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Implications of Exchange Rate Objectives under Incomplete Exchange Rate Pass-Through

Malin Adolfson*

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Abstract

This paper analyzes the central bank's optimal objective function in a small open economy model allowing for incomplete exchange rate pass-through. The results indicate that there are welfare gains from different types of monetary policy inertia. The welfare improvements of exchange rate stabilization are, however, dependent on the degree of discretionary stabilization bias. If the stabilization bias has been mitigated through a low weight on output stabilization social welfare can not be improved by inclusion of an explicit exchange rate term in the delegated objective function, irrespective of the degree of pass-through. Welfare can, though, be enhanced by appointing a central banker with greater preference for interest rate smoothing than that of society. The optimal degree of interest rate smoothing is increasing in the degree of pass-through.

Keywords: Exchange rate pass-through, inflation targeting, interest rate inertia, monetary policy, small open economy

JEL classification: E52, E58, F41

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1. Introduction

From time to time we see that central banks intervene on foreign exchange rate markets. Should policy makers care about the exchange rate and target it? Does exchange rate stabilization improve macroeconomic performance? The reason why exchange rate stabilization might be beneficial for social welfare is the exchange rate's role of transmitting monetary policy. In forward-looking models a 'stabilization bias' arises under discretionary policy where the policy maker can not precommit to a policy rule (see, e.g., Clarida et al. (1999), and Woodford (1999)). As shown by Woodford, the discretionary stabilization bias is due to insufficient monetary policy inertia. Social welfare might, therefore, be improved if the delegated central bank objectives can make the policy responses more persistent. Prior literature has suggested many different welfare improving modifications of the central bank objective for closed economies; for example, interest rate smoothing (Woodford (1999)), emphasizing inflation objectives (Clarida et al. (1999)), and price level targeting (Vestin (2000)). This paper analyzes, in contrast, the stabilization bias in an open economy, and focuses on whether an exchange-rate augmented policy can imply a more inertial reaction function and reduce the stabilization bias. Can the policy maker's control over the inflation-output variability trade-off be improved by augmenting the delegated objective function with an exchange-rate stabilization term?

In an open economy, exchange rate movements affect inflation through direct changes in import prices as well as via aggregate demand, which is influenced by alterations in the relative price between foreign and domestic goods. In the presence of exchange rate disturbances, the policy maker can not stabilize demand without creating fluctuations in inflation, because the exchange rate has this twofold effect on both the demand and supply relations. The policy maker is thus forced to trade off reduced output variability for inflation variability. In contrast to the closed economy setting, this trade-off occurs for all types of shocks that enter the economy, since all adjustments of the policy controlled interest rate also generate movements in the exchange rate (see, e.g., Walsh (1999)).

Movements in the terms of trade can consequently affect the trade-off between monetary policy objectives, and fluctuations in the exchange rate may be of importance for controlling inflation. Clarida et al. (2001), though, advocate that the closed and open economy policy objectives are (qualitatively) isomorphic as long as the terms of trade are proportional to the output gap. In this case the welfare-optimizing policy results in complete stabilization of domestic inflation, without explicit consideration of the exchange rate (see also Aoki (2001), Galí and Monacelli (2000), and Sutherland (2000)[1]). However, this finding builds on an assumption of complete and immediate exchange rate pass-through (i.e., a one-to-one correspondence between exchange rate movements and import prices changes). There is, nonetheless, considerable empirical evidence of limited exchange rate pass-through also for small open economies (see, e.g., Adolfson (1997), Campa and Goldberg (2001), and Naug and Nymoen (1996)). It is therefore interesting to examine; *i*) whether an explicit exchange rate objective should be introduced in the open-economy policy under incomplete exchange rate pass-through, and *ii*) how prior closed-economy results regarding, for example, discretionary optimality are related to the degree of pass-through (i.e., Woodford's (1999) result on monetary policy inertia).

Given incomplete exchange rate pass-through, there have been some suggestions that the design of the optimal policy differs between closed and open economies. Moreover, the (optimal) open-economy policy seems to be dependent on the degree of pass-through (see Corsetti and Pesenti (2001), and Smets and Wouters (2001)). If the degree of pass-through is small the effectiveness of the exchange rate channel (transmitting monetary policy) is reduced, and there is less conflict between inflation and output objectives in the face of, for example, demand shocks and exchange rate disturbances. On the other hand, a low pass-through also necessitates larger exchange rate movements to alleviate disturbances requiring relative price adjustments (see Adolfson (2001)). This implies that the optimal policy must balance the costs of exchange rate variability against the possible flaws of stabilizing the exchange rate.

Corsetti and Pesenti (2001), and Smets and Wouters (2001) derive the goals of monetary policy under incomplete exchange rate pass-through directly from the social welfare function (i.e., the costs of price stickiness). However, they do not discuss whether the policy trade-off can be improved by assigning a different objective function to the open economy-policy maker compared to society. The approach taken in this paper is, in contrast, to analyze how the delegated policy objective should be specified in order to mitigate the discretionary stabilization bias. What are the appropriate objectives, in terms of social welfare, that should be pursued by a discretionary policy maker in an open economy with incomplete exchange rate pass-through? In particular, should the policy maker explicitly target the exchange rate or just react to the informational content of exchange rate fluctuations, and is this contingent upon the degree of pass-through?

[1] Sutherland (2000) finds that domestic inflation targeting is optimal, although the policy implementation in that paper is done through targeting CPI inflation *and* the nominal exchange rate level.

The analysis is performed within an aggregate supply–aggregate demand model adjusted for incomplete exchange rate pass-through. The results indicate that the welfare improvements of including an exchange rate term among the policy objectives are dependent on the degree of discretionary stabilization bias. If the true social objectives are pursued, the policy maker can improve social welfare by also targeting the nominal exchange rate level since this makes monetary policy more persistent and affects agents' expectations. However, if the stabilization bias already is mitigated by other means, for example because of a lower delegated weight on output stabilization than social preferences imply, inclusion of an exchange rate policy objective does not generate any welfare gains. A direct, and explicit, stabilization of nominal or real exchange rates appears to be redundant in this case, both when pass-through is limited and when it is complete. Further, the paper also points out that although the incomplete exchange rate pass-through induces persistent policy responses to certain shocks, there are gains from appointing a central banker with greater preference for interest rate smoothing than the social objective, as proposed by Woodford (1999). The results here show that the optimal degree of explicit interest rate smoothing decreases as pass-through decreases. The reason is that low pass-through as such generates more inertial interest rate reactions.

In Section 2, the model economy, the social loss function, and different central bank objectives, are outlined and parameterized. Section 3 contains the optimized central bank objective function, evaluated from a social loss rationale, and the resulting policy trade-offs under different types of disturbances. Robustness issues are discussed in Section 4, while some conclusions are presented in Section 5.

2. Model

The theoretical setting is a forward-looking open economy aggregate supply-aggregate demand model allowing for incomplete exchange rate pass-through. Most prior developments of open economy models have assumed the law of one price to hold, such that the exchange rate pass-through is complete (see, for example, Svensson (2000), and McCallum and Nelson (1999)). In contrast, in the model used here, the foreign producer can not fully adjust her domestic currency (import) price in the face of exchange rate changes because of nominal price adjustment costs (à la Rotemberg (1982)). This implies a limited exchange rate pass-through and, consequently, a modified supply relation where the degree of pass-through can be altered by simply changing the level of import price stickiness.[2]

2.1. Inflation, output, and interest rate relations

Consider an open economy with consumption of both domestically produced goods and imported foreign goods. The economy consists of an aggregate supply relation, an aggregate demand relation, and an interest rate parity condition pinning down expected exchange rate changes. The nominal interest rate is determined from an explicit central bank objective function. This economy (called domestic) is assumed to be small compared to the rest of the world (called foreign), such that foreign inflation, foreign output and foreign monetary policy are exogenously given.

The domestic aggregate supply equation is derived from the producers' optimal price setting relations assuming nominal (Rotemberg) price stickiness, and using the underlying constant elastic substitution (CES) function for the households' aggregate consumption. Inflation of domestically produced goods ($\pi_t^D = p_t^D - p_{t-1}^D$) and import goods inflation denoted in the domestic currency ($\pi_t^M = p_t^M - p_{t-1}^M$) compose aggregate inflation (π_t), i.e., consumer price index (CPI) inflation, according to the following:[3]

$$\text{(1a)} \qquad \pi_t^D = \alpha_\pi \mathrm{E}_t \pi_{t+1}^D + \frac{1}{(1-\kappa_M)}\left(\alpha_y y_t + \alpha_q (p_t^M - p_t^D) + \varepsilon_t^\pi\right),$$

$$\text{(1b)} \qquad \pi_t^M = \alpha_\pi \mathrm{E}_t \pi_{t+1}^M + \frac{\alpha_p}{\kappa_M}\left(p_t^* + e_t - p_t^M\right),$$

$$\text{(1c)} \qquad \begin{aligned} \pi_t &= (1-\kappa_M)\pi_t^D + \kappa_M \pi_t^M = \\ &= \alpha_\pi \mathrm{E}_t \pi_{t+1} + \alpha_y y_t + \alpha_q (p_t^M - p_t^D) + \alpha_p (p_t^* + e_t - p_t^M) + \varepsilon_t^\pi, \end{aligned}$$

where κ_M denotes the (steady-state) import share of domestic consumption, $0 < \alpha_\pi < 1$ is a discount factor, and α_y, α_q, and α_p are positive constants. y_t is domestic output, p_t^M the

[2] For a more thorough discussion and derivation of the model, see Adolfson (2001).

