Adolfson, Malin

Working Paper

Incomplete Exchange Rate Pass-Through and Simple Monetary Policy Rules

Sveriges Riksbank Working Paper Series, No. 136

Provided in Cooperation with:
Central Bank of Sweden, Stockholm

Suggested Citation: Adolfson, Malin (2002) : Incomplete Exchange Rate Pass-Through and Simple Monetary Policy Rules, Sveriges Riksbank Working Paper Series, No. 136, Sveriges Riksbank, Stockholm

This Version is available at:
https://hdl.handle.net/10419/82404

SVERIGES RIKSBANK

Sveriges Riksbank Working Paper Series

Incomplete Exchange Rate Pass-Through and Simple Monetary Policy Rules

June 2002

No. 136

Malin Adolfson

WORKING PAPERS ARE OBTAINABLE FROM

Sveriges Riksbank • Information Riksbank • SE-103 37 Stockholm
Fax international: +46 8 787 05 26
Telephone international: +46 8 787 01 00
E-mail: info@riksbank.se

The Working Paper series presents reports on matters in
the sphere of activities of the Riksbank that are considered
to be of interest to a wider public.
The papers are to be regarded as reports on ongoing studies
and the authors will be pleased to receive comments.

Incomplete Exchange Rate Pass-Through and Simple Monetary Policy Rules

Malin Adolfson*

Sveriges Riksbank Working Paper Series

No. 136

June 2002

Abstract

This paper investigates the performance of various monetary rules in an open economy with incomplete exchange rate pass-through. Implementing monetary policy through an exchange rate augmented policy rule does not improve social welfare compared to using an optimized Taylor rule, irrespective of the degree of pass-through. A direct exchange rate response improves welfare only if the other reaction coefficients, on inflation and output, are sub-optimal. However, an indirect exchange rate response, through a policy reaction to Consumer Price Index (CPI) inflation rather than to domestic inflation, is welfare enhancing. This result is independent of whether society values domestic or CPI inflation stabilization.

Keywords: Exchange rate pass-through, monetary policy, simple policy rules, small open economy, Taylor rule

JEL classification: E52, E58, F41

---

* *Research Department, Sveriges Riksbank, SE-103 37 Stockholm, E-mail*: malin.adolfson@riksbank.se

I am grateful to Paul Söderlind, Ulf Söderström, Marianne Nessén, Henrik Jensen, and Anders Vredin for suggestions and valuable discussions. I have also benefited from comments from seminar participants at Sveriges Riksbank. I would, moreover, like to thank Paul for providing extraordinary GAUSS routines. Financial support from Jan Wallander's Foundation is gratefully acknowledged. This paper is part of my thesis written at Stockholm School of Economics. The views expressed in this paper are solely the responsibility of the author and should not be interpreted as reflecting the views of the Executive Board of Sveriges Riksbank.

1. Introduction

In a small open economy, where the exchange rate influences inflation and output via import prices and relative prices, the exchange rate will transmit monetary policy in addition to the traditional (i.e., closed economy) interest rate channel. If the exchange rate contains information about, for example, inflationary impulses, the policy maker might improve social welfare by extending her simple monetary policy rule to include a direct feedback from the exchange rate. The reason for this is multifaceted; first, augmenting the policy rule with an exchange rate term does, to some extent, internalize the 'total' effects interest rate adjustments have on the economy, since movements in the interest rate also influence the exchange rate. Hence, there might be an informational advantage to such a policy rule, measuring the overall position of the policy (see, e.g., Ball (1999)). Second, inclusion of a lagged exchange rate term in the policy rule implies that the central banker can filter out transitory effects of exchange rate fluctuations on inflation when adjusting the interest rate (Ball (2000)). In this case, a purchasing power parity-adjusted measure of inflation is targeted, which might imply less volatility in the interest rate. This, in turn, circumvents excessive variations in output. Third, a policy rule that includes the exchange rate is less restrictive in that it incorporates a direct reaction to the inflationary impulse of exchange rate fluctuations rather than only responding to the result of the exchange rate movement (i.e., changes in inflation and output). This implies a possibility to directly adjust the interest rate and offset exchange rate effects on, for example, spending, which consequently might reduce the sub-optimality of the simple policy rule.

