume that there is no lag in the pass-through of import costs to domestic prices of imported goods.

Aggregate demand for domestically produced goods is given by the aggregate demand equation (expressed in terms of the output gap, (2.2)),

$$y_{t+1} = \beta_y y_t - \beta_\rho \rho_{t+1|t} + \beta_y^* y_{t+1|t}^* + \beta_q q_{t+1|t} - (\gamma_y^n - \beta_y) y_t^n + \eta_{t+1}^d - \eta_{t+1}^n, \quad (2.7)$$

where y_t^* is (log) foreign output, all coefficients are constant and nonnegative, with $0 \leq \beta_y < 1$, and η_{t+1}^d is a zero-mean i.i.d. demand shock. The variable ρ_t is defined as

$$\rho_t \equiv \sum_{\tau=0}^{\infty} r_{t+\tau|t}, \quad (2.8)$$

⁹ The share of imported goods in the CPI is approximately constant for small deviations around a steady state. It is exactly constant if the utility function over domestic and imported goods has a constant elasticity of substitution equal to unity (that is, is a Cobb-Douglas utility function), as is actually assumed below.

¹⁰ Since there is no interest-rate component in the CPI, it is best interpreted as CPIX; that is, CPI inflation (and domestic inflation) are exclusive of any credit service costs.

where r_t , the (short domestic-good) real interest rate (measured as the deviation from a constant mean, the natural real interest rate), fulfills

$$r_t \equiv i_t - \pi_{t+1|t}, \quad (2.9)$$

where i_t is the (short) nominal interest rate (measured as the deviation from the sum of the inflation target and the natural real interest rate). The nominal interest rate is the instrument of the central bank.¹¹

Thus, the variable ρ_t is the sum of current and expected future (deviations of) real interest rates. The sum enters in the aggregate demand since the latter is the forward solution of an Euler condition involving the short real interest rate, cf. Svensson [35]. The sum always converges in the equilibria examined below (recall that everything is measured as deviations from constant means). The variable ρ_t is (under the expectations hypothesis) related to (the deviations from the mean of) a long real zero-coupon bond rate: Consider the real rate r_t^T with maturity T . Under the expectations hypothesis, it fulfills

$$r_t^T = \frac{1}{T} \sum_{\tau=0}^T r_{t+\tau|t}.$$

Hence, for a long (but finite) maturity T , the variable ρ_t is approximately the product of the long real rate and its maturity,

$$\rho_t \approx T r_t^T. \quad (2.10)$$

The aggregate demand is predetermined one period in advance. It depends on lagged expectations of accumulated future real interest rates, foreign output and the real exchange rate. The aggregate demand equation is derived, from a first-order condition consistent with optimization and hence with some microfoundations, and discussed in further detail in Svensson [35].¹² ¹³

The exchange rate fulfills the interest parity condition

$$i_t - i_t^* = s_{t+1|t} - s_t + \varphi_t,$$

where i_t^* is the foreign nominal interest rate and φ_t is the foreign-exchange risk premium. The foreign-exchange risk premium incorporates any exogenous residual disturbances to the exchange

¹¹ The variable ρ_t fulfills $\rho_t = \sum_{\tau=0}^{\infty} r_{t+\tau|t}^c - \omega q_t$, where $r_t^c \equiv i_t - \pi_{t+1|t}^c = r_t - \omega(q_{t+1|t} - q_t)$ is the CPI real interest rate. Hence, we can express ρ_t in terms of r_t^c rather than r_t (the derivation in Svensson [35] actually starts from an Euler condition in terms of r_t^c). Since $\pi_{t+1|t}$ is a predetermined state variable, whereas $\pi_{t+1|t}^c$ is forward-looking, I find it is more practical to use r_t rather than r_t^c .

¹² There is an obvious similarity to the closed-economy aggregate demand function of Fuhrer and Moore [16], except that a *lagged* long real coupon-bond rate enters in their function.

¹³ The natural output level enters in (2.7) because the equation is first derived for the level of aggregate demand. It is then expressed in terms of the output gap by subtraction of the natural output level.

rate, including changes in portfolio preferences, credibility effects, etc. In order to eliminate the non-stationary exchange rate, I use (2.4) to rewrite this as the real interest parity condition¹⁴

$$q_{t+1|t} = q_t + i_t - \pi_{t+1|t} - i_t^* + \pi_{t+1|t}^* - \varphi_t. \quad (2.11)$$

I assume that foreign inflation, foreign output and the foreign-exchange risk premium follow stationary univariate AR(1) processes,

$$\pi_{t+1}^* = \gamma_\pi^* \pi_t^* + \varepsilon_{t+1}^* \quad (2.12)$$

$$y_{t+1}^* = \gamma_y^* y_t^* + \eta_{t+1}^* \quad (2.13)$$

$$\varphi_{t+1} = \gamma_\varphi \varphi_t + \xi_{\varphi,t+1}, \quad (2.14)$$

where the coefficients are nonnegative and less than unity, and the shocks are zero-mean i.i.d. Furthermore, I assume that the foreign interest rate follows a Taylor-type rule, that is, that it is a linear function of foreign inflation and output,

$$i_t^* = f_\pi^* \pi_t^* + f_y^* y_t^* + \xi_{it}^*, \quad (2.15)$$

where the coefficients are constant and positive, and ξ_{it}^* is a zero-mean i.i.d. shock. These specifications of the exogenous variables are chosen for simplicity; obviously the exogenous variables may be cross-correlated in more general ways without causing any difficulties, and additional variables can be introduced to represent the state of the rest of the world.

Note that ρ_t and q_t are closely related. By (2.8)–(2.11) we have (assuming $\lim_{\tau \rightarrow \infty} q_{t+\tau|t} = 0$)

$$\begin{aligned} q_t &= - \sum_{\tau=0}^{\infty} r_{t+\tau|t} + \sum_{\tau=0}^{\infty} (i_{t+\tau|t}^* - \pi_{t+1+\tau|t}^* + \varphi_{t+\tau|t}) \\ &= - \rho_t + \sum_{\tau=0}^{\infty} (i_{t+\tau|t}^* - \pi_{t+1+\tau|t}^* + \varphi_{t+\tau|t}). \end{aligned} \quad (2.16)$$

By (2.12)–(2.15), we have (exploiting the sum of a geometric series)

$$\begin{aligned} \sum_{\tau=0}^{\infty} (i_{t+\tau|t}^* - \pi_{t+1+\tau|t}^*) &= i_t^* + \sum_{\tau=1}^{\infty} i_{t+\tau|t}^* - \sum_{\tau=1}^{\infty} \pi_{t+\tau|t}^* \\ &= i_t^* + f_\pi^* \frac{\gamma_\pi^*}{1 - \gamma_\pi^*} \pi_t^* + f_y^* \frac{\gamma_y^*}{1 - \gamma_y^*} y_t^* - \frac{\gamma_\pi^*}{1 - \gamma_\pi^*} \pi_t^* \\ &= i_t^* + \frac{(f_\pi^* - 1) \gamma_\pi^*}{1 - \gamma_\pi^*} \pi_t^* + \frac{f_y^* \gamma_y^*}{1 - \gamma_y^*} y_t^*; \end{aligned} \quad (2.17)$$

