Optimal Monetary Policy Delegation under Incomplete Exchange Rate Pass-Through

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Abstract

The central bank's optimal objective function is analyzed in a small open economy model allowing for incomplete exchange rate pass-through. The results indicate that social welfare can only be marginally improved by including an explicit exchange-rate term in the delegated objective function, irrespective of the degree of pass-through. An implicit response to the exchange rate, through Consumer Price Index (CPI) inflation targeting is, however, beneficial. Welfare can, moreover, be enhanced by appointing a central banker with a greater preference for interest rate smoothing than that of the society, as a result of surpassing some of the stabilization bias arising under a discretionary policy. Consequently, there are welfare gains from monetary policy inertia. 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

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1. Introduction

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 thus faces a trade-off between inflation and output 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. The exchange rate works as an additional transmission mechanism of monetary policy, besides the traditional interest rate channel. Consider, for example, a positive demand shock. In a closed economy, this demand shock can be completely countered, without affecting inflation, by simply raising the interest rate.[1] In an open economy framework, the increase in the interest rate increase also affects the exchange rate, which appreciates and, in turn, feeds into both inflation and output. This implies that the central bank is forced to trade off reduced output variability for inflation variability (see e.g. Walsh (1999)).

Movements in the terms of trade can consequently affect the trade-off between monetary policy objectives. Accordingly, because of the exposure to exchange rate fluctuations, there have been some suggestions that the design of the optimal policy differs between closed and open economies (see e.g. Sutherland (2000)).[2,3] Is it possible to ease the goal conflict, and diminish the trade-off, by assigning a different objective function to the open economy-policy maker? Should the policy maker use a different inflation measure, or perhaps explicitly respond to exchange rate fluctuations? By strictly targeting consumer price (CPI) inflation, the policy maker may induce large interest rate variability, since such a policy aims at neutralizing the price effect of every exchange rate fluctuation. On the other hand, by only focusing on domestic

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[1] Note that this is contingent upon a central bank loss function that does not penalize interest rate changes, as well as on a forward-looking model without transmission lags of monetary policy.
[2] On the other hand, Clarida et al. (2001) advocate that the closed and open economy policy objectives are isomorphic as long as the terms of trade are proportional to the output gap.
[3] For a related discussion about relative price changes and the appropriate goal variables for the central bank in a closed economy, see Aoki (2001). Aoki suggests that his results can be applied to a small open economy, where accordingly domestic inflation should be completely stabilized. However, Aoki assumes import prices to be fully flexible, and that the law of one price holds. On the contrary, when the degree of price stickiness differs across sectors, Benigno (2001) finds that the optimal monetary policy in a currency area implies that a larger policy weight should be given to the inflation rate with a higher degree of nominal rigidity.

conditions, the policy maker can create excessive exchange rate volatility, which may be a sub-optimal outcome (Svensson (2000)).[4]

However, because of deliberate price discrimination or nominal rigidities, an exchange rate movement need not necessarily generate a one-to-one change in import prices (i.e. there may be an incomplete exchange rate pass-through), which is why the impact on the economy might be quite limited. If the degree of pass-through is small, the effect of exchange rate changes is minor and there is less need for the policy maker to adjust the interest rate to such disturbances. In the face of, for example, demand shocks and exchange rate disturbances, this implies that the conflict between inflation and output objectives is reduced, which shifts the policy frontier towards the closed economy outcome (see Adolfson (2001)). Consequently, also the (optimal) open-economy policy objective may be dependent on the degree of pass-through.

The purpose of this paper is to analyze the optimal objective, in terms of social welfare, that should be pursued by a discretionary policy maker of an open economy with incomplete exchange rate pass-through. What are the effects of exchange rate fluctuations on the optimized loss function, and is the optimal policy objective contingent upon the degree of pass-through? In particular, is it relevant to augment the delegated objective function with an exchange-rate stabilization term that may improve the policy maker's control over the inflation-output variability trade-off? This paper also deals with other ways of correctly specifying the policy objective to mitigate the 'stabilization bias', or less inertial policy responses, that arises under a discretionary policy (see e.g. Woodford (1999)). Are there any gains from assigning a different objective to the policy maker as compared to society, for example in terms of the degree of interest rate smoothing? Moreover, how does incomplete pass-through affect this stabilization bias?

The analysis is performed within an aggregate supply–aggregate demand model adjusted for incomplete exchange rate pass-through. The results indicate that the social welfare improvements of including an exchange-rate term among the policy objectives are small. Consequently, a direct, and explicit, stabilization of nominal or real exchange rates appears to be redundant, both when pass-through is limited and when it is complete. However, an indirect response to the exchange rate, through targeting CPI inflation rather than domestic inflation, is

[4] Nevertheless, rather than changing the inflation measure to target, high interest rate and exchange rate volatility might be avoided if the policy maker is more concerned about the real effects of the policy (i.e. flexible inflation targeting with some concern for output stabilization), which makes the policy more gradual.

welfare enhancing. 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 a greater preference for interest rate smoothing than the social objective, as proposed by Woodford (1999). However, 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, and the central bank objectives, are outlined and parameterized. Section 3 contains the optimized central bank objectives, 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.[5]

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. Aggregate inflation in the domestic economy (π_t), i.e. consumer price index (CPI) inflation, is composed by inflation of domestically produced goods ($\pi_t^D = p_t^D - p_{t-1}^D$) and import goods inflation denoted in the domestic currency ($\pi_t^M = p_t^M - p_{t-1}^M$), according to the following (see equations (A1) and (A2) in the Appendix):[6]

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

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^D is the price of domestically produced goods, p_t^M is the price of import goods denoted in the domestic currency, p_t^* is the foreign currency price of import goods, and e_t is the nominal exchange rate (domestic currency per unit of foreign currency). CPI inflation is a function of expected future inflation, aggregate output (or demand), the relative price of imports (which can be interpreted as a real exchange rate[7]), and the deviation between the optimal price of import goods in the absence of any nominal rigidities and the price actually charged (i.e., $p_t^* + e_t - p_t^M$).[8] This wedge term is what makes the pass-through adjusted supply relation different from a standard Phillips curve with complete exchange rate pass-through. The price stickiness implies that the domestic currency price can not be fully adjusted to alterations in, for example, the exchange rate. 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.[9] The

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[5] For a more thorough discussion of the model, see Adolfson (2001).
[6] 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*.
[7] This is, in effect, the inverse of the terms of trade, and only one particular definition of the real exchange rate.
[8] 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.
[9] In the long run, the producer expects to charge the optimal flexible price such that $(p^M - e - p^*) \sim I(0)$.