[3] The notation is as follows; lower case letters denote logarithmic values (i.e., deviations from steady-state), a superscript indicates whether domestic or import goods are considered, and foreign variables are represented by an asterisk. A price denoted in foreign currency is thus characterized by an asterisk. Finally, E_t denotes rational expectations as of period *t*.

price of import goods denoted in the domestic currency, p_t^D the price of domestically produced goods, p_t^* the foreign currency price of import goods, and e_t the nominal exchange rate (domestic currency per unit of foreign currency). Lastly, ε_t^π is a supply disturbance (i.e., a domestic cost-push shock) that is assumed to follow the autoregressive process, $\varepsilon_{t+1}^\pi = \tau_\pi \varepsilon_t^\pi + u_{t+1}^\pi$, where u_{t+1}^π is an iid disturbance with zero mean and variance σ_π^2.

Domestic inflation is indirectly affected by the exchange rate through the (inverse of the) terms of trade ($p_t^M - p_t^D$), which turns up in equation (1a) because of imported intermediate inputs. Import inflation in equation (1b) is affected by the exchange rate through a wedge term that captures deviations from the optimal price of import goods in the absence of any nominal rigidities and the price actually charged (i.e., $p_t^* + e_t - p_t^M$).[4] The import price (denoted in domestic currency) can not be fully adjusted to, for example, alterations in the nominal exchange rate because of the import price stickiness. This creates a wedge between marginal cost (captured by the price charged in the foreign market adjusted for the exchange rate; $p_t^* + e_t$) and the price actually charged (p_t^M). This implies incomplete pass-through and short-run deviations from the law of one price.[5] It is also this wedge term that makes the pass-through adjusted supply relation different from a standard Phillips curve with complete exchange rate pass-through. The degree of pass-through is controlled by α_p, which is a function of the structural parameter determining the import price stickiness and the import share of total consumption. By imposing a larger nominal rigidity on the foreign producer, indicated by a lower α_p, a smaller exchange rate pass-through is generated. A higher cost of adjusting prices implies that less of an exchange rate movement will affect the current price. Furthermore, these adjustment costs lead to gradual price changes, implying that the producer alters this period's price in the direction of the expected future optimal price.[6]

The aggregate demand relation is obtained using a standard Euler equation for the (representative) household's intertemporal choice of consumption, and the CES function:

[4] Given equal demand elasticities in the two destinations to which the foreign producer sells, there are no incentives to deviate from the law of one price in the absence of nominal rigidities because of the constant elastic substitution function. The optimal domestic flex price is just the price charged in the foreign market corrected for the exchange rate.

[5] In the long run, the producer expects to charge the optimal flexible price such that $(p^* + e - p^M) \sim I(0)$.

[6] Note that Roberts (1995) shows that the behaviour of the aggregate price is similar using the Rotemberg (1982) approach for introducing price stickiness, as when using the Calvo (1983) formulation (which, in contrast, renders staggeredness in the individual prices).

(2) $$y_t = \mathrm{E}_t y_{t+1} - \beta_q \mathrm{E}_t(\pi^M_{t+1} - \pi^D_{t+1}) - \beta_i(i_t - \mathrm{E}_t \pi_{t+1}) + \beta_e(\mathrm{E}_t \pi^D_{t+1} - (\mathrm{E}_t e_{t+1} - e_t) - \mathrm{E}_t \pi^*_{t+1}) - \beta^*_y(\mathrm{E}_t y^*_{t+1} - y^*_t) + \varepsilon^y_t,$$

where i_t is the domestic interest rate, π^*_t foreign inflation, and y^*_t foreign output. ε^y_t is a demand shock (e.g. to preferences) that follows, $\varepsilon^y_{t+1} = \tau_y \varepsilon^y_t + u^y_{t+1}$, where u^y_{t+1} is an iid disturbance with zero mean and variance σ^2_y. Domestic output is a function of expected future output, the expected change in the relative price of imports, $\mathrm{E}_t\Delta(p^M_{t+1} - p^D_{t+1})$, the real interest rate, the expected change in the relative price of exports, $\mathrm{E}_t\Delta(p^D_{t+1} - e_{t+1} - p^*_{t+1})$, and the expected change in foreign output.[7] The (change in the) relative price of imports appears through its effect on domestic demand for domestic goods, while the (change in the) relative price of exports and the (change in) foreign output show up due to their influence on foreign demand for domestic goods. The difference between the demand relation in equation (2) and a full pass-through demand curve lies in the deviation from the law of one price (i.e., $p^M_t \neq p^*_t + e_t$), which makes the relative price of imports ($p^M_t - p^D_t$) and the (inverse of the) relative price of exports ($p^D_t - e_t - p^*_t$) diverge. The limited pass-through is thus implicitly incorporated also in the aggregate demand relation, through the import price (p^M_t).

The exchange rate fulfills a modified uncovered interest rate parity condition, which links the expected exchange rate change to the difference in domestic and foreign interest rates:

(3) $$i_t - i^*_t = \mathrm{E}_t e_{t+1} - e_t + \varepsilon^\phi_t,$$

where i_t is the domestic interest rate, i^*_t the foreign interest rate, and ε^ϕ_t a risk premium following, $\varepsilon^\phi_{t+1} = \tau_\phi \varepsilon^\phi_t + u^\phi_{t+1}$, where u^ϕ_{t+1} is an iid disturbance with zero mean and variance σ^2_ϕ. Anything affecting this interest rate differential will also affect the exchange rate (such as foreign, and domestic, inflation or output shocks that generate some policy response) which is

[7] Note that the relative price *level* affects the *intra*temporal allocation between consumption of imports and domestic goods, while the *change* in the relative price affects the *inter*temporal consumption decision. However, observe additionally that all difference terms disappear when solving equation (2) forward;

$$y_t = \beta_q(p^M_t - p^D_t) - \beta_i \sum_{s=0}^{\infty} \mathrm{E}_t(i_{t+s} - \pi_{t+s+1}) - \beta_e(p^D_t - e_t - p^*_t) + \beta^*_y y^*_t + \sum_{s=0}^{\infty} \mathrm{E}_t \varepsilon^y_{t+s},$$

(footnote continues on the next page)

why 'independent' exchange rate shocks can be hard to distinguish. However, since risk premium shocks have the same (short-run) effects as autonomous disturbances to expectations about the future exchange rate, the risk premium shocks can be interpreted as 'pure' exchange rate disturbances.

Adjustments of the nominal interest rate will feed into the economy via the real interest rate and the exchange rate. The real interest rate and the exchange rate both affect aggregate demand which, in turn, affects inflation, but the exchange rate also has a direct effect on inflation through changes in import prices. The two components in CPI inflation, that is, inflation of domestic goods (π_t^D) and inflation of import goods (π_t^M), are linked differently to the transmission channels of monetary policy. Inflation of import goods only responds to exchange rate alterations, while inflation of domestic goods is affected by real interest rate changes (i.e., via aggregate demand changes) as well as by exchange rate changes. Since the degree of pass-through affects the extent to which exchange rate movements have an impact on the economy, it will influence the monetary policy transmission as well as the degree of exposure to foreign shocks, such as exchange rate disturbances.

The foreign economy, in turn, consists of exogenous AR(1) processes for inflation and output, and a simple Taylor rule, with some persistence added, that determines the foreign interest rate (see, e.g., Clarida et al. (2000)):

(4) $$y_{t+1}^* = \rho_y^* y_t^* + u_{t+1}^{y*},$$

(5) $$\pi_{t+1}^* = \rho_\pi^* \pi_t^* + u_{t+1}^{\pi*},$$

(6) $$i_t^* = (1-\rho_i^*)(b_\pi^* \pi_t^* + b_y^* y_t^*) + \rho_i^* i_{t-1}^* + u_t^{i*},$$

where ρ_y^*, ρ_π^*, ρ_i^* are non-negative coefficients less than unity, and u_{t+1}^{y*}, $u_{t+1}^{\pi*}$, u_{t+1}^{i*} are iid disturbances with zero mean and variance σ_{y*}^2, $\sigma_{\pi*}^2$, and σ_{i*}^2 , respectively.

2.2. Social preferences and policy implementation

To evaluate the central bank's alternative objectives, and performance, a standard social loss function is assumed to prevail in the economy

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using the appropriate transversality conditions.

$$
\text{(7)} \quad \begin{aligned} &\min \quad E_t \sum_{j=0}^{\infty} \beta^j L_{t+j}^S \\ &\text{where} \quad L_t^S = \left[\pi_t^2 + \lambda^S y_t^2 \right], \end{aligned}
$$

such that the social loss consists of quadratic deviations of CPI inflation and output from their (constant and zero) targets, and λ^S is the relative weight society puts on output stabilization. The output target is assumed to be equal to the natural output level so that there is no inflation bias in the model.[8]

That society cares about inflation stems from the fact that the nominal rigidities in the model cause a relative price dispersion between the optimal flexible price and the sticky price actually charged. Even if the producers face the same price adjustment costs, such price dispersion is detrimental for social welfare, since the best possible output level is not achieved. Reducing the incentives to adjust prices will, thus, improve welfare. In economies with nominal rigidities, Woodford (2001) therefore suggests that the *general* price level should be stabilized in order to reduce the relative price dispersion between flexible and fixed price producers. Stabilization of (CPI) inflation can reduce this price dispersion and, hence, uncertainty about future real consumption, which is welfare improving for the risk averse consumers. In a closed economy, CPI inflation and domestic inflation are equivalent. However, this is not the case in an open economy, and some argue that domestic inflation, rather than CPI inflation, determines the open economy-welfare criterion.[9] On the other hand, CPI inflation targeting mitigates the two distortions that arise in the model used here, namely that domestic *and* import prices are sticky (given incomplete exchange rate pass-through). To reduce these two distortions and overcome the inefficient price dispersion *both* domestic and import prices must be stabilized.[10] When the open economy-policy maker seeks to stabilize the economy around the flexible price outcome,

[8] The theoretical underpinnings of this objective function are characterized by a second-order Taylor approximation of the expected utility of a representative household (see Woodford (2001) for a closed economy derivation).