¹⁴ Equation (2.11) may give the impression that the real exchange rate will have a unit root. This is not the case in equilibrium, however. All real variables, inflation rates and interest rates are then stationary. The nominal price level and exchange rate are nonstationary.

hence,

$$\rho_t = -q_t + i_t^* + \frac{(f^* - 1)\gamma_\pi^*}{1 - \gamma_\pi^*} \pi_t^* + \frac{f_y^* \gamma_y^*}{1 - \gamma_y^*} y_t^* + \frac{1}{1 - \gamma_\varphi} \varphi_t. \quad (2.18)$$

As shown in Svensson [35], the variable ρ_t can be interpreted as the negative of an infinite-horizon market discount factor, that is, the present value of domestic goods infinitely far into the future.

In summary, the model consists of the aggregate supply equation, (2.1), the CPI equation, (2.5), the aggregate demand equation, (2.7), the definitions of the sum of current and expected future real interest rates and the real interest rate, (2.8) and (2.9), real interest-rate parity, (2.11), and the equations for the exogenous variables: foreign inflation and output, the foreign-exchange risk premium and the foreign interest rate, (2.12)–(2.15).

The timing and the lags have been selected to provide realistic relative lags for the transmission of monetary policy. Consider a change in the instrument i_t in period t . Current domestic inflation and the output gap are predetermined. Domestic inflation in period $t + 1$ is also predetermined; hence so are domestic inflation expectations, $\pi_{t+1|t}$. Thus, the short real interest rate, r_t , is immediately affected, as are the forward-looking variables, the real exchange rate, q_t , the sum of expected current and future real interest rates, ρ_t , and the expected domestic inflation in period $t + 3$, $\pi_{t+3|t}$. Current CPI inflation is by (2.5) affected by the current real exchange rate (this is the direct exchange rate channel). The aggregate demand in period $t + 1$, y_{t+1} , is by (2.7) affected via the instrument's effect on the expected real exchange rate, $q_{t+1|t}$, (part of the exchange rate channel) and the sum of expected future real interest rates, $\rho_{t+1|t}$, (the aggregate demand channel). Domestic inflation in period $t + 2$, π_{t+2} , is by (2.1) affected by the instrument via the expected real exchange rate $q_{t+2|t}$ (the remaining part of the exchange rate channel), via the output gap in period $t + 1$ (the aggregate demand channel), and by domestic-inflation expectations, $\pi_{t+3|t}$ (the inflation-expectations channel).

Thus, there is no lag in the monetary policy effect on CPI inflation, a one-period lag in the effect on aggregate demand, and a two-period lag in the effect on domestic inflation. Both VAR evidence and practical central-bank experience indicate that there is a shorter lag for CPI inflation and aggregate demand than for domestic inflation.¹⁵

¹⁵ See for instance Cushman and Zha [13].

2.2 The loss function

I assume that the central bank's loss function is the unconditional expectation, $E[L_t]$, of a period loss function given by

$$L_t = \mu_\pi^c \pi_t^{c2} + \mu_\pi \pi_t^2 + \lambda y_t^2 + \nu_i (i_t - i_{t-1})^2, \quad (2.19)$$

where all weights are nonnegative. Thus, the loss function is

$$E[L_t] = \mu_\pi^c \text{Var}[\pi_t^c] + \mu_\pi \text{Var}[\pi_t] + \lambda \text{Var}[y_t] + \nu_i \text{Var}[i_t - i_{t-1}], \quad (2.20)$$

that is, the weighted sum of the corresponding unconditional variances. The first two terms correspond to CPI-inflation targeting and domestic-inflation targeting, respectively. The third term corresponds to output-gap stabilization, and the fourth to instrument or nominal interest-rate smoothing.¹⁶

This loss function is assigned to the central bank by the announcement of the inflation-targeting regime. As discussed in section 1 and in more detail in Faust and Svensson [14] and Svensson [34], it is enforced by the high degree of transparency and accountability under inflation-targeting. Thus, different variants of inflation targeting correspond to different variants of the loss function. “Strict CPI-inflation targeting” corresponds to μ_π^c positive and all other weights are equal to zero. “Flexible CPI-inflation targeting” allows other positive weights, for instance λ , μ_i or ν_i . “Domestic” inflation targeting rather than “CPI” inflation targeting has μ_π positive weight rather than μ_π^c . Thus, the decision problem for the bank is to choose the instrument, i_t , conditional upon the information available in period t , so as to minimize (2.20).¹⁷

2.3 State-space form

It is shown in Svensson [35] that the model can be written in a convenient state-space form. Let X_t and Y_t denote the (column) vectors of predetermined state variables and goal variables, respectively, let x_t denote the (column) vector of forward-looking variables, and let v_t denote

¹⁶ The flexibility of the model allows us to include any variable of interest in the period loss function. One could, for instance, include the terms $\mu_i i_t^2$, $\mu_r r_t^2$, $\nu_r (r_t - r_{t-1})^2$, $\mu_s s_t^2$, $\nu_s (s_t - s_{t-1})^2$, $\mu_q q_t^2$ and $\nu_q (q_t - q_{t-1})^2$, corresponding to stabilization of the nominal interest rate, and stabilization and smoothing of real interest rates and nominal and real exchange rates.

¹⁷ The loss function (2.20) can be seen as the (scaled) limit of the intertemporal loss function

$$(1 - \delta) E_t \sum_{\tau=0}^{\infty} \delta^\tau L_{t+\tau}, \quad (2.21)$$

when the discount factor δ , fulfilling $0 < \delta < 1$, approaches unity (see Svensson [35] for details).