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 changes in the price, implying that the producer alters the price charged in this period in the direction of the expected future optimal price.[10] 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.

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

$$
\begin{aligned}
(2) \qquad y_t = {} & \mathrm{E}_t y_{t+1} - \beta_q \mathrm{E}_t(\pi_{t+1}^M - \pi_{t+1}^D) - \beta_i(i_t - \mathrm{E}_t\pi_{t+1}) + \beta_e(\mathrm{E}_t\pi_{t+1}^D - (\mathrm{E}_t e_{t+1} - e_t) - \mathrm{E}_t\pi_{t+1}^*) \\
& - \beta_y^*(\mathrm{E}_t y_{t+1}^* - y_t^*) + \varepsilon_t^y ,
\end{aligned}
$$

where i_t is the domestic interest rate, π_t^* is foreign inflation, and y_t^* is foreign output. ε_t^y is a demand shock (e.g. to preferences) that follows, $\varepsilon_{t+1}^y = \tau_y\varepsilon_t^y + u_{t+1}^y$, where u_{t+1}^y is an iid disturbance with zero mean and variance σ_y^2. Domestic output is a function of expected future output, the change in the expected future relative price of imports, $\mathrm{E}_t\Delta(p_{t+1}^M - p_{t+1}^D)$, the real interest rate, the change in the expected future relative price of exports, $\mathrm{E}_t\Delta(p_{t+1}^D - e_{t+1} - p_{t+1}^*)$, and the change in expected future foreign output.[11] 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

[10] 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).

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

$$
y_t = \beta_q(p_t^M - p_t^D) - \beta_i \sum_{s=0}^{\infty} \mathrm{E}_t(i_{t+s} - \pi_{t+s+1}) - \beta_e(p_t^D - e_t - p_t^*) + \beta_y^* y_t^* + \sum_{s=0}^{\infty} \mathrm{E}_t\varepsilon_{t+s}^y ,
$$

using the appropriate transversality conditions.

(i.e. $p_t^M \neq p_t^* + e_t$), which makes the relative price of imports ($p_t^M - p_t^D$) and the (inverse of the) relative price of exports ($p_t^D - e_t - p_t^*$) diverge. The limited pass-through is thus implicitly incorporated, also in the aggregate demand relation, through the import price (p_t^M).

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

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

where i_t is the domestic interest rate, i_t^* is the foreign interest rate, and ε_t^ϕ is a risk premium following, $\varepsilon_{t+1}^\phi = \tau_\phi \varepsilon_t^\phi + u_{t+1}^\phi$, where u_{t+1}^ϕ is an iid disturbance with zero mean and variance σ_ϕ^2. 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 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.

The foreign economy consists of exogenous AR(1) processes for inflation and output, and a simple Taylor rule with some persistence added, determining 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, the following social loss function is assumed to prevail in the economy:

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

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.[12]

That society cares about inflation stems from the fact that the nominal rigidities in the model cause a relative price dispersion between goods. Such price dispersion is detrimental for social welfare, since it induces differences in output across otherwise identical producers.[13] Woodford (2001) suggests that the *general* price level should be stabilized in economies with nominal rigidities, in order to reduce this price dispersion between flexible and fixed price producers. Stabilization of (CPI) inflation can reduce the 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.[14] On the other hand, CPI inflation targeting might better mitigate the two distortions that arise in the model used here, namely that domestic *and* import prices are both sticky (given incomplete exchange rate pass-through).[15] When the open economy-policy maker seeks to stabilize the economy around the flexible price outcome, the consequences of high interest rate variability must be considered, since this induces exchange rate fluctuations and terms of trade distortions.[16]

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[12] 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).

[13] Note, however, that foreign and domestic producers are not identical in this model. For instance, they use somewhat different inputs in production.

[14] 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).

[15] 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.

[16] Moreover, the consumption bundle, consisting of domestic and foreign goods, is priced in terms of aggregate prices, which is why agents intuitively care about CPI inflation.

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)):

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

The monetary policy, in turn, 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:

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

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 occuring under a discretionary policy, the objective that is 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

Two issues are studied in this paper; *i*) how are the prior findings of (discretionary) optimal policy inertia affected by open economy aspects and incomplete exchange rate pass-through? *ii*) Is there a role for an explicit exchange rate objective in the policy maker's loss function? The stabilization bias may be reduced, and social welfare improved, by delegating a policy objective incorporating, for example, some interest rate smoothing, low output stabilization, or the stabilization of nominal or real exchange rates.