[9] Benigno and Benigno (2000) show that the open economy welfare criterion can be characterized by a loss function based on stabilization of consumption and domestic inflation, assuming producer currency pricing and full pass-through. Given incomplete exchange rate pass-through, Sutherland (2001) derives the welfare function in terms of the variances of domestic prices and the nominal exchange rate. However, Corsetti and Pesenti (2001) show that the open economy monetary policy objective can be represented as (equivalent) functions of either, *i*) expected markups, *ii*) the consumer price index, or *iii*) the output gap and deviations from the law of one price. As a result, they conclude that the use of appropriate policy trade-offs is important (i.e., that optimal policies trade off a larger output gap for lower import prices).

[10] Note that Smets and Wouters (2001), in a forward-looking open economy model with sticky domestic and import prices, derive the (central bank's) loss function from the resource cost that is due to relative price variability. They find that this loss function is a weighted average of both domestic price inflation and import price inflation. Further, Benigno (2001) shows that a weighted average of two regional inflation rates should be targeted in an optimal currency area, given nominal rigidities in both regions.

the consequences of high interest rate variability must implicitly be considered, since this induces exchange rate fluctuations and terms of trade distortions that show up in, for instance, import inflation.[11]

As the discount factor, β, approaches unity, the intertemporal loss function becomes proportional to the unconditional mean of the period loss function, implying that the following relation can be used to quantify the social preferences (see, e.g., Svensson (2000)):

$$\text{(8)} \qquad \mathrm{E}\left[L_t^S\right] = \mathrm{var}(\pi_t) + \lambda^S \, \mathrm{var}(y_t) \, .$$

Monetary policy is assumed to be implemented through a policy objective function, from which an explicit reaction function for the policy instrument can be obtained. The policy maker is lacking (certain) commitment technologies so that she, by assumption, solves her optimization problem under discretion and re-optimizes every period, treating the agents' expectations as given and independent of the current policy choice. The central bank adjusts its policy instrument, i.e. the nominal interest rate, to minimize the intertemporal loss function:

$$\text{(9)} \qquad \min_{\{i_{t+j}\}_{j=0}^{\infty}} \quad \mathrm{E}_t \sum_{j=0}^{\infty} \beta^j L_{t+j}^{CB} \, ,$$

where β is a discount factor, and L_t^{CB} is the central bank period loss function. The question at hand is whether the central bank should pursue a different objective than that of the social preferences. Because of the stabilization bias that occurs under a discretionary policy, the (welfare maximizing) objective delegated to the policy maker (L_t^{CB}) need not necessarily be identical to the social loss function (L_t^S).

2.3. Policy delegation

Since agents are forward-looking, the policy maker can exploit the private agents' expectations about future inflation and output when implementing the monetary policy although there is no inflation bias in this model. The discretionary stabilization bias can therefore be reduced if expectations about the future can be affected by the current monetary policy choice (in the same

[11] Moreover, the consumption bundle, consisting of both domestic and foreign goods, is priced in terms of aggregate *(footnote continues on the next page)*

way as is done under commitment). By just looking at equation (1), one sees that a smaller contraction in aggregate demand yields the adequate drop in inflation if expectations about future inflation can be lowered by, for example, committing to some policy choice. A commitment policy can then make the trade-off between inflation and output variability more efficient, reducing the value of the loss function.[12] As shown by Woodford (1999), the commitment response is more inertial than the discretionary policy so the latter might possibly be improved upon by making it more persistent. Accordingly, Woodford suggests that by assigning a different objective function to the policy maker, with larger weight on interest rate smoothing than that of the society's objective, the discretionary outcome can be brought closer to the commitment solution.[13] This results from exploiting the agents' forward-looking behaviour and the role of expectations, and by simulating a 'commitment environment' social welfare can, consequently, be improved.

Modifications of the central bank objective to improve social welfare can be done in a number of ways, as long as the private agents' beliefs are affected. This paper studies whether social welfare can be improved by delegating a policy objective that incorporates stabilization of nominal or real exchange rates, some interest rate smoothing, or low output stabilization. The issues dealt with here are, consequently; *i*) Is there a role for an explicit exchange rate objective in the policy maker's loss function? *ii*) How are prior findings of discretionary optimal policy inertia, along the lines of Woodford (1999) and Walsh (1999), affected by open economy aspects and incomplete exchange rate pass-through?

Walsh (1999) shows in an open economy with full pass-through that there are gains from appointing a 'conservative' banker in the sense of Clarida et al. (1999) (i.e., with a lower degree of output stabilization than society). Note that in forward-looking models these welfare gains occur even in the absence of the standard inflation bias, as opposed to Rogoff (1985). If the policy maker is perceived to emphasize inflation objectives in the face of, e.g., a positive cost-push shock, expected future inflation will rise less (compared to if the output stabilization, in contrast, is larger). This implies that less of an output reduction is needed, which improves the inflation-output variability trade-off and reduces the discretionary stabilization bias.

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prices, which is why agents intuitively care about CPI inflation.

[12] A smaller initial *nominal* interest rate change is required to alter demand if inflation expectations can be lowered, since the induced *real* interest rate will be larger in this case (see equation (2)).

An exchange-rate augmented policy might also reduce the stabilization bias since such a policy can induce a more inertial reaction function. Stabilization of the nominal exchange rate level implies that deviations from the exchange rate target affect future losses and that an offsetting future movement must counter such a deviation, exactly in the same way as with a price-level target.[14] Targeting the nominal exchange rate level, consequently, implies that monetary policy actions persist, which makes the policy reaction function more inertial.

Moreover, by alleviating fluctuations in the exchange rate, the policy maker gets a better chance of controlling the inflation-output variability trade-off in the face of certain shocks, such as domestic demand shocks. Since every interest rate adjustment also implies a change in the exchange rate, such an additional exchange rate stabilization-objective internalizes the actual impact of an interest rate response, which as well feeds into the economy through the exchange rate. Hence, this suggests that the total effect of monetary policy is taken into account, and that considerable variation in the exchange rate might be avoided.[15] Note that even if the policy maker puts some weight on interest rate smoothing, the volatility in the nominal exchange rate need not be kept small since the exchange rate is dependent on all future values of the interest rate, which is more persistent in this case.

The postulated central bank period objective function is quadratic in deviations of CPI inflation and output from their constant targets (normalized to zero), and quadratic in variations of the interest rate. This objective function is, in addition, augmented with real or nominal exchange rate terms according to the following:

(10a) $$L_t^{\Delta i} = \pi_t^2 + \lambda^{CB} y_t^2 + \nu_i (i_t - i_{t-1})^2 ,$$

(10b) $$L_t^{PPP} = \pi_t^2 + \lambda^{CB} y_t^2 + \nu_i (i_t - i_{t-1})^2 + \mu_{(p^*+e-p)} (p_t^* + e_t - p_t)^2 ,$$

(10c) $$L_t^{\Delta e} = \pi_t^2 + \lambda^{CB} y_t^2 + \nu_i (i_t - i_{t-1})^2 + \mu_{\Delta e} (e_t - e_{t-1})^2 ,$$

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[13] Other examples of delegation schemes that make monetary policy more inertial are; nominal income growth targeting (Jensen (2001)), money growth targeting (Söderström (2001)), and price level targeting (Vestin (2000)). These schemes are not dealt with in this paper, however.

[14] In fact, nominal exchange rate stabilization approximates import price level targeting for some types of shocks. In this model, the law of one price states that $(\hat{p}^* + e - p^M) \sim I(0)$. For shocks that keep the foreign currency price unaltered, this implies that $\lim_{s\to\infty} \mathrm{E}_t e_{t+s} = \lim_{s\to\infty} \mathrm{E}_t p_{t+s}^M$, given $\pi^M \sim I(0)$.

[15] Note that targeting the exchange rate is something different from responding to it. In this model the central bank's reaction function is solved optimally. This implies that the policy maker responds to, for example, risk premium shocks, even in the absence of an explicit exchange rate objective, since these shocks contain information about inflation and output. For a discussion of incorporating the exchange rate into (sub-optimal) simple policy rules, see, e.g., Ball (1999), and Taylor (2001).

(10d) $L_t^e = \pi_t^2 + \lambda^{CB} y_t^2 + \nu_i (i_t - i_{t-1})^2 + \mu_e e_t^2$,

where λ^{CB} is the relative weight on output stabilization, ν_i is the parameter determining the rate of interest rate smoothing, $\mu_{(p^*+e-p)}$, $\mu_{\Delta e}$, and μ_e are the relative weights on different forms of exchange rate stabilization. The central bank's *benchmark* objective is to directly implement the social preferences, which is accomplished by assigning equation (10a) with $\lambda^{CB} = \lambda^S$ and ν_i = 0. Appointing a policy maker with preferences for interest rate smoothing and low output stabilization implies $\nu_i > 0$ and $\lambda^{CB} < \lambda^S$, respectively. The exchange rate is incorporated into the policy objective through quadratic deviations (from zero targets) of either; b) the real exchange rate (defined as the relative price between foreign and domestic CPIs), c) the nominal exchange rate difference, or d) the nominal exchange rate level.