the (column) vector of innovations to the predetermined state variables,

$$\begin{aligned}
X_t &= (\pi_t, y_t, \pi_t^*, y_t^*, i_t^*, \varphi_t, y_t^n, q_{t-1}, i_{t-1}, \pi_{t+1|t})' \\
Y_t &= (\pi_t^c, \pi_t, y_t, i_t - i_{t-1})' \\
x_t &= (q_t, \rho_t, \pi_{t+2|t})' \\
v_t &= (\varepsilon_t, \eta_t^d - \eta_t^n, \varepsilon_t^*, \eta_t^*, f_\pi^* \varepsilon_t^* + f_y^* \eta_t^* + \xi_{it}^*, \xi_{\varphi t}, \eta_t^n, 0, 0, \alpha_\pi \varepsilon_t + \alpha_y \beta_y (\eta_t^d - \eta_t^n))',
\end{aligned}$$

where $'$ denotes the transpose. Let $Z_t = (X_t', x_t')$ be the vector of the predetermined state variables and the forward-looking variables. Denote the dimensions of X_t , x_t , Y_t and Z_t by n_1 , n_2 , n_3 and $n = n_1 + n_2$, respectively ($n_1 = 10$, $n_2 = 3$, $n_3 = 4$). Then the model can be written

$$\begin{bmatrix} X_{t+1} \\ x_{t+1|t} \end{bmatrix} = AZ_t + Bi_t + B^1 i_{t+1|t} + \begin{bmatrix} v_{t+1} \\ 0 \end{bmatrix} \quad (2.22)$$

$$Y_t = C_Z Z_t + C_i i_t \quad (2.23)$$

$$L_t = Y_t' K Y_t, \quad (2.24)$$

where A is an $n \times n$ matrix; B and B^1 are $n \times 1$ column vectors; C_Z is an $n_3 \times n$ matrix; C_i is an $n_3 \times 1$ column vector; and K is an $n_3 \times n_3$ diagonal matrix with the diagonal $(\mu_\pi^c, \mu_\pi, \lambda, \nu_i)$ and with all off-diagonal elements equal to zero (see Svensson [35] for details).

2.4 The solution

Except for the term $B^1 i_{t+1|t}$, the model is a standard linear stochastic regulator problem with rational expectations and forward-looking variables (the standard problem is solved in Oudiz and Sachs [24], Backus and Driffill [2], and Currie and Levine [12], and applied in Svensson [30]). Svensson [35] shows how the new term $B^1 i_{t+1|t}$ is handled.

With forward-looking variables, there is a difference between the case of discretion and the case of commitment to an optimal rule, as discussed in the above references. In the discretion case, the forward-looking variables will be linear functions of the predetermined variables,

$$x_t = H X_t,$$

where the $n_2 \times n_1$ matrix H is endogenously determined. The optimal reaction function will be a linear function of the predetermined variables,

$$i_t = f X_t, \quad (2.25)$$

where the $1 \times n_1$ row vector f is endogenously determined.

In the commitment case, the optimal policy and the forward-looking variables also depend on the shadow prices of the forward-looking variables. Only the discretion solution is considered here. See Svensson [35] for details of the solution.

The dynamics of the economy are then described by

$$X_{t+1} = M_{11}X_t + v_{t+1} \quad (2.26)$$

$$x_t = HX_t \quad (2.27)$$

$$i_t = fX_t \quad (2.28)$$

$$Y_t = (C_{Z1} + C_{Z2}H + C_i f)X_t, \quad (2.29)$$

where the $n \times n$ matrix M is given by

$$M \equiv (I - B^1 F)^{-1}(A + BF),$$

where $F = (f, 0 \dots 0)$ is the $1 \times n$ row vector where n_2 zeros are inserted at the end of f , and where the matrices

$$M = \begin{bmatrix} M_{11} & M_{21} \\ M_{12} & M_{22} \end{bmatrix}, \quad C_Z = \begin{bmatrix} C_{Z1} \\ C_{Z2} \end{bmatrix}$$

are partitioned according to X_t and x_t .

3 Results on optimal policies

3.1 Model parameters

In this version of the paper, no attempt is made to calibrate or estimate the model. The parameters are simply selected to be, a priori, not unreasonable. The numerical results are therefore only indicative.

The following parameters are selected: In the aggregate supply equation, (2.1): $\alpha_\pi = 0.6$, $\alpha_y = (1 - \alpha_\pi)\tilde{\alpha}_y$ where $\tilde{\alpha}_y = 0.2$, $\alpha_q = (1 - \alpha_\pi)\tilde{\alpha}_q$ where $\tilde{\alpha}_q = 0.025$, and $\sigma_\varepsilon^2 = 1$ (the last parameter is the variance of the cost-push shock). In the CPI equation, (2.5): $\omega = 0.3$. In the aggregate demand equation, (2.7): $\beta_y = 0.8$, $\beta_y^* = (1 - \beta_y)\tilde{\beta}_y^*$ where $\tilde{\beta}_y^* = 0.27$, $\beta_\rho = (1 - \beta_y)\tilde{\beta}_\rho$ where $\tilde{\beta}_\rho = 0.35$, $\beta_q = (1 - \beta_y)\tilde{\beta}_q$ where $\tilde{\beta}_q = 0.195$, $\gamma_y^n = 0.96$, $\sigma_d^2 = 1$ and $\sigma_n^2 = 0.5$ (σ_d^2 and σ_n^2 are the variance of the demand and supply shocks, η_t^d and η_t^n , respectively). In the equations for the exogenous variables, (2.3) and (2.12)–(2.15): $\gamma_\pi^* = \gamma_y^* = \gamma_\varphi = 0.8$, $f_\pi^* = 1.5$, $f_y^* = 0.5$

and $\sigma_{\varepsilon^*}^2 = \sigma_{\eta^*}^2 = \sigma_{\xi\varphi}^2 = \sigma_{\xi i^*}^2 = 0.5$ (the coefficients in the equation for the foreign interest rate conform to the Taylor rule).¹⁸

3.2 Targeting cases and Taylor rules

The different cases of monetary-policy targeting are defined by the weights in the loss function. The four targeting cases (combinations of positive weights) to be examined are displayed in table 1. The case of strict CPI-inflation targeting does not converge unless a small weight on interest smoothing is added; for uniformity, the weight ν_i is set equal to 0.01 for all targeting cases.¹⁹ In addition, two versions of the Taylor rule are included, corresponding to whether the instrument responds to domestic inflation or to CPI inflation.

Table 1. Targeting cases and Taylor rules

1. Strict domestic-inflation targeting	$\mu_\pi = 1, \nu_i = 0.01$
2. Flexible domestic-inflation targeting	$\mu_\pi = 1, \nu_i = 0.01, \lambda = 0.5$
3. Strict CPI-inflation targeting	$\mu_\pi^c = 1, \nu_i = 0.01$
4. Flexible CPI-inflation targeting	$\mu_\pi^c = 1, \nu_i = 0.01, \lambda = 0.5$
5. Taylor rule, domestic inflation	$i_t = 1.5\pi_t + 0.5y_t$
6. Taylor rule, CPI inflation	$i_t = 1.5\pi_t^c + 0.5y_t$

3.3 Summary results on reaction functions

The coefficients in the reaction functions, the elements of the row vectors f corresponding to the four optimal reaction functions and the two Taylor rules, are summarized for the six cases in table 2. Note that by the certainty-equivalence of a linear-quadratic model, the reaction functions are independent of the variances of the shocks.

First, the Taylor rule (table 2, rows 5 and 6) makes the instrument depend on current inflation (domestic or CPI) and the output gap only, with coefficients 1.5 and 0.5, respectively. In this model, the Taylor rule for CPI inflation (row 6) has the property that the reaction function depends on a forward-looking variable, q_t (since CPI inflation by (2.5) fulfills $\pi_t^c = \pi_t + \omega(q_t - q_{t-1})$).