Consider, for example, that the policy maker (in contrast to the assumption made above) can commit to repeatedly raising interest rates. In this case, a smaller interest rate adjustment renders the same effect as a discretionary policy. The reason is that expectations about the future are affected by the current monetary policy choice under commitment. Since agents are forward-looking, the policy maker can, in this case, exploit the private agents' expectations about inflation and output, when implementing the monetary policy, although there is no inflation bias in this model. 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 could then diminish the interest rate variance, reduce the loss and thereby make the trade-off between inflation and output variability more efficient.[17] Given that the commitment response is more inertial than the discretionary policy, the latter might possibly be improved upon by making it more persistent. Accordingly, Woodford (1999) 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.[18] This results from exploiting the agents' forward-looking behaviour, and the role of expectations. Woodford argues that interest rate persistence implies that expectations about future short interest rate changes yield a greater effect on *long* rates, and thereby also have a more substantial impact on aggregate demand.[19] Consequently, the larger weight on interest rate smoothing seems to be a way of simulating a 'commitment environment', which improves social welfare.

Walsh (1999) shows that there are gains from appointing a conservative banker in Rogoff's (1985) sense (i.e. with a lower degree of output stabilization than society) in an open economy with full pass-through when using a non-inertial rule (i.e. with no interest rate smoothing). As in Woodford's case of interest rate inertia, the reasoning builds on the possibility of exploiting the private agents' expectations. Consider a cost-push shock that raises inflation. If the policy maker is perceived to emphasize inflation objectives, 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. In Rogoff's 'conservative banker' case as well as in Woodford's 'interest rate inertia' case, the policy maker is hence perceived to emphasize inflation objectives, either directly through lower output stabilization or, as in the latter case, indirectly through larger interest rate persistence.

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[17] 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)).

[18] 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.

[19] That future expected interest rates, i.e. the *long* interest rate, are of importance for output can be seen by solving equation (2) forward (see Footnote 11).

The reason why nominal or real exchange rate stabilization might be beneficial for social welfare, or to be more precise, might reduce the discretionary stabilization bias, is the exchange rate's role of transmitting monetary policy. By alleviating fluctuations in, for example, the nominal 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, as mentioned in the Introduction. Since every interest rate adjustment also implies a change in the exchange rate, such an additional exchange rate stabilization-objective could internalize the actual impact caused by 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.[20] However, recall that if the policy maker puts some weight on interest smoothing, the volatility in the nominal exchange rate is probably already kept small. Alternatively, by directly stabilizing the real exchange rate (i.e. either the relative price of imports or the relative consumer price) the central bank might, straight off, achieve a more stable inflation rate. The welfare improvement will, consequently arise from a more efficient stabilization of consumption, which is affected by relative price distortions that might possibly be mitigated by an exchange rate objective. However, note that the exchange-rate augmented policies might, indirectly, reduce the stabilization bias, since they imply a more inertial reaction function.

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

(10c) $$L_t^{TOT} = \pi_t^2 + \lambda^{CB} y_t^2 + \nu_i (i_t - i_{t-1})^2 + \mu_{(p^M - p^D)}(p_t^M - p_t^D)^2 ,$$

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

where λ^{CB} is the relative weight on output stabilization, ν_i is the parameter determining the rate of interest rate smoothing, and $\mu_{\Delta e}$, $\mu_{(p^M - p^D)}$ and $\mu_{(p^* + e - p)}$ are the relative weights on

[20] For a somewhat related discussion of incorporating the exchange rate into simple policy rules, see, e.g., Ball (1999), and Taylor (2001).

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 nominal exchange rate difference, c) the relative import price (i.e. the inverse of the terms of trade), or d) the relative price between foreign and domestic CPIs (hereafter called deviations from Purchasing Power Parity (PPP)).[21]

Given incomplete exchange rate pass-through, the two real exchange rate definitions in equations (10c) and (10d) are not equivalent. The first exchange rate characterization is, in fact, a sub-set of the latter real exchange rate definition. That is, deviations from PPP in equation (10d) consist of two parts; the relative price of imports, as in equation (10c), as well as an explicit term capturing deviations from the Law of One Price.[22]

Policy 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. The inflation of import goods only responds to exchange rate alterations, while the 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.

[21] A possible extension is to include stabilization of the nominal exchange rate *level* in the delegated policy. However, this requires a different state-space representation where the (possibly non-stationary) level of the exchange rate is introduced. When the state vector contains non-stationary variables, it is though unclear whether the numerical algorithm captures the solution to the policy maker's problem. However, a feasible alternative (keeping the state vector stationary) is to expand the state-space representation with several lagged changes in the nominal exchange rate. In the limit, targeting the sum of these terms will approximate exchange rate level targeting. Note, however, that such an approach does not seem to change the main results obtained in the paper.

[22] That is, $(p_t^* + e_t - p_t) = (1-\kappa_M)(p_t^M - p_t^D) + (p_t^* + e_t - p_t^M)$.

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.[23] 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 are chosen along the lines of e.g. Svensson (2000).[24]

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-

[23] 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.

[24] The parameters are based on underlying deep model parameters that imply 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 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. Disturbance variances are more or less taken from Leitemo and Røisland (2000).

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 numerically solved, resulting in an explicit reaction function for the central bank, as well as the 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.

3.1. Optimal interest rate inertia and optimal output stabilization

Figures 1 and 2 illustrate that social loss can be reduced by appointing a discretionary policy maker with a larger degree of interest rate smoothing or with a lower degree of output stabilization, compared to the preferences of the society.[25] This implies that the open-economy policy maker can exploit expectations about inflation and output as in the commitment case, which consequently 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.

Figure 1 shows that the inflation-output trade-off frontier is situated closer to the origin as the policy maker puts more weight on interest rate stabilization (i.e. larger ν_i). In some sense, the policy maker ‘commits’ to continuously fighting inflation, thereby implying that current inflation can be lowered with a smaller output reduction. Further, the optimal rate of interest

[25] 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.

rate smoothing appears to be smaller in the cases with more limited pass-through (cf. Figures 1a and 1d).

Figure 2a shows that appointing a 'Rogoff-conservative' policy maker 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.