The model (i.e., equations (1)-(6)) can be represented in state-space form, implying that the central bank's optimization problem can be expressed as a linear-quadratic problem (see the Appendix). The central bank's objective function, equations (9) and (10), closes the model. In the discretionary case, the central bank's reaction function will relate the interest rate to the predetermined variables of the model, and these reaction coefficients are unraveled by iterating on the value function.[16,17] The model is solved by numerical methods, described in, e.g., Söderlind (1999), and therefore requires some parameterization.

2.4. Parameterization

To illustrate the monetary policy trade-off under different policy objectives, and varying degrees of exchange rate pass-through, the social loss is calculated using the choice of model parameters and shock variances shown in Table 1. These parameter values are chosen from reasonable underlying deep parameters.[18] For an exact mapping between the model parameters shown in Table 1 and the deep parameters, see Adolfson (2001).

[16] Note that when the state-space form contains non-stationary variables, it is unclear whether the numerical algorithm captures the solution to the policy maker's problem. Therefore, policy equations (10a) – (10c) require a state-space representation which excludes the non-stationary nominal exchange rate level. However, if the policy maker uses equation (10d), with an exchange-rate level target, the nominal exchange rate becomes stationary which is why it can be introduced in the state-space representation (cf. equations (A3a) and (A3b) in Appendix A.1.).

[17] Note that in the commitment case, the current behaviour of monetary policy additionally affects the private agents' expectations, which is why the optimal commitment policy also depends on the shadow prices of the forward-looking variables.

[18] The underlying deep parameters capture the following; a discount factor yielding an annual interest rate of 4% (assuming quarterly periods), a price elasticity of demand generating a 20 % markup over marginal cost, an import share consisting of 30 % of total consumption, an export share of 30 % of aggregate demand, an intertemporal *(footnote continues on the next page)*

Table 1: Parameter values

Social preferences	Supply relation	Demand relation	Foreign economy	Shock persistence	Shock variance
$\beta = 0.99$ $\lambda^S = 0.5$	$\kappa_M = 0.3$ $\alpha_\pi = 0.99$ $\alpha_y = 0.056$ $\alpha_q = 0.007$ $\alpha_p = \{30, 0.6, 0.15, 0.03\}$	$\beta_q = 1.26$ $\beta_i = 0.35$ $\beta_e = 1.8$ $\beta_y^* = 0.27$	$\rho_y^* = 0.8$ $\rho_\pi^* = 0.8$ $\rho_i^* = 0.8$ $b_y^* = 0.5$ $b_\pi^* = 1.5$	$\tau_\pi = 0.8$ $\tau_y = 0.8$ $\tau_\phi = 0.8$	$\sigma_\pi^2 = 0.4$ $\sigma_y^2 = 0.6$ $\sigma_\phi^2 = 0.8$ $\sigma_{\pi *}^2 = 0.05$ $\sigma_{y *}^2 = 0.1$ $\sigma_{i *}^2 = 0$

Since the degree of exchange rate pass-through in this model is generated by the nominal rigidity imposed on the foreign producer, pass-through is highly dependent on the exogenously given degree of import price stickiness. The level of adjustment costs (i.e., the level of nominal rigidity captured in parameter α_p) is chosen such that the degree of partial exchange rate pass-through is 0.99, 0.66, 0.33, and 0.09, respectively. In the first case, an exchange rate movement, consequently, immediately alters the import price by 99 % of the exchange rate movement. Hence, this set of values captures the standard open economy case of almost full pass-through, and three intermediate cases of incomplete pass-through. The empirical evidence seems to suggest that also small open economies lie in one of the intermediate categories. Adolfson (1997) reports 21 % immediate, partial, exchange rate pass-through, and another 12 % within a month, to aggregate Swedish import prices, whereas Naug and Nymoen (1996) obtain something like a 20% pass-through per quarter for data on aggregate Norwegian imports.

3. Optimal policy objectives - results

The model is solved numerically, resulting in an explicit reaction function for the central bank, as well as a transition matrix for the state variables (see the Appendix). The transition matrix is subsequently used to calculate the asymptotic variances of, for example, inflation and output which, in turn, determine the policy trade-off and the social loss (see equation (8)) under the various policy objectives.

elasticity of substitution of 0.5, and a parameter linking output to marginal costs such that the steady-state output elasticity of marginal costs is 0.8 (see, for example, Svensson (2000)). Disturbance variances are more or less taken from Leitemo and Røisland (2000).

3.1. Optimal exchange rate stabilization

Table 2 illustrate that social welfare can be improved by appointing a discretionary policy maker that in addition to pursuing the true social objectives (i.e., inflation and output stabilization; $\lambda^{CB} = \lambda^{S} =$ 0.5) also stabilizes the exchange rate.[19] The optimal exchange rate stabilization weights and the resulting social loss, when delegating equation (10b), (10c), or (10d) to the policy maker, are displayed in Table 2. The welfare gain from stabilization of the nominal exchange rate level appears to be greater compared to stabilization of, for example, the real exchange rate. By targeting the nominal exchange rate level, monetary policy becomes more inertial and the open-economy policy maker can exploit the agents' expectations about the future, which produces a better trade-off between inflation and output stabilization. It seems that such a reduction in the loss can be achieved irrespective of whether pass-through is complete or incomplete.[20] Exchange rate targeting implies that policy actions affecting the nominal exchange rate also have an effect on future policy losses. Movements in today's exchange rate are affecting tomorrow's exchange rate level and, thus, the central bank loss function. As is the case with price level stabilization, the forward-looking public understands that an exchange rate level target implies that deviations from target will be countered by future policy movements. This, consequently, reduces the discretionary stabilization bias.

Table 2: Social loss (L^S) and optimized exchange rate policy parameters, under benchmark policy (i.e., λ^{CB} = 0.5, and ν_i = 0)

	Benchmark	Policy weights, λ^{CB} = 0.5, ν_i = 0					
	equation (10a)	equation (10b)		equation (10c)		equation (10d)	
Pass-through	L^S	$\hat{\mu}_{(p^*+e-p)}$	Rel. L^S	$\hat{\mu}_{\Delta e}$	Rel. L^S	$\hat{\mu}_e$	Rel. L^S
0.99	22.368	-0.3	0.999	2.0	0.848	0.1	0.548
0.66	22.214	0.3	0.998	1.8	0.854	0.1	0.541
0.33	21.648	0.9	0.963	1.5	0.867	0.1	0.537
0.09	19.156	1.0	0.808	1.0	0.907	0.1	0.557

Note: The optimized exchange rate weights are established by a grid search, with step 0.1, over the values -1 to 3.

19 The economy is hit by a combination of all disturbances, with variances specified in Table 1 (see the Appendix for the variance-covariance matrix). Recall that only the social welfare and the inflation-output trade-off are affected by the size of the shocks. The policy maker's reaction function is certainty equivalent and thus independent of the disturbances' covariance matrix.

20 Note that the benchmark policy shows that social loss is increasing in the degree of pass-through. However, comparing the absolute loss *level* across different pass-through cases is of limited interest, since these cases represent different structural economies.

However, it is well-known that delegating other weights on output and interest rate stabilization than social preferences imply, typically improves welfare in closed economies (see, e.g., Woodford (1999), and Clarida et al. (1999)). Recall that a large weight on output stabilization implies that the delegated policy is more gradual compared to the case when a 'conservative' banker, with lower output weight, is appointed. This, in turn, has consequences for the exchange-rate augmented policy functions. Gradual interest rate responses imply that risk premium shocks yield prolonged departures of the exchange rate from its long-run level, for example. Remember that the exchange rate is a forward-looking variable and dependent on all future interest rates. This implies that also policy induced exchange rate fluctuations will be larger under a gradual and more persistent policy, even if the initial interest rate response is small. Note also that exchange rate volatility is higher when output stabilization is large (not shown). Consequently, there seems to be more reason to stabilize the exchange rate when the discretionary stabilization is large (i.e., when a 'conservative' banker can not be appointed).

This can be seen in Figure 1, which shows the social loss resulting from different monetary policies when varying the degree of output stabilization between 0 and 0.5. These different policies include either interest rate smoothing or some exchange rate stabilization (i.e., loss functions (10a) – (10d)). The delegated loss function can be manipulated in many different ways, and Figure 1 demonstrates that the welfare outcome of these various specifications depends on the degree of stabilization bias. When the discretionary stabilization bias is being eased through a low policy weight on output stabilization, the exchange-rate augmented policies, for example, seem to perform worse. In the next Section, the policy loss function is, therefore, optimized with respect to the degree of output stabilization and interest rate smoothing.

3.2. Optimal interest rate inertia and optimal output stabilization

Figure 2a shows that appointing a 'conservative' policy maker with low weight on output stabilization reduces the social loss. Note, however, that the adverse effects of driving output stabilization entirely to zero are fairly large. Moreover, the optimal degree of output stabilization does not seem to be dependent on the degree of pass-through.

Although the policy maker's reaction function is already based on lagged variables, such as the prior relative price, some additional policy inertia reduces the social loss (see Figure 2b).[21] Policy inertia, for instance generated by an interest rate smoothing objective, implies that the agents' expectations about future policy responses are affected. This is especially apparent in the model used here, where the persistence comes from exogenous disturbances only. The nominal price rigidity per se only renders forward-looking behaviour of the agents, and does not imply any backward-looking components in the equilibrium relations. Both the supply and the demand relations thus lack explicit backward-looking terms, so that their dependence on past values of the endogenous variables only comes from the policy rule (see equations (1) and (2)).[22]

Table 3 displays the social loss and the optimal policy weights on output and interest rate stabilization when delegating equation (10a) to the policy maker. Neither the reduction in social loss nor the optimal weight on output stabilization seem dependent on the degree of pass-through, but the optimal degree of interest rate smoothing is increasing in the degree of pass-through (see Table 3).[23] The optimal weight on interest rate stabilization is thus larger in the full pass-through case, compared to if pass-through is low.