¹⁸ Behind these parameters are the underlying parameters (see Svensson [35]) $\alpha = 0.5, \vartheta = 1.25, \tilde{\omega} = 0.8, \xi = \frac{(1-\alpha)(1-\alpha\delta)}{\alpha(1+\tilde{\omega}\vartheta)} = 0.25, \gamma = 0.1, \tilde{\alpha}_q = \xi\gamma = 0.025, \tilde{\alpha}_y = \xi\tilde{\omega} = 0.2, \kappa = 1 - \omega = 0.7, \sigma = 0.5, \theta = 1, \theta^* = 2, \omega^* = 0.15, \tilde{\beta}_\rho = \kappa\sigma = 0.35, \tilde{\beta}_y^* = 0.9, \tilde{\beta}_y^* = (1 - \kappa)\tilde{\beta}_y^* = 0.27, \tilde{\beta}_q = (1 - \kappa)\theta^*\omega^* - \kappa(\sigma - \theta)\omega = 0.195$.

¹⁹ To my knowledge, the convergence properties of the algorithm for the discretionary equilibrium of the optimal linear regulator with forward-looking variables have not been systematically examined in the literature.

Table 2. Reaction-function coefficients

Case	π_t	y_t	$\pi_{t+1 t}$	π_t^*	y_t^*	i_t^*	φ_t	y_t^n	q_{t-1}	i_{t-1}	q_t
1. Strict domestic	0.00	0.27	2.43	0.14	0.11	0.00	0.20	0.02	0.00	0.62	-
2. Flexible domestic	0.00	1.39	1.42	0.17	0.14	0.00	0.24	0.07	0.00	0.53	-
3. Strict CPI	0.02	-0.01	-2.28	-0.79	0.01	1.00	1.01	0.01	-0.01	0.00	-
4. Flexible CPI	0.72	-0.26	-0.69	-0.47	0.15	0.97	1.41	0.28	-0.22	0.01	-
5. Taylor, domestic	1.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
6. Taylor, CPI	1.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	-0.45	0.00	0.45

Second, the reaction functions for domestic-inflation targeting look somewhat similar to the Taylor rule for domestic inflation, except that (1) they depend on expected domestic inflation $\pi_{t+1|t}$ (which is predetermined) rather than current domestic inflation, (2) the coefficients differ from those of the Taylor rule, and (3) they also depend on other state variables. The reason for (1) is that by (2.1) expected domestic inflation two periods ahead (the shortest horizon at which domestic inflation is affected by the instrument) does not depend on current domestic inflation but on (the predetermined) expected domestic inflation one period ahead. The reaction functions for domestic-inflation targeting are intuitive in that strict inflation targeting (with no weight on output-gap stabilization) has a smaller coefficient on the output gap and a larger coefficient on expected domestic inflation than flexible inflation targeting. The coefficients on expected inflation and (for flexible domestic-inflation targeting) on the output gap are larger than those of the Taylor rule; however, optimal Taylor-type rules (that is, linear reaction functions with optimized coefficients on current inflation and the output gap and all other coefficients equal to zero) are often found to have somewhat larger coefficients than 1.5 and 0.5 (cf. Rudebusch and Svensson [29] and other papers in Taylor [38]). Hence, (2) is not so surprising. With regard to (3), it is natural that optimal reaction functions depend on several of the state variables; it is somewhat surprising that the coefficients are so small, except the coefficient for i_{t-1} . On the other hand, it is somewhat surprising that that coefficient is so large, since the weight ν_i is only 0.01.

Third, the reaction functions for CPI-inflation targeting look very different from the Taylor rule. The negative coefficients on expected domestic inflation and on the output gap stand out. We can, of course, not draw specific conclusions from the actual numerical values of the output-gap coefficients, since the model's parameters have not been calibrated or estimated. Nevertheless, a sizeable negative coefficient on the output gap and expected domestic inflation

is certainly a stark contrast to the Taylor rule. Also, the coefficients on the foreign interest rate and the foreign exchange risk premium are relatively large, that is, about one, rather than zero.

The reason for the coefficients for strict CPI-inflation targeting is that by (2.5) the exchange rate channel gives the central bank a possibility to stabilize CPI inflation completely. Suppose expected CPI inflation is equal to zero, which gives

$$\pi_{t+1|t}^c = \pi_{t+1|t} + \omega(q_{t+1|t} - q_t) = 0, \quad (3.1)$$

that is,

$$q_{t+1|t} - q_t = -\frac{1}{\omega}\pi_{t+1|t}. \quad (3.2)$$

Furthermore, by (2.11) the instrument fulfills

$$\begin{aligned} i_t &= \pi_{t+1|t} + q_{t+1|t} - q_t + i_t^* - \pi_{t+1|t}^* + \varphi_t \\ &= -\frac{1-\omega}{\omega}\pi_{t+1|t} + i_t^* - \gamma_\pi^* \pi_t^* + \varphi_t, \end{aligned} \quad (3.3)$$

where I have used (3.2) and (2.12). This is indeed the reaction function displayed in table 2 for strict CPI-inflation targeting (row 3), except that it is slightly modified since $\nu_i = 0.01$ and the central bank smooths the instrument to a small extent.

Flexible CPI-inflation targeting increases the coefficient on current domestic inflation from zero to positive, and reduces the coefficient on the output gap from zero to negative. At first, this seems counterintuitive, and we must look at the corresponding impulse responses below to understand this.

Fourth, we note that current CPI inflation, π_t^c , does not enter in the reaction function, due to the fact that it is not an independent state variable, but a linear combination of the state variables. Indeed, since π_t^c and i_t are both linear combinations of the state variables,

$$\begin{aligned} \pi_t^c &= (1-\omega)\pi_t + \omega(\pi_t + q_t - q_{t-1}) \equiv aX_t \\ i_t &= fX_t, \end{aligned}$$

the reaction function can, of course, be expressed as a (non-unique) function of π_t^c and the state variables, for instance

$$i_t = \kappa\pi_t^c + (f - \kappa a)X_t,$$

for any arbitrary coefficient κ .

Fifth, we note that the current real exchange rate, q_t , does not enter for the optimal reaction function. The reaction function is a function of predetermined variables only, not of any forward-looking variables. The lagged real exchange rate, q_{t-1} , is a state variable, though, and does enter in some of the reaction functions. Note that since q_t is a linear function of the state variables,

$$q_t = H_1.X_t \tag{3.4}$$

where H_1 denotes the first row of matrix H , we can, of course (as above for CPI inflation), write the reaction function as a (non-unique) function of q_t .