Hence, although the policy maker's reaction function is already based on lagged variables, such as the prior relative price, some additional policy inertia seems to be reducing the social loss.[26] The reason for this is that additional policy inertia, for instance generated by an interest rate smoothing objective, implies that the agents' expectations about future policy are affected. This is especially apparent in the model used here, where the persistence comes from exogenous disturbances. 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)).[27]

Table 2 displays the optimal policy weights, and the resulting social loss, when delegating equation (10a) to the policy maker. Neither the reduction in social loss nor the optimal weight on output stabilization are 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 2).[28,29] 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 might be explained by considering an exchange rate disturbance. A low

[26] Details on the reaction function are found in Table A1 in the Appendix.
[27] Note that even if the demand and supply relations were more backward-looking, changes in the policy rule would alter the agents' expectations. However, some forward-looking components are necessary for inertial policy-making to be optimal.
[28] Comparing the absolute loss *level* across different pass-through cases is of limited interest, since these cases represent different structural economies.
[29] The optimal interest rate inertia is also increasing in the degree of pass-through for λ^{CB} = 0.5, when narrowing the grid (not shown).

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).

Table 2: Social loss (L^S) and optimized policy parameters ($\hat{\lambda}^{CB}$, $\hat{v}_i$), equation (10a)

	Benchmark	Optimizing the policy weights concerning:						
	$v_i = 0$	interest rate		output		output and interest rate jointly		
	$\lambda^{CB} = 0.5$	$\lambda^{CB} = 0.5$		$v_i = 0$				
Pass-through	$L^{CB} = L^S$	$\hat{v}_i$	Rel. L^S	$\hat{\lambda}^{CB}$	Rel. L^S	$\hat{\lambda}^{CB}$	$\hat{v}_i$	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

Note: The optimized policy weights are established by a grid search, with step 0.1, over the values 0-1.

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 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 (v_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 v_i) as in the full pass-through case.

The gains from appointing a 'Rogoff banker' appears to be larger than the gains from optimizing the degree of interest rate smoothing, i.e. appointing a 'Woodford banker' (see Table 2). Although the driving mechanism of both welfare improvements works through the expectation channel, the direct emphasis on inflation objectives (i.e. lower λ^{CB}) appears to have a greater influence on agents' expectations than the interest rate smoothing objective. The amount of optimal inertia, or persistence in the policy responses, is though dependent 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 of optimizing the degree of interest rate smoothing becomes larger, the lower is the degree of output stabilization (λ^{CB}).

3.2. Optimal exchange rate stabilization

Now, consider the question of whether the exchange rate should be incorporated in the policy objective in order to enhance social welfare. Could some form of exchange rate stabilization capture the same type of favourable policy inertia, as induced by an interest rate smoothing objective, and reduce the discretionary stabilization bias? Figures 3a-3c illustrate the social loss under the three exchange-rate augmented loss functions (i.e. equations (10b) – (10d)). The welfare gains from delegating an exchange rate objective, if any, appear to be minor. Table 3 confirms this outcome, displaying the social loss and the optimized exchange rate parameters for a given level of (separately optimized) output and interest rate stabilization.[30]

The policy maker does not seem to be able to improve social welfare through equation (10b) by limiting fluctuations in the nominal exchange rate. The optimized weight on the exchange rate difference, $\hat{\mu}_{\Delta e}$, is zero in all pass-through cases (see Table 3).[31] Hence, trying to smooth out changes in the nominal exchange rate does not create the same kind of policy inertia that was found to be beneficial for the social loss above.[32] 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.

[30] 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.

[31] Note that Sutherland (2000) finds that CPI inflation targeting creates too little volatility in the nominal exchange rate, and that social welfare improves if the exchange rate level is included in the central bank objective function. Consequently, the optimal weight on the nominal exchange level rate turns out to be negative in Sutherland's full pass-through model (while the optimal output stabilization is zero). This effectively replicates domestic inflation targeting, which is the first-best outcome in that particular model, implying that the exchange rate element of CPI inflation should optimally be offset. On the other hand, in the model used here, targeting CPI inflation is welfare enhancing (see the discussion below).

[32] Note, however, that there seems to be some role for exchange rate stabilization (i.e. $\mu_{\Delta e} > 0$) if the stabilization bias is worse or, in other words, if the policy maker uses a more gradual policy (see Section 4.1. below).

Neither targeting the relative price of imports in equation (10c), (i.e. stabilizing the (inverse of the) terms of trade), nor alleviating deviations from PPP through equation (10d), seems to considerably improve social welfare. The optimized policy weights on the different real exchange rate definitions are zero, or close to zero, in most pass-through cases (see Table 3).[33] Neither the full pass-through case, nor the two intermediate pass-through cases, indicates that any of the exchange-rate terms 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 to any noticeable extent. 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 lager 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.[34]

Table 3: 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	$\hat{\mu}_{\Delta e}$	Rel. L^S	$\hat{\mu}_{(p^M-p^D)}$	Rel. L^S	$\hat{\mu}_{(p^*+e-p)}$	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	0.998	0	1.0
0.09	0.1	0.4	15.082	0	1.0	0.4	0.979	0.1	0.983

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 1. However, some negative parameters do not yield a solution to the system.

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

[34] 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 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.

3.3. Domestic inflation targeting

It might be argued that the low optimized weights on the different exchange rate objectives above originate from the fact that the exchange rate is already *indirectly* incorporated in the policy maker's objective function through targeting CPI inflation and output, which is why a *direct* aim is redundant. Since inflation and output are both affected by exchange rate fluctuations, and agents are forward-looking, future exchange rate expectations are already incorporated into the realized outcomes of inflation and output (see e.g. equation (1)). If this is the case, it suggests that the exchange rate should be given a different emphasis if the policy maker, in contrast, targets domestic inflation. Since the direct exchange rate component that enters CPI inflation through import prices, is filtered out from domestic inflation, certain effects of an exchange rate movement are removed.[35,36] Consequently, if stabilizing the exchange rate is truly important, the optimized weight must be larger if the policy maker targets domestic inflation.