Prior literature analyzing open economies and simple monetary policy rules has explored a broad set of exchange rate augmented policy rules, without attaining complete consensus of whether or not it is beneficial to include some feedback from an exchange rate variable in the central bank's instrument rule.[1] The purpose of this paper is to study and describe an appropriate simple policy rule in an open economy with incomplete exchange rate pass-through. In

[1] Among the previously evaluated policies are, for example, rules incorporating the real exchange rate, the current and lagged real exchange rate, or the change in the nominal exchange rate. Ball (1999, 2000) uses a backward-looking model, concluding that the optimal simple rule should encompass a real exchange rate term and that 'long-run' inflation should be targeted (i.e., excluding transitory effects of the exchange rate). For the use of exchange rate augmented policy rules in forward-looking models, see, e.g., Batini et al. (2001), Leitemo and Söderström (2001), McCallum and Nelson (1999), and Taylor (2001). The majority of these authors find that the welfare performance of different simple rules is only marginally improved (if at all) by including a direct feedback from some exchange rate term. In contrast, Monacelli (1999) and Weerapana (2000) both show that the welfare improvement of using a policy rule incorporating an exchange rate term is somewhat more substantial, at least when the exchange rate pass-through is incomplete or, as in Weerapana's case, when the volatility of exchange rate shocks is large. In addition, Cecchetti et al. (2000) find that a response to the real exchange rate is beneficial, also when using inflation forecast based rules for implementing policy.

particular, the analysis focuses on the importance of the degree of pass-through. If the open economy policy maker implements her policy through an instrument rule, should the nominal or real exchange rate be incorporated into this rule, and is this affected by whether the exchange rate pass-through is incomplete? That is, can inclusion of an exchange rate response among the policy maker's reactions mitigate the sub-optimality of the instrument rule? The analysis is pursued in a simple aggregate demand-aggregate supply model, where incomplete exchange rate pass-through is included in the model via nominal import price rigidities. This, consequently, implies short-run deviations from the law of one price.

The main results obtained in the paper are as follows; *i*) the social welfare improvement of incorporating an exchange rate term in the *fully optimized* policy rule is practically zero, irrespective of the degree of pass-through. However, adding a real exchange rate term to the *non-optimized* Taylor (1993) rule does enhance social welfare somewhat, since it reduces the sub-optimality of the overall policy response. *ii*) An indirect exchange rate response, attained through a policy reaction to CPI inflation rather than domestic inflation, is welfare enhancing. This result holds independent of the degree of pass-through. Moreover, this result is not contingent upon society's preferences for CPI inflation stabilization or domestic inflation stabilization.

In Section 2, the economic model as well as three different exchange rate augmented policy rules are presented. These simple rules incorporate either a nominal or a real exchange rate term, in order to take advantage of any latent exchange rate effects, as discussed above. Section 3 contains the optimal policy reactions and the stabilization outcome of the different policy rules in terms of social welfare. Robustness issues are discussed in Section 4, and lastly some conclusions are provided in Section 5.

2. Model

The model is an open economy aggregate supply-aggregate demand model, adjusted for short-run incomplete exchange rate pass-through, and based on agents' optimizing behaviour. The consumers attain utility from consumption of domestic as well as import goods, supplied by a domestic and a foreign producer, respectively. Both producers sell their goods to the domestic and the foreign market, setting prices optimally under quadratic adjustment costs, following

Rotemberg (1982).[2] The economy of primary interest (called domestic) consists of three (log-linearized) equations determining inflation, output, and expected exchange rate changes:[3]

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

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

$$(3)\qquad i_t - i_t^* = \mathrm{E_t} e_{t+1} - e_t + \varepsilon_t^\phi .$$

Equation (1) is an aggregate supply relation obtained from the aggregate price index underlying the constant elasticity of substitution (CES) function for consumption, and the producers' optimal price setting, assuming nominal rigidities. Aggregate inflation (i.e., consumer price inflation) is a convex combination of inflation of domestically produced goods (π_t^D) and imported inflation (π_t^M). The variable y_t denotes aggregate output, ($p_t^M - p_t^D$) is the relative price of imports describing the inverse of the terms of trade (which turns up because of imported intermediate inputs), and e_t is the nominal exchange rate (domestic currency per unit of foreign currency). Deviations from the law of one price arise due to nominal import price stickiness and are captured by the term ($p_t^* + e_t - p_t^M$), where the price stickiness parameter α_p governs the degree of exchange rate pass-through. A less complete, or smaller, short-run pass-through occurs in the model by assigning greater import price rigidity, that is, a smaller α_p. Finally, ε_t^π encapsulates a disturbance to domestic supply (or to be exact, a domestic cost push shock that does not directly affect aggregate output) following 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 mean zero and variance σ_π^2.