Sixth, the reaction function is generally not of the form frequently used in the literature,²⁰

$$\Delta i_t \equiv i_t - i_{t-1} = bX_t,$$

for some row vector b (where b_9 , the coefficient for i_{t-1} , is zero). Accordingly, the reaction functions are generally not such that the change in the instrument depends on the state variables (other than i_{t-1}), that is, the coefficient on i_{t-1} is not equal to minus one. In the cases in table 2, the lagged interest rate enters only because there is a small weight on interest smoothing, $\nu_i = 0.01$.

3.4 Discussion of targeting cases

Selected unconditional standard deviations are reported for the six cases in table 3.²¹

Table 3. Unconditional standard deviations

Targeting case	π_t^c	π_t	y_t	q_t	i_t	r_t
1. Strict domestic-inflation	2.00	1.25	1.91	9.82	3.23	2.62
2. Flexible domestic-inflation	2.66	1.51	1.51	10.12	3.46	2.96
3. Strict CPI-inflation	0.04	2.00	3.62	13.79	4.41	6.05
4. Flexible CPI-inflation	1.09	1.32	1.96	6.73	2.50	2.41
5. Taylor rule, domestic	2.13	1.59	1.74	8.13	2.45	1.35
6. Taylor rule, CPI	1.84	1.66	1.77	8.26	2.54	1.82

Figures 3.1–3.3 report impulse responses for the three cases of strict domestic-inflation and strict and flexible CPI-inflation targeting (units are percent or percent per year). Impulse responses from the other cases are reported in Svensson [35]. In each figure, column 1 reports

²⁰ See, for instance, Williams [41].

²¹ The nominal exchange rate is nonstationary, so its unconditional standard deviation is unbounded.

the impulse responses to a cost-push shock to domestic inflation, π_t , in period 0 ($\varepsilon_0 = 1$), cf. (2.1). This shock also affects the domestic inflation expected for period 1, $\pi_{1|0}$, by $\alpha_\pi \varepsilon_0$.

Column 2 reports impulse responses to a demand shock to the output gap, y_t , in period 0 ($\eta_0^d = 1$), cf. (2.7). This shock also affects the inflation expected for period 1, $\pi_{1|0}$, by $\alpha_y \beta_y \eta_0^d$. Column 3 reports the impulse responses to a *negative* productivity shock ($\eta_0^n = -1$). This shock implies a *positive* shock to the output gap ($-\eta_0^n = 1$), cf. (2.7), and to the inflation expected for period 1, $\pi_{1|0}$ ($-\alpha_y \beta_y \eta_0^d = \alpha_y \beta_y > 0$), cf. (2.1). Column 4 reports impulse responses to a shock to foreign inflation, π_t^* , in period 0 ($\varepsilon_0^* = 1$). This shock also implies a shock $f_\pi^* \varepsilon_0^* = 1.5$ to the foreign interest rate, i_t^* , due to the assumption that the foreign interest rate follows the Taylor rule, cf. (2.15). Column 5 reports impulse responses to a shock to the foreign exchange risk premium, φ_t , in period 0 ($\xi_{\varphi 0} = 1$). In column 6, shocks to the interest rate set $i_t = 1$ for the first 4 periods, $t = 0, \dots, 3$ (the shocks at $t = 1, 2, 3$ are assumed to be anticipated in period 0).

3.4.1 Strict domestic-inflation targeting

For a cost-push shock to domestic inflation in period 0 ($\varepsilon_0 = 1$), domestic inflation increases to 1 in period 0 and to $\alpha_\pi = 0.6$ in period 2 (figure 3.1, column 1, row 2). There is a strong monetary policy response: a large increase in the nominal interest rate (row 4). As a result, the real interest rate rises (row 5), and there is a large appreciation of the real exchange rate (row 6; note that the vertical scale is smaller than for the other rows). As a result, the output gap contracts, and domestic inflation falls and reaches its target level after about 6 periods.

The shock to domestic inflation leads (for constant real exchange rate) to an equal shock to CPI inflation, cf. (2.5). However, the large real appreciation causes import prices to fall such that the net effect is an initial fall in CPI inflation. The real depreciation that follows, and the shock to domestic inflation in period 1, cause a sizeable increase in CPI inflation in period 1.

For a demand shock ($\eta_0^d = 1$) (column 2), we see a somewhat smaller increase in the nominal and real interest rate, and a smaller real appreciation. As a result, the output gap falls back to zero in about three periods, and then undershoots a little. Domestic inflation is insulated to a large extent.

In column 3, we see that a negative productivity shock has effects remarkably similar to those of a positive demand shock. It increases the output gap (row 3) and increases domestic inflation in period 1 (row 2), and leads to a similar monetary policy response (row 4). This

is of course due to the symmetric way in which demand and productivity shocks enter in the aggregate supply and demand functions (when the latter are expressed in terms of the output gap), (2.1) and (2.7). The impulse responses are not identical, though, since the shock to the natural output level has a persistent effect on the output gap, cf. the fifth term on the right side of (2.7), since $\gamma_y^n - \beta_y = 0.16$ with the parameters I have chosen. In particular, the response of the real exchange rate is much more persistent than its response to a demand shock (row 6, columns 2 and 3), since the persistent fall in aggregate demand due to the persistent productivity shock (when the output gap has closed) requires a persistent (but not permanent) appreciation of the real exchange rate. If β_y and γ_y^n were equal, the impulse responses would be equal for demand and supply shocks.

For shocks to foreign inflation and the foreign exchange risk premium (columns 4 and 5), monetary policy almost perfectly insulates domestic inflation (row 2).

In table 3, row 1, we see that the resulting variability of domestic inflation is relatively low, whereas the variability of CPI inflation and the output gap is relatively high. The variability of the real exchange rate is particularly high.

3.4.2 Flexible domestic-inflation targeting

For a shock to domestic inflation, the increase in the nominal and real interest rates, and the real appreciation, under flexible domestic-inflation targeting, are more moderate than for strict domestic-inflation targeting. As a result, the output gap falls much less, and domestic inflation returns to the target more gradually. The output gap is stabilized to a greater extent than for strict domestic-inflation targeting.

For a demand shock, there is a larger monetary policy contraction, and the output gap is stabilized further than for strict domestic-inflation targeting. As a consequence, there is more variability in CPI inflation. For shocks to foreign inflation and the foreign-exchange risk premium, monetary policy more or less cancels the effects on both domestic inflation and the output gap.

Compared to the case of strict domestic-inflation targeting, as we noted in table 2 (row 2), the reaction function has a lower coefficient for expected domestic inflation, and a higher coefficient for the output gap. The variability of both domestic and CPI inflation is higher (table 3, row 2), and the variability of the output gap is lower. The variability of both the real exchange rate and the real interest rate are higher.