Comparing the social loss under CPI inflation targeting and domestic inflation targeting indicates that the former scheme provides larger welfare (cf. Tables 2 and 4). The difference between the two targeting schemes is about 3% for the full pass-through case, but becomes smaller as the degree of pass-through decreases. This suggests that the indirect exchange rate component of CPI inflation is, in fact, beneficial for the policy outcome. Note also that the nominal exchange rate volatility is slightly lower when targeting CPI inflation (see Table A2 in the Appendix). However, although it appears to be better for the policy maker to target CPI inflation, the welfare improvement of including an exchange-rate term is not larger under domestic inflation targeting (see Table 4b). The direct exchange rate responses do not seem to be given higher emphasis and overall, the optimized exchange rate coefficients appear to be quite similar to the ones under CPI targeting. Consequently, *explicit* exchange rate stabilization does not play a welfare enhancing role, irrespective of whether the policy maker targets CPI inflation or domestic inflation, while an *implicit* exchange rate response through CPI inflation targeting is beneficial.

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[35] Despite this, the exchange rate still influences domestic inflation both via expenditure switching effects in aggregate demand, as well as via imported input intermediates.

[36] Recall that there are no transmission lags of the monetary policy in this model, which implies that the policy maker will react to all disturbances, permanent as well as temporary. If, in contrast, the policy maker faces transmission lags in the effect of monetary policy, interest rate adjustments to temporary fluctuations in the real exchange rate (i.e. deviations from purchasing power parity) might produce excessive variations in both inflation and output, which is clearly undesirable for the policy maker (see e.g. Taylor (2001)). In that case, the policy maker would aspire to exactly filter out temporary inflationary impulses (stemming from short-run departures from the law of one price), from the inflation measure she is targeting.

Table 4a: Social loss (L^S), and optimized output and interest rate stabilization ($\hat{\lambda}^{CB}$, $\hat{\nu}_i$), under domestic inflation targeting

	equation (10a), π^D - targeting								
		Optimizing the policy weights concerning:							
	$\nu_i = 0$	interest rate		output		output and interest rate jointly			
	$\lambda^{CB} = 0.5$	$\lambda^{CB} = 0.5$		$\nu_i = 0$					
Pass-through	L^S	$\hat{\nu}_i$	Rel. L^S	$\hat{\lambda}^{CB}$	Rel. L^S	$\hat{\lambda}^{CB}$	$\hat{\nu}_i$	Rel. L^S	
0.99	22.951	0.2	0.997	0.1	0.839	0.1	0.6	0.777	
0.66	22.614	0.2	0.996	0.1	0.842	0.1	0.7	0.770	
0.33	21.856	0.2	0.994	0.1	0.849	0.1	0.7	0.772	
0.09	19.175	0.2	0.994	0.1	0.878	0.1	0.6	0.800	

Table 4b: Social loss (L^S), and optimized exchange rate stabilization ($\hat{\mu}_{\Delta e}, \hat{\mu}_{(p^M - p^D)}, \hat{\mu}_{(p^* + e - p)}$), under domestic inflation targeting

	π^D - targeting								
Pass-	equation (10a)			equation (10b)		equation (10c)		equation (10d)	
through	$\hat{\lambda}^{CB}$	$\hat{\nu}_i$	L^S	$\hat{\mu}_{\Delta e}$	Rel. L^S	$\hat{\mu}_{(p^M - p^D)}$	Rel. L^S	$\hat{\mu}_{(p^* + e - p)}$	Rel. L^S
0.99	0.1	0.6	17.827	0.1	0.988	0	1.0	0	1.0
0.66	0.1	0.7	17.421	0.1	0.993	0	1.0	0	1.0
0.33	0.1	0.7	16.879	0	1.0	-0.1	0.997	0	1.0
0.09	0.1	0.7	15.346	0	1.0	0.3	0.985	0.1	0.982

As discussed in Section 2.2., it seems as if society should be concerned about CPI inflation when pass-through is incomplete. Note, however, that the results are qualitatively robust to changing the social preferences, such that society values stable *domestic* inflation (i.e. evaluating the delegated policies from a social loss function of the form; $L^D = \text{var}(\pi^D) + \lambda^S \text{var}(y)$). In particular, the results suggest that the policy maker should target CPI inflation, even if domestic inflation is an argument in the social loss function (cf. Tables 5a and 5b). The reason is that exchange rate fluctuations indirectly also influence domestic inflation. Movements in the exchange rate affect the domestic producer's marginal cost through intermediate imports 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.

Table 5a: Social loss ($L^D = \text{var}(\pi^D) + \lambda^S \text{var}(y)$), and optimized policy parameters, delegating CPI inflation targeting

Pass-through	π - targeting								
	equation (10a)			equation (10b)		equation (10c)		equation (10d)	
	$\hat{\lambda}^{CB}$	$\hat{v}_i$	L^D	$\hat{\mu}_{\Delta e}$	Rel. L^D	$\hat{\mu}_{(p^M - p^D)}$	Rel. L^D	$\hat{\mu}_{(p^*+e-p)}$	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	0.997	0	1.0
0.09	0.1	0.4	16.345	0	1.0	0.5	0.972	0.1	0.982

Table 5b: Social loss ($L^D = \text{var}(\pi^D) + \lambda^S \text{var}(y)$), and optimized policy parameters, delegating domestic inflation targeting

Pass-through	π^D - targeting								
	equation (10a)			equation (10b)		equation (10c)		equation (10d)	
	$\hat{\lambda}^{CB}$	$\hat{v}_i$	L^D	$\hat{\mu}_{\Delta e}$	Rel. L^D	$\hat{\mu}_{(p^M - p^D)}$	Rel. L^D	$\hat{\mu}_{(p^*+e-p)}$	Rel. L^D
0.99	0.1	0.7	17.942	0.1	0.991	0	1.0	0	1.0
0.66	0.1	0.7	17.735	0.1	0.997	0	1.0	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	0.4	0.98	0.1	0.98

4. Robustness

4.1. Increased stabilization bias and exchange-rate augmented policies

How do the exchange-rate augmented policy functions perform when the discretionary stabilization bias is worse? That is, although the explicit exchange rate stabilization is not welfare improving compared to delegating a policy optimized with respect to output and interest rate stabilization, the exchange rate may play a role if, for some reason, a conservative ‘Rogoff-banker’ can not be appointed.