The reason for the interrelation between the interest rate smoothing and the exchange rate pass-through is that incomplete pass-through induces some inherent persistence into the policy reaction function. This can be explained by considering an exchange rate disturbance. A low pass-through implies that the exchange rate movement is only incorporated into the import price to a small extent. Because of this low pass-through, the move towards the long-run steady-state (with complete pass-through) is gradual, which implies that the exchange rate disturbance has a prolonged effect on inflation. Hence, when pass-through is low, the policy maker will require a smaller, but more persistent, response to an exchange rate disturbance (i.e., a risk premium shock).

[21] Details on the reaction function are found in Table A1 in the Appendix.
[22] Note that even if the demand and supply relations were more backward-looking, changes in the policy objective would alter the agents' expectations. However, some forward-looking components are necessary for inertial policy-making to be optimal.
[23] The optimal interest rate inertia is increasing in the degree of pass-through also for $\lambda^{CB} = 0.5$, when narrowing the grid (not shown).

Table 3: Social loss (L^S) and optimized policy parameters ($\hat{\lambda}^{CB}$, $\hat{\nu}_i$), equation (10a)

Pass-through	Benchmark $\nu_i = 0$ $\lambda^{CB} = 0.5$ $L^{CB} = L^S$	Optimizing the policy weights concerning: interest rate $\lambda^{CB} = 0.5$ $\hat{\nu}_i$	Rel. L^S	output $\nu_i = 0$ $\hat{\lambda}^{CB}$	Rel. L^S	output and interest rate jointly $\hat{\lambda}^{CB}$	$\hat{\nu}_i$	Rel. L^S
0.99	22.368	0.3	0.996	0.1	0.857	0.1	1.0	0.781
0.66	22.214	0.3	0.995	0.1	0.847	0.1	0.9	0.773
0.33	21.648	0.3	0.994	0.1	0.842	0.1	0.7	0.771
0.09	19.156	0.2	0.995	0.1	0.849	0.1	0.4	0.787

Such a response can also be seen from the policy reaction function. Compared to the full pass-through case, the policy maker responds less to a risk premium shock (ε_t^{ϕ}) when pass-through is small, while concurrently adjusting its interest rate more to the lagged interest rate (i_{t-1}) (see, e.g., Table A1b in the Appendix). The reaction coefficient on i_{t-1} is thus decreasing in the degree of pass-through. Consequently, also the optimal interest rate inertia (ν_i) will be dependent on the degree of pass-through. Since the degree of actual interest rate persistence (measured as the reaction coefficient on the lagged interest rate) is larger when pass-through is small, it is not necessary to induce as large interest rate smoothing (i.e., increasing ν_i) as in the full pass-through case.

Note also that the amount of optimal inertia, or persistence in the policy responses, depends on the degree of output stabilization. Larger weights on output stabilization and on interest rate smoothing *both* imply that inflation is more gradually brought back to the targeted level of inflation. This similar role thus implies that less *additional* interest rate persistence in the form of an interest rate smoothing objective is required when the weight on output stabilization is large. Consequently, the additive value (i.e. the welfare gain) of optimizing the degree of interest rate smoothing becomes larger, the lower is the degree of output stabilization (λ^{CB}).

3.3. Exchange rate targeting and fully optimized central bank objectives

Now, consider whether the exchange rate should be targeted given that the discretionary stabilization bias is being eased through optimization of the weights put on other policy objectives. As seen above, the stabilization bias can be mitigated in many different ways, for example through a low weight on output stabilization. Table 4 displays the social loss and the optimized exchange rate parameters of equations (10b) – (10d) for the optimal policy weights on output stabilization and interest rate smoothing.[24] Given that the stabilization bias already is mitigated there does not seem to be any additional welfare gains from delegating an exchange rate objective. Note though that the policy maker still *reacts* to the exchange rate, using its informational content, even if she does not *target* it.

The optimized weights on both the nominal exchange rate level ($\hat{\mu}_e$), and the difference ($\hat{\mu}_{\Delta e}$) are zero in all pass-through cases (see Table 4). The small stabilization bias thus implies that the policy maker can not improve social welfare any further by stabilizing the exchange rate. The discretionary distortion is reduced by other means and, consequently, the policy maker does not get any extra leverage from targeting the exchange rate. In contrast, a positive weight on nominal exchange rate stabilization appears to create excessive variability in output and relative prices (not shown). In fact, unrestrained exchange rate adjustments might be helpful in alleviating disturbances requiring relative price adjustments, which then make this kind of policy persistence detrimental.[25]

The optimized weight on the real exchange rate ($\hat{\mu}_{(p^*+e-p)}$) is also zero, or close to zero, in most pass-through cases (see Table 4). Neither the full pass-through case, nor the two intermediate pass-through cases, indicates that the real exchange rate should be incorporated into the policy maker's objective function. It is only for the case with the smallest pass-through that some real exchange rate stabilization is welfare improving. This is somewhat surprising, given that the expenditure switching effects (or the relative price distortions) caused by exchange rate movements ought to be small in this case, at least in the face of risk premium shocks. However, note that the volatility of the endogenously determined exchange rate increases as pass-through decreases (see Table A2 in the Appendix). When pass-through is low, a country-specific shock can not be absorbed by the (exogenously) sticky import price, and the required relative price adjustments are therefore generated through larger movements in the endogenously determined exchange rate. This implies that the unconditional variance of the relative price of imports is, in fact, larger when pass-through is low than when pass-through is complete, which induces a policy response to the real exchange rate in the former case.[26]

[24] Recall that the coefficients placed on each objective are *relative* weights, implying that it is difficult to compare the size of specific policy weights between the benchmark case and cases incorporating additional variables.

[25] The results do not seem to be affected by the degree of policy inertia (ν_i). Even without any interest rate smoothing, the optimal exchange rate weights are low in most cases (see Table A3 in the Appendix).

[26] Note that Devereux and Engel (2000) show that with zero pass-through, the optimal policy objective in their model is independent of the exchange rate volatility. When pass-through is zero, the optimal policy is therefore consistent *(footnote continues on the next page)*

Table 4: Social loss (L^S) and optimized exchange rate policy parameters

Pass-through	equation (10a)			equation (10b)		equation (10c)		equation (10d)	
	$\hat{\lambda}^{CB}$	$\hat{v}_i$	L^S	$\hat{\mu}_{(p^*+e-p)}$	Rel. L^S	$\hat{\mu}_{\Delta e}$	Rel. L^S	$\hat{\mu}_e$	Rel. L^S
0.99	0.1	1.0	17.461	0	1.0	0	1.0	0	1.0
0.66	0.1	0.9	17.176	0	1.0	0	1.0	0	1.0
0.33	0.1	0.7	16.683	0	1.0	0	1.0	0	1.0
0.09	0.1	0.4	15.082	0.1	0.983	0	1.0	0	1.0

Note: The output and interest rate stabilization is separately optimized to reflect the marginal advantage of incorporating an exchange rate term. The optimized exchange rate weights are established by a grid search, with step 0.1, over the values -1 to 3.

4. Robustness

4.1. Alternative parameterizations

Even if the stabilization bias has been alleviated, can an exchange rate objective play a welfare improving role if the economy becomes more open, where openness is measured in terms of import and export shares? A more open economy implies that the exposure to foreign disturbances increases, and that the impact on both demand and supply relations is greater, thereby requiring larger interest rate responses. However, although the real exchange rate affects inflation and output more significantly in this case, the exchange rate per se is less influenced. Since the domestic sector is already affected, there is less need for exchange rate induced relative price adjustments, which lower the exchange rate volatility (not shown). Therefore, neither nominal, nor real, exchange rate stabilization yields any substantial welfare enhancement, compared to delegating a policy function with optimal output and interest rate stabilization (see Table A4a in the Appendix). Consequently, the results appear to be qualitatively robust to changing the degree of openness.

The importance of the exchange rate channel also increases if the risk premium becomes more persistent, or if the relative variances of risk premium disturbances and other foreign shocks increase. Persistent shocks warrant more prolonged interest rate responses, which is why the optimal interest rate inertia is slightly larger in this case (see Table A4b in the Appendix). However, there are still no welfare improvements from explicitly stabilizing the exchange rate,

with fixed exchange rates in response to real shocks. In the full pass-through case, the exchange rate is, in contrast, employed for stabilizing consumption, although there is now a welfare cost of exchange rate volatility. However, this volatility is traded off for the benefits of exchange rate adjustments in reducing consumption variance.

as long as the delegated policy is optimized with respect to output and interest rate stabilization. Larger variances of the foreign disturbances, in turn, imply that the optimal policy must be somewhat more aggressive to offset these shocks. Since this is reflected by a lower degree of interest rate smoothing, welfare is not improved by adding an explicit exchange rate term to the policy maker's other (optimized) objectives (see Table A4c in the Appendix).

Consequently, the results are not qualitatively sensitive to the particular parameterization chosen here. The results are neither contingent upon the fully forward-looking model specification. Introducing some (ad hoc) persistence in the supply and demand relations (i.e., some backward-looking elements) does not alter the main results.[27]

4.2. Other social preferences

As mentioned in Section 2.2., there remain some uncertainty about what the true social objectives are in the open economy. Are the results in this paper sensitive to the particular social loss function used?