3.4.3 Strict CPI-inflation targeting

For a shock to domestic inflation ($\varepsilon_0 = 1$), CPI inflation is almost completely insulated under strict CPI-inflation targeting, even though the same shock (for a given real exchange rate) by (2.5) hits CPI inflation. As noted above, cf. (3.1), the reason is that the central bank uses the direct real exchange-rate channel and makes real exchange-rate depreciation cancel the effect of domestic inflation on CPI inflation. This is apparent in row 6 in figure 3.2. An initial real appreciation is followed by further appreciation, and only when domestic inflation has fallen below zero does the real exchange rate start to depreciate. This requires a rather sophisticated management of the real interest rate. Recall that for a zero foreign real interest rate and foreign exchange risk premium, the real interest rate is the expected real rate of depreciation. Consequently, the real interest rate (row 5) must be proportional to the negative of domestic inflation lead by one period (column 2). Thus, the real interest rate must be negative (relative to its constant mean) while domestic inflation is positive the next period, and vice versa. This requires the reaction function for the nominal interest rate discussed above, (3.3). In particular, the initial response to the inflation shock is to reduce the nominal interest rate.

Similarly, for a demand shock, monetary policy must ensure that the real interest rate is proportional to the negative of expected domestic inflation lead by one period. This requires a negative nominal interest rate (relative to its constant mean) for the first five periods.

It is apparent from figure 3.2 and table 3, row 3, that strict CPI-inflation targeting, although successful in stabilizing CPI inflation, ends up causing large variability in domestic inflation, the output gap, and, particularly, the real exchange rate and the real interest rate.

3.4.4 Flexible CPI-inflation targeting

Strict CPI-inflation targeting causes considerable output-gap variability. Under flexible CPI-inflation targeting, with some weight on output-gap stabilization, that output-gap variability must be reduced. As a result, CPI inflation can no longer be completely insulated from shocks. For a shock to domestic inflation (figure 3.3, column 1), CPI inflation gradually returns to its target in about seven periods. The nominal interest rate is increased, the real interest rate is initially almost unchanged and then increases. The real exchange rate appreciates somewhat and then gradually depreciates towards its steady state value. The output gap contracts somewhat, and domestic inflation falls gradually towards the target.

For a demand shock, output returns to the steady state level in about four periods. Except

in the initial period, there is a more contractionary monetary policy response, with the nominal interest rate becoming positive after period 1. Compared to strict CPI-inflation targeting, there is much less fluctuation, and hardly any cycles, in nominal and real interest rates, the real exchange rate, and output.

It remains to be understood why the output gap coefficient goes from zero to negative, from strict to flexible CPI-inflation targeting (cf. table 2, rows 3 and 4). Look at column 2 in figure 3.3, that is, the response to a demand shock. In order to stabilize CPI inflation, it is necessary to generate an expected real depreciation between periods 0 and 1, in order to counter the positive effect on CPI inflation in period 1 from the domestic inflation in period 1 caused by the demand shock. Therefore, the real and hence the nominal interest rate must be reduced in period 0. The increase in expected domestic inflation is moderate, and much smaller than the impulse to the output gap. A negative coefficient on the output gap is an efficient way of achieving the desired fall in the nominal interest rate, although this appears somewhat counterintuitive.

As in the other targeting cases, the response to a negative productivity shock, column 3, is remarkably similar to that of a demand shock, except that the response to the real exchange rate is much more persistent than for a demand shock, for the same reasons as noted above for strict domestic-inflation targeting.

With regard to variability (table 3, row 4), we see that variability is higher for CPI inflation, but lower for domestic inflation, the output gap, the real exchange rate, the instrument, and the real interest rate. Flexible CPI-inflation targeting allows for a less activist monetary policy, which brings about lower variability in these variables.

3.4.5 Taylor rules

The Taylor rule responding to domestic inflation results in a smooth return of domestic inflation, the output gap and the real exchange rate for both inflation and demand shocks. CPI inflation and the real exchange rate react strongly to shocks to the foreign exchange risk premium and to foreign inflation (as is the case for domestic-inflation targeting); this is not surprising, since the Taylor rule does not directly respond to these variables.

In table 3, row 5, we see that the variability of domestic inflation and the output gap is moderate, whereas it is large for CPI inflation and the real exchange rate.

The Taylor rule responding to CPI inflation results in a smoother response of CPI inflation. We see in table 3, row 6, that the variability of CPI inflation is smaller, the variability of the

real interest rate is larger, and that the variability of the other variables is somewhat larger.²²

3.5 Conclusions from the comparison of targeting cases

From this comparison of the different targeting cases and the two versions of the Taylor rule, it appears that the flexible domestic-inflation targeting successfully stabilizes both domestic inflation and the output gap, although the variability of CPI inflation and the real exchange rate is high. Strict domestic-inflation targeting naturally stabilizes domestic inflation further, but increases the variability of the output gap and the real exchange rate.

Strict CPI-inflation targeting highlights the consequences of vigorous use of the direct exchange rate channel to stabilize CPI inflation. This vigorous use results in very high variability of the real exchange rate, and high variability of the other variables. Concern about the stability of the other variables is obviously a good reason for not trying to fulfill the CPI inflation target at a very short horizon.

In contrast, flexible CPI-inflation targeting ends up causing low to moderate variability in all variables. The low variability of the real exchange rate (relative to the other cases) demonstrates that CPI-inflation targeting may involve a considerable amount of real exchange rate stabilization, as long as the ambition to stabilize CPI inflation is checked by some concern for output-gap stabilization. With some implicit social loss function that values stability in several variables, flexible CPI-inflation targeting in an open economy may be an attractive alternative.²³

The Taylor rule for domestic inflation stabilizes the variables less than the inflation-targeting cases, with the exception of the nominal and real interest rate. This might indicate that the coefficients are relatively low. The Taylor rule is, of course, not efficient, in two senses: (1), as emphasized by Ball [3], the coefficients are not optimal among the class of reaction functions responding only to current inflation and the output gap, and (2), as emphasized by Svensson [31] and [32], it disregards information not captured by current inflation and the output gap. For an open economy, such information is likely to be quite important. In this model, this is indicated by the impulse responses to shocks to foreign inflation and the foreign exchange risk premium. On the other hand, the Taylor rule for either domestic inflation or CPI inflation does not create particularly high variability in any variable except the real exchange rate. Hence, it appears somewhat robust; perhaps surprisingly robust.

²² I am grateful to Akila Weeranpana, who discovered and corrected a programming error of mine for the Taylor rule for CPI inflation.

²³ Note that, due to (2.5), the term $\mu_{\pi}^c \pi_t^{c2}$ in the period loss function is equal to $\mu_{\pi}^c \pi^2 + \mu_{\pi}^c \omega^2 (q_t - q_{t-1})^2 + 2\mu_{\pi}^c \pi_t (q_t - q_{t-1})$.

4 Conclusions

I have presented a relatively simple model of a small open economy, with some microfoundations, and with stylized, reasonably realistic relative lags for the different channels for the transmission of monetary policy: The direct exchange rate channel to the CPI has the shortest lag (for simplicity set to a zero lag), the aggregate demand channel's effect on the output gap has an intermediate lag (set to one period), and the aggregate demand and expectations channels on domestic inflation have the longest lag (set to two periods).