A larger weight on output stabilization implies that the delegated policy is more gradual, compared to the case when a 'Rogoff-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. Note also that exchange rate volatility is higher when output stabilization is larger (not shown). Consequently, there seems to be more reason to stabilize the exchange rate in this case.

As a result, when the policy weight on output stabilization is kept at the same level as the social preferences (i.e. $\lambda^{CB} = \lambda^{S} = 0.5$), the optimized weight on the nominal exchange rate change, in equation (10b), turns out positively in every pass-through case. Moreover, this reduces social loss by up to 15% (see Table A4 in the Appendix). On the other hand, the results regarding the real exchange-rate augmented policy functions are somewhat more ambiguous. As is the case when output stabilization is optimized, stabilization of the terms of trade, or of the departures from PPP, can not reduce social loss in the full pass-through case, but improves welfare when pass-through is low.

4.2. Other parameterizations

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 A5a 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 A5b in the Appendix).

However, there are still no welfare improvements from explicitly stabilizing the exchange rate, 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 A5c in the Appendix).

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.

However, there are only small welfare improvements, if any, of incorporating an explicit nominal, or real, exchange-rate term in the policy maker's optimized objective function. Neither the stabilization of nominal exchange rate changes, nor of real exchange rates (i.e. either the relative price of imports, or deviations from Purchasing Power Parity), does improve the policy maker's performance in terms of social welfare. However, an indirect exchange rate response, achieved by targeting CPI inflation, appears to be sufficient for reducing the social loss somewhat, compared to if the policy maker targets domestic inflation. The reason is that expectations about future exchange rates affect both inflation and output, and that CPI inflation targeting generates lower exchange rate volatility. Moreover, CPI inflation targeting seems to do better than domestic inflation targeting, irrespective of whether the exchange rate pass-through is limited or complete. This result is neither dependent on the society's preferences for CPI inflation stabilization or domestic inflation stabilization.

Still, there are other aspects than the relative price distortions above 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 'Rogoff-conservative banker' with lower weight on output stabilization or through appointing an interest rate smoothing policy maker ('Woodford banker'). By exploiting the agents' expectations about future policy, the inflation-output trade-off is made more favourable which, in turn, reduces social loss. The welfare improvement of 'pure' interest rate smoothing appears to be low, while combining a low weight on output stabilization with interest rate smoothing gives a sizeable effect.

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-though 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

The two components in aggregate (CPI) inflation, that is inflation of import goods and inflation of domestic goods, follow:

$$\text{(A1)} \qquad \pi_t^M = \beta \, \mathrm{E}_t \pi_{t+1}^M + \frac{\alpha_p}{\kappa_M}\left(p_t^* + e_t - p_t^M\right),$$

$$\text{(A2)} \qquad \pi_t^D = \beta \, \mathrm{E}_t \pi_{t+1}^D + \frac{1}{(1-\kappa_M)}\left(\alpha_y y_t + \alpha_q (p_t^M - p_t^D) + \varepsilon_t^\pi\right).$$

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

$$\text{(A3)} \qquad (p_t^M - p_t^D) = (p_{t-1}^M - p_{t-1}^D) + \pi_t^M - \pi_t^D ,$$

$$\text{(A4)} \qquad (p_t^* + e_t - p_t^M) = (p_{t-1}^* + e_{t-1} - p_{t-1}^M) + \pi_t^* + \Delta e_t - \pi_t^M .$$

This implies that the complete model, i.e. the system of equations (1)-(6), the three shock processes[37], plus (A1)-(A4), can be rewritten in state-space form:

$$\text{(A5)} \qquad \tilde{A}_0 \begin{bmatrix} x_{1,t+1} \\ \mathrm{E}_t x_{2,t+1} \end{bmatrix} = \tilde{A} \begin{bmatrix} x_{1,t} \\ x_{2,t} \end{bmatrix} + \tilde{B} i_t + \tilde{\upsilon}_{t+1} ,$$

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

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

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

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,

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[37] 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 $\varepsilon_{t+1}^\phi = \tau_\phi \varepsilon_t^\phi + u_{t+1}^\phi$.

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

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

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

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

(A6)
$$J(x_t) = \min_{i_t} \left\{ x_t' \tilde{Q} x_t + \beta \, \mathrm{E}_t J(x_{t+1}) \right\} = \min_{i_t} \left\{ \begin{bmatrix} x_t' & i_t \end{bmatrix} \begin{bmatrix} Q & U \\ U' & R \end{bmatrix} \begin{bmatrix} x_t \\ i_t \end{bmatrix} + \beta \, \mathrm{E}_t J(x_{t+1}) \right\}$$
$$= \min_{i_t} \left\{ x_t' Q x_t + 2 x_t' U i_t + i_t' R i_t \right\} + \beta \, \mathrm{E}_t J(x_{t+1}),$$

where Q, U and R are matrices mapping the goal variables (i.e. π_t, y_t, $(i_t - i_{t-1})$) 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:

(A7a) $x_{1,t+1} = M^d x_{1,t} + \upsilon_{t+1}$,

(A7b) $x_{2,t} = H^d x_{1,t}$,

(A7c) $i_t = F^d x_{1,t}$.