The results are qualitatively robust to evaluating the delegated policies from a social loss function that values stable domestic inflation (suggested by, e.g., Benigno and Benigno (2000) in a full pass-through model). The alternative social loss function is, thus, of the form $L^D = \text{var}(\pi^D) + \lambda^S \text{var}(y)$. Note that even if domestic inflation is an argument in the social loss function, it is welfare improving for the policy maker to target CPI inflation (cf. Tables A5a and A5b in the Appendix). The reason is that exchange rate fluctuations indirectly influence domestic inflation. Movements in the exchange rate affect the domestic producer's marginal cost through imported intermediates and through relative price changes in aggregate demand. By targeting CPI inflation, the policy maker achieves an implicit response to the exchange rate, which also reduces the domestic inflation variability. Since CPI inflation targeting generates lower exchange rate volatility, which improves the variance trade-off between domestic inflation and output, this is helpful for stabilizing domestic inflation.

Smets and Wouters (2001) find that the social objective under incomplete pass-through, in contrast, is a weighted average of domestic and imported inflation and depends on the degree of price stickiness. The social loss function is $L^{SW} = \gamma_D \text{var}(\pi^D) + (\kappa_M + \kappa_W/(1+\kappa_W)) \text{var}(\pi^M)$,

[27] Results from the model with backward-looking components are available upon request.

in this case. Note that Smets and Wouters' derivation, by construction, does not contain any output term. Given that there is no explicit trade-off between inflation and output stabilization, an additional exchange rate objective does not improve welfare if the policy maker follows this social objective and separately targets imported inflation (see Table A6 in the Appendix). The results are, thus, not sensitive to what social loss function is used for evaluating the different policies.

5. Conclusions

The optimal discretionary policy objective is analyzed within a forward-looking aggregate supply-aggregate demand model, adjusted for incomplete exchange rate pass-through. The monetary policy trade-off between inflation and output variability is eased as the degree of pass-through decreases, since the exchange rate channel then transmits monetary policy, and foreign disturbances, to a smaller extent. This implies that also the delegated policy objective function is dependent on the degree of pass-through in the economy.

The results show that welfare improvements of explicit exchange rate stabilization depend on the importance of the discretionary stabilization bias. If the policy maker pursues the social objectives, she can improve welfare by making the monetary policy more inertial, for example through inclusion of an additional nominal exchange rate level target. In the same way as with a price level target such exchange rate stabilization exploits agents' expectations about future policy, which produces a better trade-off between inflation and output stabilization, reducing the discretionary stabilization bias.

However, the stabilization bias can be alleviated in many different ways and if this bias already is mitigated, for instance because of lower (policy) stabilization of output than the social preferences imply, exchange rate targeting does not reduce social loss. There are in this case, thus, no additional welfare gains of incorporating stabilization of the nominal or the real exchange rate in the policy maker's optimized objective function. Just responding to the informational content of the exchange rate appears to be sufficient for the policy maker's performance in terms of social welfare.

Welfare improving modifications of the central bank objective can only be achieved to the extent the delegated policy makes the inflation-output trade-off more favourable which, in turn, reduces social loss. There are, however, other aspects than exchange rate stabilization that can be altered such that a different objective than that of the society is delegated to the policy maker. The results indicate that some of the stabilization bias that occurs under a discretionary policy can be mitigated through appointing a 'conservative' banker with lower weight on output stabilization or through appointing an interest rate smoothing policy maker ('Woodford banker'). The optimized weight on output stabilization appears, in principle, to be independent of the degree of pass-through. In contrast, the policy weight on the optimized interest rate inertia is increasing in the degree of pass-through. The reason is that incomplete, and gradual, pass-through requires a prolonged interest rate response when, for example, a risk premium disturbance hits the economy. This inherent interest rate persistence consequently implies that less additional interest rate inertia, in the form of an interest rate smoothing objective, is needed when pass-through is incomplete.

Appendix

A.1. The central bank's optimization problem

To formulate the state-space representation of the model, the following identities are used:

(A1) $(p_t^M - p_t^D) = (p_{t-1}^M - p_{t-1}^D) + \pi_t^M - \pi_t^D$,

(A2) $(p_t^* + e_t - p_t^M) = (p_{t-1}^* + e_{t-1} - p_{t-1}^M) + \pi_t^* + \Delta e_t - \pi_t^M$.

This implies that the complete model, i.e. the system of equations (1)-(6), the three shock processes[28], plus (A1)-(A2), can be rewritten in state-space form:

(A3a) $$\tilde{A}_0 \begin{bmatrix} x_{1,t+1} \\ \mathrm{E}_t x_{2,t+1} \end{bmatrix} = \tilde{A} \begin{bmatrix} x_{1,t} \\ x_{2,t} \end{bmatrix} + \tilde{B} i_t + \tilde{\upsilon}_{t+1},$$

$$x_{1,t} = \begin{bmatrix} i_{t-1} & y_t^* & i_t^* & \pi_t^* & \varepsilon_t^\pi & \varepsilon_t^\phi & \varepsilon_t^y & (p_{t-1}^M - p_{t-1}^D) & (p_{t-1}^* + e_{t-1} - p_{t-1}^M) \end{bmatrix}',$$

$$x_{2,t} = \begin{bmatrix} y_t & \pi_t^D & \pi_t^M & \Delta e_t \end{bmatrix}',$$

$$\tilde{\upsilon}_{t+1} = \begin{bmatrix} 0 & u_{t+1}^{y*} & u_{t+1}^{i*} & u_{t+1}^{\pi*} & u_{t+1}^{\pi} & u_{t+1}^{\phi} & u_{t+1}^{y} & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}',$$

where $x_{1,t}$ is a 9×1 vector of predetermined state variables, $x_{2,t}$ is a 4×1 vector of forward-looking variables, and $\tilde{\upsilon}_{t+1}$ is a 13×1 vector of disturbances,

$$\tilde{A}_0 = \begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -b_y^*(1-\rho_i^*) & 1 & -b_\pi^*(1-\rho_i^*) & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & (1-\kappa_M)\beta_i + \beta_q + \beta_e & \kappa_M \beta_i - \beta_q & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{\kappa \alpha_q}{(1-\kappa_M)} & 0 & 0 & \alpha_\pi & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{a_p}{\kappa_M} & 0 & 0 & \alpha_\pi & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{bmatrix},$$

[28] That is, $\varepsilon_{t+1}^\pi = \tau_\pi \varepsilon_t^\pi + u_{t+1}^\pi$, $\varepsilon_{t+1}^y = \tau_y \varepsilon_t^y + u_{t+1}^y$, and $\varepsilon_{t+1}^\phi = \tau_\phi \varepsilon_t^\phi + u_{t+1}^\phi$.

$$
\widetilde{A}=\begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & \rho_y^* & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0 & \rho_i^* & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0 & 0 & \rho_\pi^* & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & \tau_\pi & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & 0 & \tau_\phi & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & 0 & 0 & \tau_y & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & -1 & 1 & 0\\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & -1 & 1\\
0 & -\beta_y^*(1-\rho_y^*) & -\beta_e & \rho_\pi^*\beta_e & 0 & -\beta_e & -1 & 0 & 0 & 1 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & -\frac{a_y}{(1-\kappa_M)} & 1 & 0 & 0\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0\\
0 & 0 & -1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix},
$$

$$
\widetilde{B}=\begin{bmatrix}1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & (\beta_i+\beta_e) & 0 & 0 & 1\end{bmatrix}'.
$$

Note that the predetermined state vector in equation (A3a) is defined from stationary variables only (i.e., excluding the exchange rate *level*), to avoid problems with the numerical algorithm that captures the discretionary solution. However, in order to allow the policy maker to target the exchange rate level (thus making it stationary), the following state-space representation is used in the case with nominal exchange-rate level stabilization (see equation (10d)):

(A3b) $$\widetilde{A}_0\begin{bmatrix}x_{1,t+1}\\ \mathrm{E}_t x_{2,t+1}\end{bmatrix}=\widetilde{A}\begin{bmatrix}x_{1,t}\\ x_{2,t}\end{bmatrix}+\widetilde{B}i_t+\widetilde{\upsilon}_{t+1},$$

$$x_{1,t}=\begin{bmatrix}i_{t-1} & y_t^* & i_t^* & \pi_t^* & \varepsilon_t^\pi & \varepsilon_t^\phi & \varepsilon_t^y & (p_{t-1}^M-p_{t-1}^D) & (p_{t-1}^*+e_{t-1}-p_{t-1}^M) & e_{t-1}\end{bmatrix}',$$

$$x_{2,t}=\begin{bmatrix}y_t & \pi_t^D & \pi_t^M & e_t\end{bmatrix}',$$

$$\widetilde{\upsilon}_{t+1}=\begin{bmatrix}0 & u_{t+1}^{y*} & u_{t+1}^{i*} & u_{t+1}^{\pi*} & u_{t+1}^{\pi} & u_{t+1}^{\phi} & u_{t+1}^{y} & 0 & 0 & 0 & 0 & 0 & 0 & 0\end{bmatrix}',$$

$$
\widetilde{A}_0=\begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & -b_y^*(1-\rho_i^*) & 1 & -b_\pi^*(1-\rho_i^*) & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & (1-\kappa_M)\beta_i+\beta_q+\beta_e & \kappa_M\beta_i-\beta_q & 0\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{\kappa\alpha_q}{(1-\kappa_M)} & 0 & 0 & 0 & \alpha_\pi & 0 & 0\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{a_p}{\kappa_M} & 0 & 0 & 0 & \alpha_\pi & 0\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{bmatrix},
$$

$$\widetilde{A} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \rho_y^* & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \rho_i^* & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \rho_\pi^* & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \tau_\pi & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \tau_\phi & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \tau_y & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & -1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & -1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & -\beta_y^*(1-\rho_y^*) & -\beta_e & \rho_\pi^*\beta_e & 0 & -\beta_e & -1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & -\frac{a_y}{(1-\kappa_M)} & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & -1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix},$$

$$\widetilde{B} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & (\beta_i + \beta_e) & 0 & 0 & 1 \end{bmatrix}'.$$