Equation (2) is an aggregate demand relation derived from a standard Euler equation of the households' intertemporal consumption decision, using the demand relations from the underlying CES aggregator. Domestic demand shocks (e.g., originating from preference shifts)

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

[3] The notation is as follows; lower case letters denote logarithmic values (deviations from steady-state), a superscript indicates whether domestic or import goods are considered, and an asterisk represents foreign variables. A price characterized with an asterisk consequently denotes the foreign currency price. Lastly, $\mathrm{E_t}$ denotes rational expectations as of period *t*.

are captured in ε_t^y that follows, $\varepsilon_{t+1}^y = \tau_y \varepsilon_t^y + u_{t+1}^y$, with u_{t+1}^y as an iid disturbance term with mean zero and variance σ_y^2. This output relation differs from its full pass-through equivalence because of short-run deviations from the law of one price, which makes the relative price of imports ($p_t^M - p_t^D$) and the relative price of exports ($p_t^D - e_t - p_t^*$) diverge.[4] The internal relative price (i.e., of imports) appears through its effect on domestic consumers' demand, while the external relative price (i.e., of exports) shows up due to the foreign consumers' demand for domestic goods.

Equation (3) is a modified uncovered interest rate parity condition derived from the consumers' optimal holdings of domestic and foreign bonds, assuming an added risk premium (ε_t^ϕ) to the foreign bond prices. The risk premium is a 'pure' exchange rate disturbance capturing autonomous shocks to expectations about the future exchange rate.[5] The risk premium follows the AR(1) process, $\varepsilon_{t+1}^\phi = \tau_\phi \varepsilon_t^\phi + u_{t+1}^\phi$, where u_t^ϕ is an iid disturbance with mean zero and variance σ_ϕ^2.

The domestic economy is small in the sense that conditions in the foreign economy are exogenously given. The foreign inflation and output relations are assumed to consist of persistent AR(1) processes, while the foreign monetary policy is presumed to be implemented through a simple Taylor rule with some interest rate persistence added, as suggested by empirical evidence (see, e.g., Clarida et al. (1998)):

(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) $$i_{t+1}^* = (1-\rho_i^*)(b_\pi^* \pi_{t+1}^* + b_y^* y_{t+1}^*) + \rho_i^* i_t^* + u_{t+1}^{i*},$$

[4] The relative price *change* turns up in equation (2) because it affects the *inter*temporal consumption decision, while the relative price *level* affects the *intra*temporal allocation between consumption of imports and domestic goods. Note, however, that the difference terms disappear when solving equation (2) forward.

[5] Other independent exchange rate disturbances are hard to distinguish since the exchange rate is affected by anything influencing the interest rate differential in equation (3). This implies that any domestic or foreign shock creating a policy reaction also generates an exchange rate movement.

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 mean zero and variance σ_{y*}^2, $\sigma_{\pi*}^2$ and σ_{i*}^2, respectively.[6, 7]

In brief, the distinguishing features of the model are consequently departures from full pass-through, in both supply and demand relations, and entirely forward-looking agents.

2.1. Simple policy rules and social preferences

Monetary policy is assumed to be implemented through commitment to a 'simple' instrument rule, as suggested by Taylor (1993), where the short-run interest rate is the policy maker's instrument. The policy maker is assumed to follow such a sub-optimal policy rule, rather than explicitly deriving her reaction function from a policy objective function, due to reasons of, for example, transparency (credibility and monitorability). It may be easier for the central bank to explain the conduct of monetary policy when following a simple rule, as well as making it more straightforward for the public to evaluate the policy maker's performance. In addition, there is some notion in the literature that the outcome of simple rules are robust across different models (see, e.g., Levin et al. (1999)). That is, even if there is uncertainty about the underlying economic relations, a simple rule will generate the same response to, for example, an inflationary impulse, irrespective of the theoretical model used. In contrast, reaction functions directly derived from the policy maker's objective function are more complex and highly contingent upon the particular choice of model representation.[8]