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, υ_{t+1}, is given by $\Sigma_\upsilon = [\Sigma_{\upsilon 1} \quad 0_{9\times 4}]$, where $\Sigma_{\upsilon 1}$ is defined as:

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

Given that the dynamics of the system can be written as (A7), the asymptotic unconditional variance-covariance matrix of the predetermined variables is given by:

(A8) $\Sigma_{x1} = M^d \Sigma_{x1} M^{d'} + \Sigma_{\upsilon 1}$,

(A9) $\mathrm{vec}(\Sigma_{x1}) = \left[I_{n1^2} - (M^d \otimes M^d) \right]^{-1} \mathrm{vec}(\Sigma_{\upsilon 1})$, 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

(A10) $\Sigma_z = T^d \, \Sigma_{x1} \, T^{d'}$.

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

	Equation (10a), $\lambda^{CB} = 0.5$, $\nu_i = 0$								
Pass-through	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

	Equation (10a), $\lambda^{CB} = 0.5$, $\nu_i = 0.1$								
Pass-through	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

	Equation (10a), optimized policy weights								
Pass-through	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), $\lambda^{CB} = 0.5$, $v_i = 0$							
	L^S	var (π)	var (y)	var (p^M-	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), $\lambda^{CB} = 0.1$, $v_i = \{1.0, 0.9, 0.7, 0.4\}$							
	L^S	var (π)	var (y)	var (p^M-	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 A2c: Unconditional variance and social loss (L^S); domestic inflation targeting

Pass-through	Equation (10a), π^D - targeting, $\lambda^{CB} = 0.1$, $v_i = \{0.6, 0.7, 0.7, 0.6\}$							
	L^S	var (π)	var (y)	var (p^M-	var (Δe)	var (i)	var (π^D)	var (π^M)
0.99	17.827	13.415	8.822	5.322	14.73	9.353	13.539	14.563
0.66	17.421	12.820	9.201	4.847	15.066	8.547	13.134	12.903
0.33	16.879	12.23	9.298	5.158	15.767	8.035	12.819	11.397
0.09	15.346	11.163	8.366	12.551	17.435	7.863	12.399	9.067

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	$\hat{\mu}_{\Delta e}$	Rel. L^S	$\hat{\mu}_{(p^M - p^D)}$	Rel. L^S	$\hat{\mu}_{(p^* + e - p)}$	Rel. L^S
0.99	0.1	0	19.173	-0.1	0.999	0	1.0	0.1	0.999
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	-0.1	0.999	0.1	0.996
0.09	0.1	0	16.266	0	1.0	0.6	0.970	0.1	0.949

Table A4: Social loss (L^S) and optimized exchange rate policy parameters, under a more gradual policy (i.e. $\lambda^{CB} = 0.5$)

Pass-through	Policy weights, $\lambda^{CB} = 0.5$, $\nu_i = 0$						
	Benchmark equation (10a)	equation (10b)		equation (10c)		equation (10d)	
	L^S	$\hat{\mu}_{\Delta e}$	L^S	$\hat{\mu}_{(p^M - p^D)}$	L^S	$\hat{\mu}_{(p^* + e - p)}$	L^S
0.99	22.368	2.0	0.848	0	1.0	0	1.0
0.66	22.214	1.8	0.854	0	1.0	0.3	0.998
0.33	21.648	1.5	0.867	0	1.0	0.9	0.963
0.09	19.156	1.0	0.907	6.4	0.778	1.0	0.808

Table A5a: Social loss (L^S) and optimized exchange rate parameters; increased openness

Pass-through	equation (10a)			equation (10b)		equation (10c)		equation (10d)	
	$\hat{\lambda}^{CB}$	$\hat{v}_i$	L^S	$\hat{\mu}_{\Delta e}$	Rel. L^S	$\hat{\mu}_{(p^M-p^D)}$	Rel. L^S	$\hat{\mu}_{(p^*+e-p)}$	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	1.0	0	1.0	0.2	0.995
0.09	0.1	0.3	12.70	0	1.0	0.3	0.964	0.1	0.953

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 A5b: Social loss (L^S) and optimized exchange rate parameters; more persistent risk premium

Pass-through	equation (10a)			equation (10b)		equation (10c)		equation (10d)	
	$\hat{\lambda}^{CB}$	$\hat{v}_i$	L^S	$\hat{\mu}_{\Delta e}$	Rel. L^S	$\hat{\mu}_{(p^M-p^D)}$	Rel. L^S	$\hat{\mu}_{(p^*+e-p)}$	Rel. L^S
0.99	0.1	1.2	17.828	0	1.0	0	1.0	0.1	0.994
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	0.999	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.

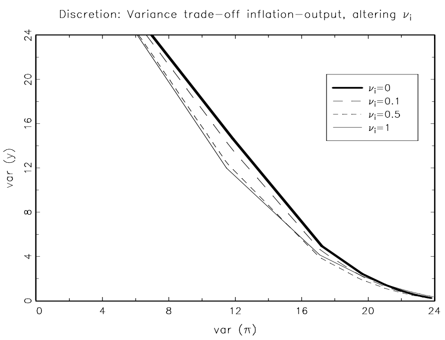
Table A5c: Social loss (L^S) and optimized exchange rate parameters; larger foreign disturbances

Pass-through	equation (10a)			equation (10b)		equation (10c)		equation (10d)	
	$\hat{\lambda}^{CB}$	$\hat{v}_i$	L^S	$\hat{\mu}_{\Delta e}$	Rel. L^S	$\hat{\mu}_{(p^M-p^D)}$	Rel. L^S	$\hat{\mu}_{(p^*+e-p)}$	Rel. L^S
0.99	0.1	0.7	17.78	0	1.0	0	1.0	0.1	0.999
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	0.4	0.982	0.1	0.977