The policy maker's control problem is a standard stochastic linear-quadratic problem:

(A4)
$$J(x_t) = \min_{i_t}\left\{ x_t'\widetilde{Q}x_t + \beta \mathrm{E}_t J(x_{t+1}) \right\} = \min_{i_t}\left\{ \begin{bmatrix} x_t' & i_t' \end{bmatrix} \begin{bmatrix} Q & U \\ U' & R \end{bmatrix} \begin{bmatrix} x_t \\ i_t \end{bmatrix} + \beta \mathrm{E}_t J(x_{t+1}) \right\} =$$
$$= \min_{i_t} \left\{ x_t'Qx_t + 2x_t'Ui_t + i_t'Ri_t \right\} + \beta \mathrm{E}_t J(x_{t+1}),$$

where Q, U and R are matrices mapping the goal variables (i.e., π_t, y_t, $(i_t - i_{t-1})$, and Δe_t, ($p_t^* + e_t - p_t$), or e_t) to the state variables. In the discretionary case, the value function will be quadratic in the predetermined state variables, $J(x_t) = x_{1,t}V_t x_{1,t} + \omega_t$, and the forward-looking variables will be a linear function of the predetermined variables, $x_{2,t} = H^d x_{1,t}$ (see, e.g., Söderlind (1999)). V is a matrix and ω is a scalar, both to be determined by iterating on the value function. The first order condition of this problem relates the interest rate to the predetermined variables, $i_t = F^d x_{1,t}$. This also implies that the predetermined variables can be written as, $x_{1,t+1} = M^d x_{1,t} + \upsilon_{t+1}$, where M^d is a matrix depending on F^d, H^d and the structural parameters in the state-space representation. The dynamics of the system under discretion is thus the following:

(A5a) $x_{1,t+1} = M^d x_{1,t} + \upsilon_{t+1}$, (A5b) $x_{2,t} = H^d x_{1,t}$,

(A5c) $i_t = F^d x_{1,t}$.

This system has a stable solution if the number of stable eigenvalues in M^d equals the number of predetermined variables. The numerical algorithm then captures the solution, that is, unravels the coefficients in the reaction function, F^d, and in H^d (see Adolfson (2001) for more details).

A.2. Variance-covariance matrices

The unconditional variance-covariance matrix of the disturbance vector corresponding to the state-space representation in (A3a) is given by $\Sigma_\upsilon = \begin{bmatrix}\Sigma_{\upsilon 1} & 0_{9\times 4}\end{bmatrix}$, where $\Sigma_{\upsilon 1}$ is defined as

$$\Sigma_{\upsilon 1} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \sigma_{y*}^2 & (1-\rho_i^*)b_y^*\sigma_{y*}^2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & (1-\rho_i^*)b_y^*\sigma_{y*}^2 & \sigma_{i*}^2 + (1-\rho_i^*)^2(b_\pi^{*2}\sigma_{\pi*}^2 + b_y^{*2}\sigma_{y*}^2) & (1-\rho_i^*)b_\pi^*\sigma_{\pi*}^2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & (1-\rho_i^*)b_\pi^*\sigma_{\pi*}^2 & \sigma_{\pi*}^2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \sigma_\pi^2 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \sigma_\phi^2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \sigma_y^2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}.$$

In the case with nominal exchange-rate level stabilization the variance-covariance matrix corresponding to the state-space form in equation (A3b) is

$$\Sigma_\upsilon = \begin{bmatrix} \Sigma_{\upsilon 1} & 0_{9\times 5} \\ 0_{1\times 9} & 0_{1\times 5} \end{bmatrix}.$$

Given that the dynamics of the system can be written as (A5), the asymptotic unconditional variance-covariance matrix of the predetermined variables is given by:

(A6) $\Sigma_{x1} = M^d \Sigma_{x1} M^{d'} + \Sigma_{\upsilon 1}$,

(A7) $\text{vec}(\Sigma_{x1}) = \left[I_{n1^2} - (M^d \otimes M^d)\right]^{-1} \text{vec}(\Sigma_{\upsilon 1})$, using $\text{vec}(A+B)=\text{vec}(A)+\text{vec}(B)$, and $\text{vec}(ABC)=(C'\otimes A)\text{vec}(B)$ (see Rudebusch and Svensson (1999)). The variables of interest can be written as a function of the predetermined variables,

$$\begin{aligned} z_{t+1} &= T_x x_{t+1} + T_i i_{t+1} \\ &= \begin{bmatrix} T_{x1} & T_{x2} \end{bmatrix} \begin{bmatrix} x_{1t+1} \\ x_{2t+1} \end{bmatrix} + T_i i_{t+1} \\ &= \begin{bmatrix} T_{x1} & T_{x2} \end{bmatrix} \begin{bmatrix} x_{1t+1} \\ H^d x_{1t+1} \end{bmatrix} - T_i F^d x_{1t+1} \\ &= T^d x_{1t+1} \ , \end{aligned}$$

implying that the variance-covariance matrix of the interest variables is

(A8) $$\Sigma_z = T^d \, \Sigma_{x1} \, T^{d'} .$$

Table A1a: Reaction function, coefficients in $-F^d$ ($i_t = -F^d x_{1,t}$), benchmark case

Pass-through	Equation (10a), $\lambda^{CB} = 0.5$, $\nu_i = 0$								
	i_{t-1}	y_t^*	i_t^*	π_t^*	ε_t^π	ε_t^ϕ	ε_t^y	$(p_{t-1}^M - p_{t-1}^D)$	$(p_{t-1}^* + e_{t-1} - p_{t-1}^M)$
0.99	0	0.033	0.932	-0.679	3.596	0.932	0.195	-0.0248	0
0.66	0	0.023	0.868	-0.686	3.627	0.868	0.377	0.072	0
0.33	0	0.018	0.83	-0.688	3.697	0.83	0.487	0.128	0
0.09	0	0.021	0.824	-0.678	3.859	0.824	0.503	0.132	0

Table A1b: Reaction function, coefficients in $-F^d$ ($i_t = -F^d x_{1,t}$), with interest rate smoothing

Pass-through	Equation (10a), $\lambda^{CB} = 0.5$, $\nu_i = 0.1$								
	i_{t-1}	y_t^*	i_t^*	π_t^*	ε_t^π	ε_t^ϕ	ε_t^y	$(p_{t-1}^M - p_{t-1}^D)$	$(p_{t-1}^* + e_{t-1} - p_{t-1}^M)$
0.99	0.015	0.034	0.913	-0.66	3.523	0.913	0.192	-0.024	0
0.66	0.025	0.025	0.842	-0.655	3.503	0.842	0.36	0.067	0
0.33	0.033	0.022	0.797	-0.647	3.529	0.797	0.46	0.12	0
0.09	0.037	0.024	0.786	-0.634	3.66	0.786	0.477	0.125	0

Table A1c: Reaction function, coefficients in $-F^d$ ($i_t = -F^d x_{1,t}$), with optimized policy weights

Pass-through	Equation (10a), optimized policy weights								
	i_{t-1}	y_t^*	i_t^*	π_t^*	ε_t^π	ε_t^ϕ	ε_t^y	$(p_{t-1}^M - p_{t-1}^D)$	$(p_{t-1}^* + e_{t-1} - p_{t-1}^M)$
0.99	0.18	0.05	0.734	-0.448	2.005	0.734	0.076	-0.054	0
0.66	0.237	0.048	0.631	-0.389	1.892	0.631	0.17	0.005	0
0.33	0.264	0.044	0.573	-0.367	1.898	0.573	0.249	0.051	0
0.09	0.239	0.039	0.579	-0.399	2.175	0.579	0.327	0.085	0

Note: The optimized policy weights are λ^{CB} = {0.1, 0.1, 0.1, 0.1}, ν_i = {1.0, 0.9, 0.7, 0.4} for pass-through = {0.99, 0.66, 0.33, 0.09}, respectively.

Table A2a: Unconditional variance and social loss (L^S); non-optimized policy weights

Pass-through	Equation (10a), $\lambda^{CB} = 0.5$, $\nu_i = 0$							
	L^S	var (π)	var (y)	var (p^M-p^D)	var (Δe)	var (i)	var (π^D)	var (π^M)
0.99	22.368	21.891	0.954	4.501	23.196	16.470	21.892	23.053
0.66	22.214	21.806	0.815	4.010	24.136	16.41	21.995	22.104
0.33	21.648	21.318	0.660	4.198	25.403	16.303	21.889	20.48
0.09	19.156	18.94	0.433	14.634	27.174	16.035	20.593	15.957

Table A2b: Unconditional variance and social loss (L^S); optimized policy weights

Pass-through	Equation (10a), $\lambda^{CB} = 0.1$, $\nu_i = \{1.0, 0.9, 0.7, 0.4\}$							
	L^S	var (π)	var (y)	var (p^M-p^D)	var (Δe)	var (i)	var (π^D)	var (π^M)
0.99	17.461	11.468	11.987	5.36	12.409	8.070	11.667	12.254
0.66	17.176	11.478	11.395	4.953	13.349	7.699	11.825	11.44
0.33	16.683	11.556	10.253	5.226	14.738	7.643	12.151	10.707
0.09	15.082	11.455	7.254	12.675	17.583	8.254	12.718	9.302

Table A3: Social loss (L^S) and optimized exchange rate parameters; without interest rate smoothing