Within this model, I have examined the properties of strict vs. flexible inflation targeting, and domestic vs. CPI-inflation targeting, especially relating them to the properties of the Taylor rule. This examination shows that flexible inflation targeting, effectively compared to strict inflation targeting, induces less variability in variables other than inflation, by effectively targeting inflation at a longer horizon. Especially, strict CPI-inflation targeting involves using the direct exchange rate channel to stabilize CPI inflation at a short horizon, which induces considerable real exchange rate variability. In contrast, flexible CPI-inflation targeting, compared to both strict CPI-inflation targeting and flexible domestic-inflation targeting, results in considerable stabilization of the real exchange rate. In a situation with weight on stabilization of both inflation and real variables, CPI-inflation targeting appears as an attractive alternative.

The implicit reaction functions arising under domestic-inflation and CPI-inflation targeting differ from the Taylor rule. CPI-inflation targeting deviates conspicuously from the Taylor rule, due to its implicit concern about real exchange rate depreciation. Such concern makes the response to foreign disturbances and variables important, whereas the Taylor rule excludes any direct response to these. Already in a closed economy, the Taylor rule uses only part of the information available; in an open economy it uses an even a smaller part. On the other hand, the Taylor rule does not result in exceptionally large variability in any variable, except possibly the real exchange rate; consequently it appears rather robust.

The model I use distinguishes between demand and supply shocks. There are two kinds of supply shocks: cost-push shocks and productivity shocks. The response to a positive demand shock and a negative productivity shock are very similar (except that the response of the real exchange rate is more persistent for the latter). This similarity may appear surprising, given the conventional wisdom that supply shocks cause a conflict between inflation and output stabilization. There are several reasons for the similarity. First, both shocks increase the output gap, and the output gap is the major determinant of domestic inflation. Second, under flexible

inflation targeting, the central bank wants to stabilize the variability of the output *gap*, rather than of output itself, as specified in the loss function I have used. For a productivity shock, there is little conflict between stabilizing the output gap and stabilizing output. For a supply shock, there is a considerable conflict between output-gap stabilization and output stabilization. Then there is little conflict between inflation stabilization and output-gap stabilization, but considerable conflict between inflation stabilization and output stabilization. Thus, since output-gap stabilization rather than output stabilization is one of the goals, there is little difference between positive demand and negative productivity shocks, except that the persistence of the shocks may be quite different. Instead, the conflict between inflation stabilization and output-gap stabilization arises for cost-push supply shocks, rather than for productivity supply shocks.²⁴

There are some obvious limitations to the analysis that may indicate suitable directions for future work. *First*, as emphasized above, there is no calibration and/or estimation of the parameters in the current version; the only criterion applied is that they must not be a priori unreasonable. As a consequence, the numerical results are only indicative. *Second*, although some microfoundations are provided for the aggregate supply and demand functions, as shown in Svensson [35], there is some arbitrariness in the assumptions of partial adjustment and the addition of disturbance terms. At the cost of introducing additional forward-looking variables, it is relatively straightforward to implement the ideas of polynomial costs of adjustment of Pesaran [26] and Tinsley [39]. Also, only sticky prices have been explicitly modelled; with sticky wages, as noted by, for instance, Andersen [1], the dynamics can be quite different. *Third*, the model is linear with a quadratic loss function. Nonnegative nominal interest rates is one source of nonlinearity, nonlinear Phillips curves is another. However, any nonlinearity would prevent the use of the convenient and powerful algorithm for the optimal linear regulator with forward-looking variables. *Fourth*, the particular relative lag structure I have used has been imposed on the model; there are obvious alternatives that may be worth pursuing.²⁵ *Fifth*, the disturbances

²⁴ Clarida, Gali and Gertler [11] note that a conflict between inflation stabilization and output-gap stabilization only arises for cost-push shocks but not for demand shocks or productivity shocks. In their framework, the monetary policy response to demand and supply shocks is different: the former are cancelled, and the latter are perfectly accommodated. The reason for this difference from the present model is that they have no lag in the effect of monetary policy, no inertia in aggregate demand, and a random walk in the natural output level. Without a lag in the effect of monetary policy, monetary policy can stabilize both inflation and the output-gap by completely cancelling any demand shock. A permanent shock to the natural output level leads, via the permanent-income hypothesis, to an equal permanent change in aggregate demand, with no effect on the output gap and inflation, and no need for a monetary policy response.

²⁵ For instance, the assumption of no lag in the pass-through of exchange rate depreciation to the CPI is certainly an extreme assumption; an alternative is to assume that the direct exchange rate channel has a one-period lag, such that import prices are predetermined one period. Another alternative, at the cost of increased complexity, is to have the 1, 2 and 3 for the direct exchange rate channel to the CPI, the aggregate demand channel to output,

and the state variables are assumed to be observable to both the central bank and the private sector. In the real world, disturbances and the state variables are not directly observable, and the private sector and the central bank have to solve complicated signal-extraction problems. Some of the implications for inflation targeting of imperfectly observed states and disturbances are examined in Svensson and Woodford [36]. *Sixth*, there is no uncertainty in the model about the central bank's loss function and the inflation target is perfectly credible. Some new results on the consequences of imperfect credibility and less than full transparency of monetary policy are provided by Faust and Svensson [14]. *Seventh*, although it would be very desirable to test the model's predictions empirically, the short periods of inflation targeting in the relevant countries probably imply that several additional years of data are necessary for any serious empirical testing.

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and the aggregate demand and expectations channels to domestic inflation, respectively. A third alternative is to impose some partial adjustment of import prices. The theoretically most satisfactory alternative would be to have a separate aggregate supply relation for imported goods, realizing that importers face a pricing decision that is, in principle, similar to that of domestic producers.

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Figure 3.1: Strict domestic-inflation targeting. Impulse responses