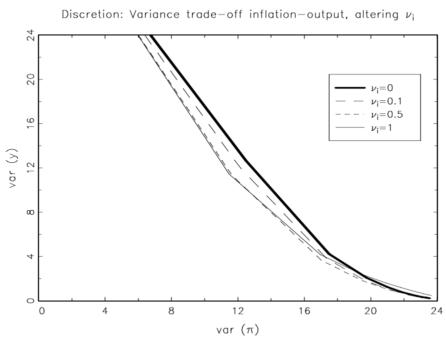
Note: Twice the variance of the foreign disturbance terms compared to the benchmark parameterization (i.e. σ_ϕ^2 = 1.6, $\sigma_{\pi*}^2$ = 0.1, σ_{y*}^2 = 0.2).

Figure 1: Inflation-output variability trade-off under different degrees of interest rate smoothing (ν_i)

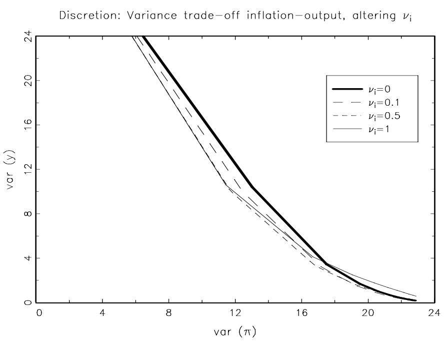
a) Pass-through = 0.99



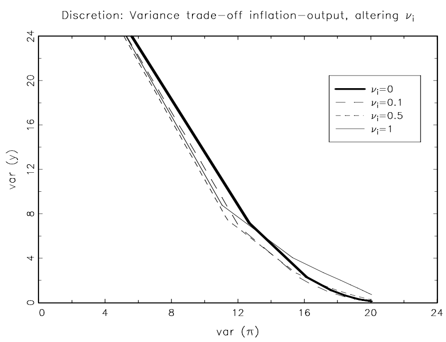
b) Pass-through = 0.66



c) Pass-through = 0.33



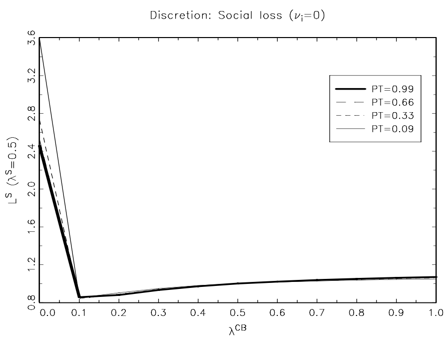
c) Pass-through = 0.09



Note: The degree of output stabilization is altered in equation (10a) such that λ^{CB} = [0,1], step 0.1. The y-axis is truncated to circumvent the extreme case of λ^{CB} = 0, which makes the trade-off frontier skewed.

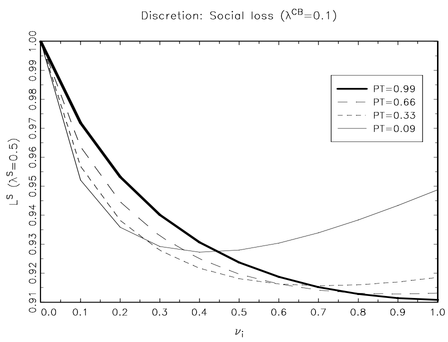
Figure 2: Social loss, varying the different policy weights

a) Output stabilization, λ^{CB}



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

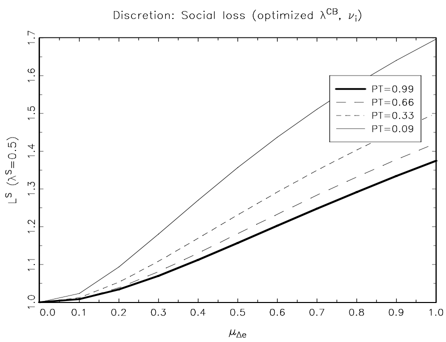
b) Interest rate smoothing, ν_i



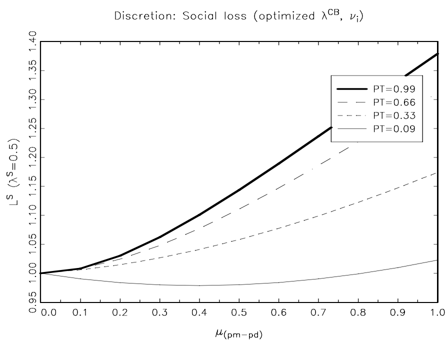
Note: Relative loss compared to an objective *without* interest rate smoothing

Figure 3: Social loss, varying the weights on the exchange-rate terms, equations (10b)–(10d)

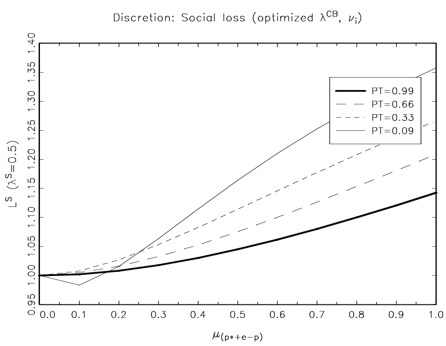
a) Nominal exchange rate change stabilization, $\mu_{\Delta e}$



b) Relative import price stabilization, $\mu_{(p^M - p^D)}$



c) Real exchange rate stabilization, $\mu_{(p^* + e - p)}$



Note: Relative loss compared to the loss resulting from an objective *without* the exchange rate.

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