Pass-through	equation (10a)			equation (10b)		equation (10c)		equation (10d)	
	$\hat{\lambda}^{CB}$	$\hat{\nu}_i$	L^S	$\hat{\mu}_{(p^*+e-p)}$	Rel. L^S	$\hat{\mu}_{\Delta e}$	Rel. L^S	$\hat{\mu}_e$	Rel. L^S
0.99	0.1	0	19.173	0.1	0.999	-0.1	0.999	0	1.0
0.66	0.1	0	18.818	0	1.0	0	1.0	0	1.0
0.33	0.1	0	18.22	0.1	0.996	0	1.0	0	1.0
0.09	0.1	0	16.266	0.1	0.949	0	1.0	0	1.0

Table A4a: Social loss (L^S) and optimized exchange rate parameters; increased openness

Pass-through	equation (10a)			equation (10b)		equation (10c)		equation (10d)	
	$\hat{\lambda}^{CB}$	$\hat{\nu}_i$	L^S	$\hat{\mu}_{(p^*+e-p)}$	Rel. L^S	$\hat{\mu}_{\Delta e}$	Rel. L^S	$\hat{\mu}_e$	Rel. L^S
0.99	0.1	1.3	17.477	0	1.0	0	1.0	0	1.0
0.66	0.1	0.8	16.992	0	1.0	0	1.0	0	1.0
0.33	0.1	0.5	16.007	0.2	0.995	0	1.0	0	1.0
0.09	0.1	0.3	12.70	0.1	0.953	0	1.0	0	1.0

Note: Twice the openness compared to the benchmark parameterization. That is, the export and import shares are both 60% of aggregate demand and consumption, respectively, and the share of imported intermediates in production is 20%.

Table A4b: Social loss (L^S) and optimized exchange rate parameters; more persistent risk premium

Pass-through	equation (10a)			equation (10b)		equation (10c)		equation (10d)	
	$\hat{\lambda}^{CB}$	$\hat{\nu}_i$	L^S	$\hat{\mu}_{(p^*+e-p)}$	Rel. L^S	$\hat{\mu}_{\Delta e}$	Rel. L^S	$\hat{\mu}_e$	Rel. L^S
0.99	0.1	1.2	17.828	0.1	0.994	0	1.0	0	1.0
0.66	0.1	1.1	17.40	0	1.0	0	1.0	0	1.0
0.33	0.1	1.0	16.832	0	1.0	0	1.0	0	1.0
0.09	0.1	0.5	15.199	0	1.0	0	1.0	0	1.0

Note: The risk premium persistence is τ_{ϕ} = 0.95.

Table A4c: Social loss (L^S) and optimized exchange rate parameters; larger foreign disturbances

Pass-through	equation (10a)			equation (10b)		equation (10c)		equation (10d)	
	$\hat{\lambda}^{CB}$	$\hat{\nu}_i$	L^S	$\hat{\mu}_{(p^*+e-p)}$	Rel. L^S	$\hat{\mu}_{\Delta e}$	Rel. L^S	$\hat{\mu}_e$	Rel. L^S
0.99	0.1	0.7	17.78	0.1	0.999	0	1.0	0	1.0
0.66	0.1	0.6	17.476	0	1.0	0	1.0	0	1.0
0.33	0.1	0.5	16.397	0	1.0	0	1.0	0	1.0
0.09	0.1	0.3	15.246	0.1	0.977	0	1.0	0	1.0

Note: Twice the variance of the foreign disturbance terms compared to the benchmark parameterization (i.e., σ_{ϕ}^2 = 1.6, $\sigma_{\pi*}^2$ = 0.1, σ_{y*}^2 = 0.2).

Table A5a: Social loss ($L^D = \text{var}(\pi^D) + \lambda^S \text{var}(y)$), and optimized policy parameters, delegating CPI inflation targeting

Pass-through	Policy maker targets CPI inflation (π)								
	equation (10a)			equation (10b)		equation (10c)		equation (10d)	
	$\hat{\lambda}^{CB}$	$\hat{v}_i$	L^D	$\hat{\mu}_{(p^*+e-p)}$	Rel. L^D	$\hat{\mu}_{\Delta e}$	Rel. L^D	$\hat{\mu}_e$	Rel. L^D
0.99	0.1	1.2	17.643	0	1.0	0	1.0	0	1.0
0.66	0.1	1.0	17.522	0	1.0	0	1.0	0	1.0
0.33	0.1	0.7	17.277	0	1.0	0	1.0	0	1.0
0.09	0.1	0.4	16.345	0.1	0.982	0	1.0	0	1.0

Table A5b: Social loss ($L^D = \text{var}(\pi^D) + \lambda^S \text{var}(y)$), and optimized policy parameters, delegating domestic inflation targeting

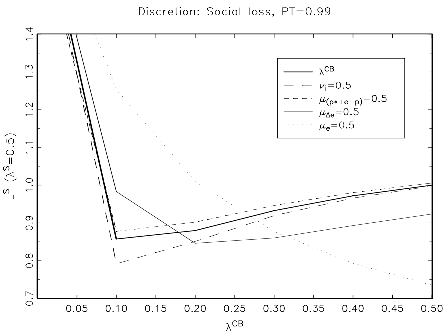
Pass-through	Policy maker targets domestic inflation (π^D)								
	$\hat{\lambda}^{CB}$	$\hat{v}_i$	L^D	$\hat{\mu}_{(p^*+e-p)}$	Rel. L^D	$\hat{\mu}_{\Delta e}$	Rel. L^D	$\hat{\mu}_e$	Rel. L^D
0.99	0.1	0.7	17.942	0	1.0	0.1	0.991	0	1.0
0.66	0.1	0.7	17.735	0	1.0	0.1	0.997	0	1.0
0.33	0.1	0.7	17.468	0	1.0	0	1.0	0	1.0
0.09	0.1	0.5	16.581	0.1	0.980	0	1.0	0	1.0

Table A6: Social loss ($L^{SW} = \gamma_D \text{ var}(\pi^D) + (\kappa_M + \kappa_W/(1+\kappa_W)) \text{ var}(\pi^M)$), and optimized exchange rate policy parameters

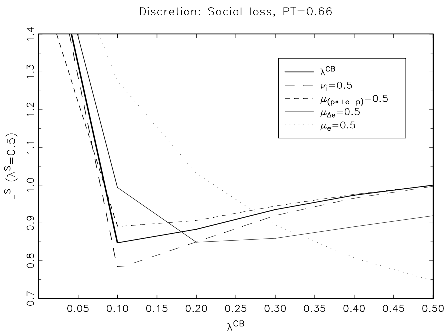
Pass-through	Benchmark policy L^{SW}	Delegating the social objective (L^{SW}) and stabilization of:					
		real exchange rate		nom. x-rate difference		nom. exchange rate level	
		$\hat{\mu}_{(p^*+e-p)}$	Rel. L^{SW}	$\hat{\mu}_{\Delta e}$	Rel. L^{SW}	$\hat{\mu}_e$	Rel. L^{SW}
0.99	0.0302	0	1.0	0	1.0	0	1.0
0.66	0.769	0	1.0	0	1.0	0	1.0
0.33	1.396	0	1.0	0	1.0	0	1.0
0.09	1.734	0	1.0	0	1.0	0	1.0

Figure 1: Social loss under different monetary policies (equations (10a) – (10d)), varying the degree of output stabilization

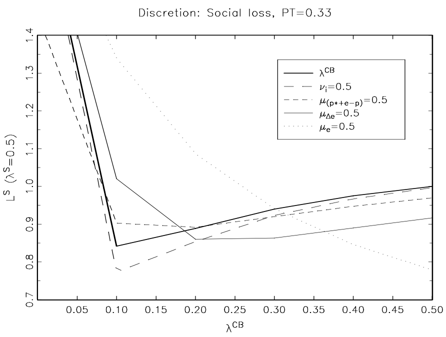
a) Pass-through = 0.99



b) Pass-through = 0.66



c) Pass-through = 0.33



c) Pass-through = 0.09

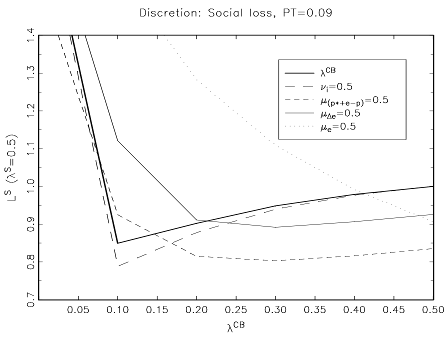
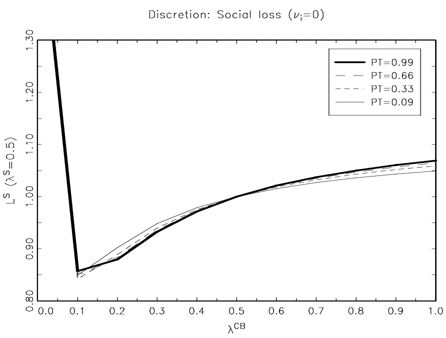
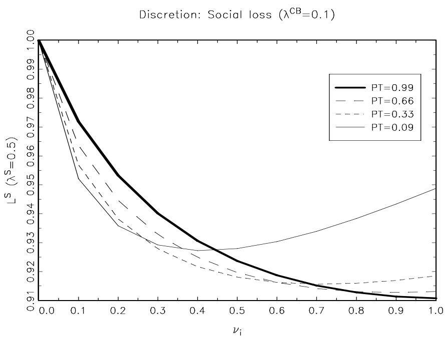


Figure 2: Social loss, varying the different policy weights

a) Output stabilization, λ^{CB}



b) Interest rate smoothing, ν_i



Note: Relative loss compared to the *benchmark* policy that delegates the social preferences

Note: Relative loss compared to an objective *without* interest rate smoothing

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