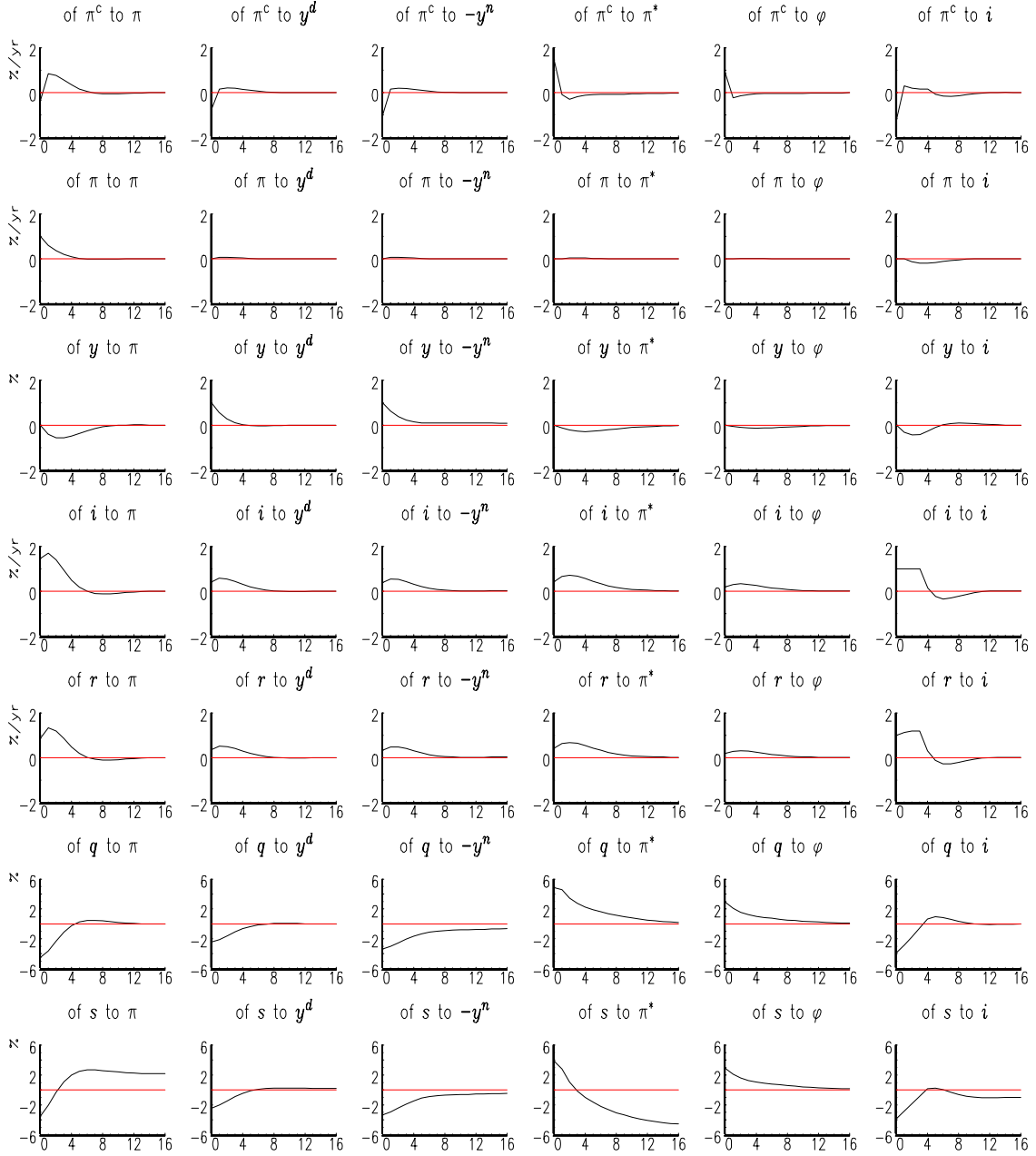


Figure 3.2: Strict CPI-inflation targeting. Impulse responses

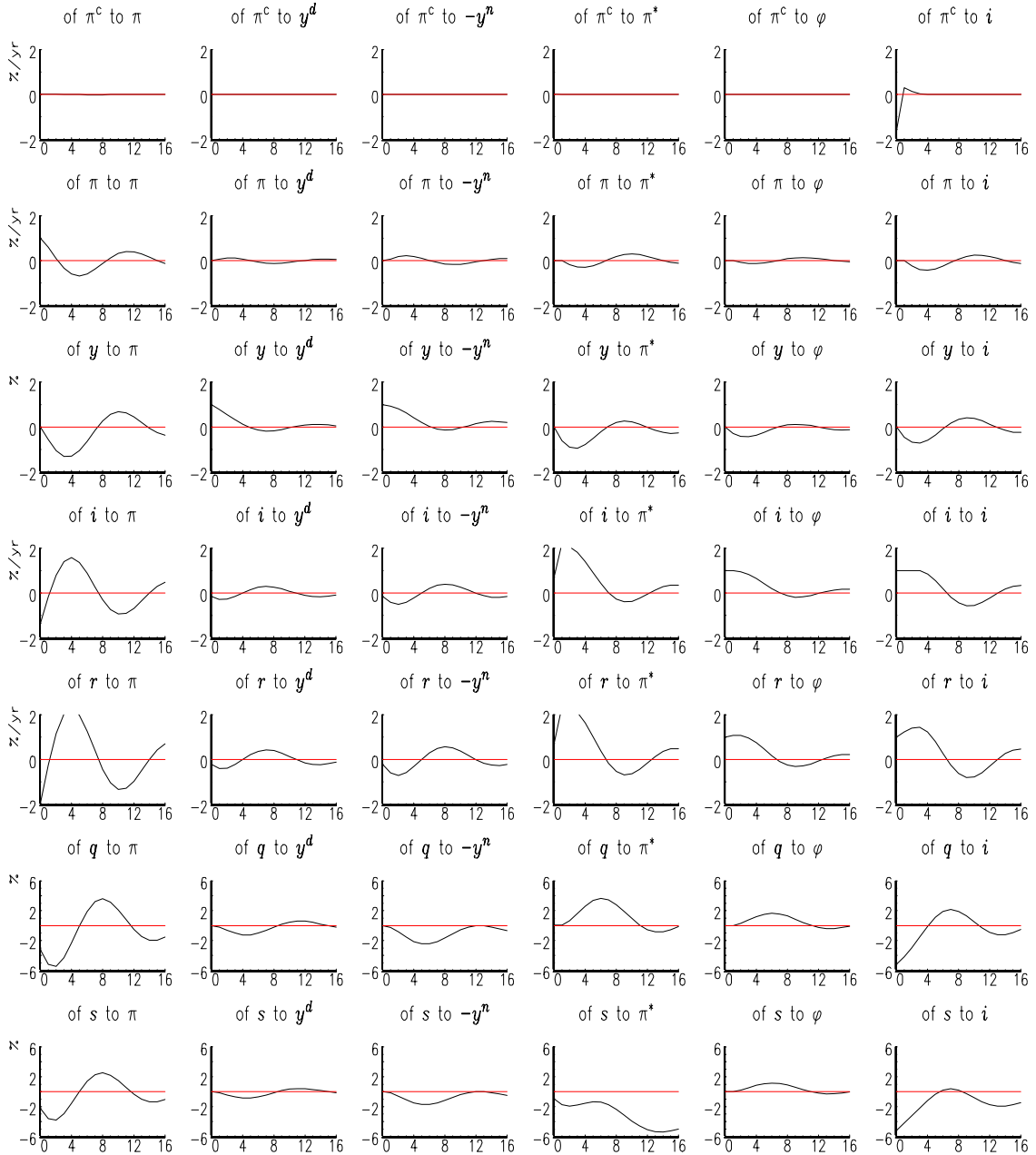


Figure 3.3: Flexible CPI-inflation targeting. Impulse responses