Nevertheless, recall that the use of simple rules was initiated as the outcome of an empirical exercise for a closed economy, and lacks major theoretical foundations.[9] Which policy rule to be followed in an open economy is therefore still a very open question. As mentioned in the Introduction, there have been suggestions that the open economy-policy rule ought to incorporate the exchange rate, so as to exploit the exchange rate's transmission of monetary policy (see, e.g., Ball (1999)). The analysis therefore focuses on the following set of different policy rules:

[6] The shocks to foreign output and inflation are assumed to be uncorrelated. Note, however, that the subsequent results are not affected by changing this assumption so that u_{t+1}^{y*} and $u_{t+1}^{\pi*}$ are correlated.

[7] Monetary policy in one country can probably be described by a simple Taylor rule. However, using a single rule to represent the cohesive policy of the 'rest of the world' is less plausible, and therefore requires a disturbance term. u_{t+1}^{i*} captures foreign interest rate changes, or monetary policy changes, that are not encapsulated by the Taylor rule.

[8] In such a setting, see Adolfson (2002) for a discussion of what the fully optimal discretionary policy should be in an open economy with incomplete exchange rate pass-through.

(7a) $i_t = (1-\rho)\left(b_\pi \pi_t + b_y y_t\right) + \rho i_{t-1}$,

(7b) $i_t = (1-\rho)\left(b_\pi \pi_t + b_y y_t + b_{\Delta e}(e_t - e_{t-1})\right) + \rho i_{t-1}$,

(7c) $i_t = (1-\rho)\left(b_\pi \pi_t + b_y y_t + b_{(pm-pd)}(p_t^M - p_t^D)\right) + \rho i_{t-1}$,

(7d) $i_t = (1-\rho)\left(b_\pi \pi_t + b_y y_t + b_{(p^*+e-p)}(p_t^* + e_t - p_t)\right) + \rho i_{t-1}$,

where b_π, b_y, $b_{\Delta e}$, $b_{(pm-pd)}$, and $b_{(p^*+e-p)}$ are the policy maker's reaction coefficients, and ρ is the degree of interest rate persistence. The policy maker sets the interest rate as a linear function of the lagged interest rate and the deviations of CPI inflation, output, and possibly some exchange rate variable, from their zero targets.[10,11] Equation (7a) with $\rho = 0$ is the simple rule suggested by Taylor (1993), while Clarida et al. (2000) advocate that the persistence parameter, ρ, is typically 0.8-0.9 for this simple rule to be consistent with the empirical evidence. The three alternative rule specifications incorporate the exchange rate in some form. Equation (7b) states that monetary policy should react to changes in the nominal exchange rate. The reason for this is that the nominal exchange rate difference possibly indicates a direct inflationary impulse, which can be offset by an explicit policy response to the change in the exchange rate. Recall, though, that such a difference might only reflect temporary fluctuations in the exchange rate.[12] The real exchange rate may also mirror temporary fluctuations, but with sticky prices and incomplete pass-through, that possibility might be smaller, since the real exchange rate is a relative price. Therefore, equations (7c) and (7d) adjust the interest rate to different real exchange rate specifications, but because of incomplete pass-through the two characterizations are not equivalent. The term ($p^M - p^D$) in equation (7c) captures the (inverse of the) terms of trade, while the term ($p^* + e - p$) in equation (7d) captures deviations from purchasing power parity (PPP) between the foreign and domestic economy. Note also that the degree of pass-through

[9] See Svensson (2001) for some critique against the use of instrument rules.

[10] Note that equations (7a)-(7d) are not reaction functions in an exact sense, since inflation, output, and the exchange rate terms are not predetermined state variables. Rather, these equations represent equilibrium relations from which the system's dynamics can be backed out; the dynamics, in turn, relate the forward-looking variables to the predetermined variables. However, note that the subsequent results are qualitatively robust to changing the policy rule so that the interest rate only depends on lagged variables.

[11] A possible extension for future research is to incorporate a response to the nominal exchange rate *level* in the policy rule. However, this requires a state-space representation that includes the exchange rate level in the state vector. When the state-space representation contains non-stationary variables, such as the nominal exchange rate level, it is though unclear whether the numerical solution procedure is reliable. Therefore, the analysis in this paper focuses on policy rules that include stationary variables which can be captured within the same state-space form.

[12] Note that there are no transmission lags of monetary policy here, so the policy maker can respond to all disturbances, temporary as well as permanent, as long as they turn up in any of the target variables. However, if interest rate volatility is detrimental to social welfare for some reason, the policy maker may want to disregard transitory exchange rate movements.

influences these two variables differently in the face of, for instance, a risk premium shock. As pass-through decreases, the deviations from purchasing power parity becomes larger (because of larger departures from the law of one price), while the terms of trade are expected to become more stable.

The policy rules suggested above are evaluated in terms of a social loss function, which is also used for optimizing the reaction rule coefficients in equations (7a) – (7d). Social preferences are assumed to follow a standard objective function with quadratic deviations of CPI inflation and output from their constant target levels (here normalized to zero for simplicity):

$$\begin{aligned} (8) \qquad & \min_{\{i_{t+j}\}_{j=0}^{\infty}} \quad \mathrm{E}_t \sum_{j=0}^{\infty} \beta^j L_{t+j}^S \ , \\ & \text{where} \quad L_t^S = \left[\pi_t^2 + \lambda^S y_t^2 \right], \end{aligned}$$

where $0 < \beta < 1$ is a discount factor, and λ^S is the relative weight society puts on output stabilization.[13] To minimize the social loss function and find the optimal simple rule, the model in equations (1) – (6) is expressed in state-space form (see Appendix A). This implies that the minimization in equation (8) can be stated as a linear-quadratic problem. The policy maker is assumed to be able to commit to one of the simple policy rules in equation (7). As the discount factor, β, approaches unity, it can be shown that the limit of the scaled intertemporal loss function can be expressed as the unconditional mean of the period loss function (see Rudebusch and Svensson (1999)):

$$(9) \qquad \mathrm{E}\left[L_t^S\right] = \mathrm{Var}(\pi_t) + \lambda^S \mathrm{Var}(y_t) \ .$$

The loss function in equation (9) is used to assess which policy rule in equation (7) provides the most efficient stabilization of the economy, as well as for optimizing the reaction coefficients in

[13] In a closed economy, Woodford (2001) shows that this objective function represents a second-order Taylor approximation of the expected utility for the representative household, making it a reasonable welfare measure for monetary policy. This loss function is also appropriate in an open economy with incomplete pass-through, since the relative price distortion that occurs due to sticky domestic prices *and* rigid import prices can be mitigated with stable CPI inflation. Stabilization of CPI inflation reduces the uncertainty about future real consumption, which is welfare improving for the risk averse consumers. Note, moreover, that Smets and Wouters (2001) find that the social cost of relative price variability (i.e., the loss function) in an open economy with such distortions is a weighted average of domestic price inflation *and* import price inflation. Further, Benigno (2001) also shows that a weighted average of the two inflation rates in an optimal currency area is the appropriate objective for monetary policy, given nominal rigidities in both sectors. For a more detailed discussion of the open economy-social objectives and their pass-through aspects, see Section 4.1. below.

each rule. Equation (9) is calculated using asymptotic variances that can be obtained from the solution (or transition matrix) of the model, both described in Appendix A. The model is solved using numerical methods, described in for example Söderlind (1999), and so it needs to be parameterized. The parameter values shown in Table 1 are based on underlying deep parameters, which are chosen along the lines of prior literature.[14]

Table 1: Parameterization

Social preferences	Benchmark policy rule	Supply relation	Demand relation	Foreign economy	Shock persistence	Shock variance
$\beta = 0.99$	$b_\pi = 1.5$	$\kappa_M = 0.3$	$\beta_q = 1.26$	$\rho_y^* = 0.8$	$\tau_\pi = 0.8$	$\sigma_\pi^2 = 0.4$
$\lambda^S = 0.5$	$b_y = 0.5$	$\alpha_\pi = 0.99$	$\beta_i = 0.35$	$\rho_\pi^* = 0.8$	$\tau_y = 0.8$	$\sigma_y^2 = 0.6$
	$\rho = 0.8$	$\alpha_y = 0.056$	$\beta_e = 1.8$	$\rho_i^* = 0.8$	$\tau_\phi = 0.8$	$\sigma_\phi^2 = 0.8$
		$\alpha_q = 0.007$	$\beta_y^* = 0.27$	$b_y^* = 0.5$		$\sigma_{\pi^*}^2 = 0.05$
		$\alpha_p = \{30, 0.6, 0.15, 0.03\}$		$b_\pi^* = 1.5$		$\sigma_{y^*}^2 = 0.1$
						$\sigma_{i^*}^2 = 0.01$

The parameter of main interest for this paper is the parameter α_p which governs the level of adjustment costs, and thereby also the degree of exchange rate pass-through. This parameter is chosen in order to cover four different rates of exchange rate pass-through; a case with almost full pass-through (99%), and three intermediate cases of incomplete pass-through (66%, 33%, and 9%).[15] The rest of the parameter-setup is fairly standard, for example capturing rather moderate import and export shares (30% of aggregate consumption and aggregate demand, respectively), a markup of 20% arising from a substitution elasticity between domestic and imported goods equal to 6, an intertemporal substitution elasticity of 0.5, and rather persistent shocks where the AR(1)-component is 0.8. Further, the variances of the disturbance terms are loosely based on a structural vector auto-regression on Norwegian data (see Leitemo and Røisland (2000)). The benchmark monetary policy rule takes on the standard reaction coefficients of 1.5 and 0.5 on inflation and output, respectively, as well as imposing some interest rate persistence; ($\rho = 0.8$).

[14] See Adolfson (2001) for an exact mapping between the parameters shown in Table 1 and the deep parameters.
[15] For empirical basis of incomplete exchange rate pass-through in small open economies, see, e.g., Adolfson (1997), Menon (1996), and Naug and Nymoen (1999). Menon's survey reports that empirical estimates of exchange rate pass-through typically lies in the range of 20-80%. Adolfson finds 33% exchange rate pass-through within a month to aggregate Swedish import prices, while Naug and Nymoen obtains about 20% pass-through per quarter for data on aggregate Norwegian imports.

3. Results

3.1. Non-optimized rule coefficients

Figure 1 illustrates the (normalized) social loss from implementing monetary policy through the three exchange rate augmented policy rules, varying the exchange rate coefficients. The reactions on inflation, output and the lagged interest rate are the ones suggested by Taylor (1993) and Clarida et al. (2000), while the response coefficient on the respective exchange rate term varies between -1 and 1. Inclusion of a positive exchange rate reaction through any of the three rules seems to reduce social loss. Moreover, the optimal degree of exchange rate response appears to depend on the degree of pass-through (cf. Figures 1a and 1d).

This is also shown in Table 2, which displays the optimized exchange rate responses and the resulting social loss. The exchange rate reaction, as well as the welfare enhancement, is increasing in the degree of pass-through.[16] Thus, when pass-through is high, the exchange rate plays a more important role in predicting inflationary impulses and, consequently, the welfare enhancement of including an exchange rate term is larger. Incorporation of either the nominal exchange rate change, the terms of trade, or deviations from PPP yield welfare improvements of 0-4% depending on the degree of pass-through. To give an idea about the magnitude of this enhancement, it is in welfare terms equivalent to a permanent decrease in inflation of 0-0.09%.[17] Moreover, the rules incorporating a real exchange rate term seem to perform somewhat better in terms of social welfare than the rule including the nominal exchange rate change. The largest welfare gain occurs when the policy maker responds to deviations from PPP. One reason for this is that the PPP term better captures the distortions that arise due to the price stickiness in the model, namely departures from the law of one price. Recall that low pass-through implies that foreign disturbances have smaller effects. On the other hand, this low pass-through is here induced by larger nominal import price rigidity. Consequently, the low impact of exchange rate

[16] Note that the benchmark policy shows that the social loss level is increasing in the degree of pass-through. The reason is that low pass-through implies less exposure to foreign disturbances, which in turn implies that output volatility becomes lower. This, together with lower inflation variability (due to more sticky import prices) reduces social loss. However, comparing the absolute loss *level* across different pass-through cases may be of limited interest since these cases represent different structural economies.

[17] To see this, note that the welfare equivalence in terms of a permanent drop in inflation can be calculated from the social loss function in equation (8). The difference in social loss between the Taylor rule (L^S_{high}) and the exchange rate augmented rule (L^S_{low}) corresponds to a permanent change in inflation ($\hat{\pi}$) according to the following;

$$\hat{\pi} = \sqrt{(1-\beta)(L^S_{high} - L^S_{low})}\,.$$

fluctuations is accompanied by large deviations from the flexible price outcome; deviations that the policy maker wants to alleviate.

Table 2: Social loss (L^S) and optimized exchange rate reaction coefficients ($\hat{b}_{\Delta e}$, $\hat{b}_{(pm-pd)}$, $\hat{b}_{(p^*+e-p)}$), using Taylor rule coefficients on b_π, b_y, ρ

	$b_\pi = 1.5,\ b_y = 0.5,\ \rho = 0.8$						
	equation (7a)	equation (7b)		equation (7c)		equation (7d)	
Pass-through	L^S	$\hat{b}_{\Delta e}$	Rel. L^S	$\hat{b}_{(pm-pd)}$	Rel. L^S	$\hat{b}_{(p^*+e-p)}$	Rel. L^S
0.99	22.627	0.3	0.980	0.4	0.964	0.6	0.963
0.66	21.321	0.2	0.992	0.3	0.982	0.6	0.960
0.33	20.316	0.1	0.997	0.2	0.994	0.6	0.960
0.09	19.027	0	1.0	0	1.0	0.4	0.971

Note: The optimized exchange rate responses are established by a grid search over –1 to 1 with step 0.1.

3.2. Optimized rule coefficients

The standard Taylor rule coefficients ($b_\pi = 1.5,\ b_y = 0.5$, and $\rho = 0.8$) need not be optimal for the specific model used here, in particular as they are derived from the monetary policy observed in a closed economy (see Taylor (1993)). If the policy rule is excessively simple, or sub-optimal, inclusion of any additional state variable is likely to yield an improvement of the rule. The welfare enhancement recorded in Table 2 could consequently originate from the fact that the exchange rate augmented policy rules simply respond to more variables than a rule without the exchange rate. However, optimization of the coefficients on inflation, output, and the lagged interest rate reduces the sub-optimality of the simple rule, which partly mitigates such a problem. Therefore all the policy coefficients are optimized, using a grid search over a range of values.

Table 3a displays the optimized rule coefficients on inflation, output, and the lagged interest rate for the policy rule without the exchange rate (i.e., equation (7a)). Note that the optimized interest rate persistence is very high ($\rho = 0.8$), for all pass-through cases, which is also consistent with the monetary policy conduct actually observed (see Clarida et al. (1998)). Moreover, given a forward-looking model, Woodford (1999) shows that the fully optimal reaction function is inertial. This implies that even if there is no explicit interest rate smoothing in the social loss function, the optimal amount of policy persistence ρ will be large.

Further, note that the response coefficients for the optimized rule do not at all resemble the policy rule suggested by Taylor (1993). Relative to Taylor's rule, the optimized responses to both inflation and output are much larger and the ratio between them is smaller, irrespective of the degree of pass-through (see Table 3a). However, that the optimized policy rule induces a more vigorous policy than what is typically found empirically is not specific to the setting used here, but appears to be a common result in many models (see, e.g., Batini et al. (2001), Rudebusch (2001), and Rudebusch and Svensson (1999)).[18] Note also that the inflation response appears to be slightly larger in the full pass-through case ($\hat{b}_\pi$ = 3.7), compared to the two intermediate cases of incomplete pass-through ($\hat{b}_\pi$ = 3.5 and $\hat{b}_\pi$ = 3.4, respectively). Since the exchange rate channel transmits shocks to a greater extent in the full pass-through case, this requires a more forceful policy reaction and induces a larger coefficient in the reaction rule. The differences are rather small, however, and moreover, dependent on which disturbances enter the economy (see Figure 2 for impulse responses).

Can an exchange rate response further improve the optimized instrument rule's outcome in terms of social welfare? Figure 3 shows the social loss resulting from the optimized rule when adding different degrees of exchange rate responses to it. The optimized reaction coefficients on inflation, output and the lagged interest rate are taken from Table 3a, while the responses to the different exchange rate terms vary between –1 and 1. In contrast to the case with sub-optimal responses to inflation and output, augmenting the *optimized* policy rule with an exchange rate term does not seem to enhance social welfare (see Figure 3).

This is described in Table 3b, which shows the social loss from the fully optimized policy rule, with optimal rule coefficients on the exchange rate as well as on inflation, output and the lagged interest rate. The responses on inflation, output, and the lagged interest rate are optimized separately, in order to scrutinize the marginal value of incorporating the exchange rate.[19] None of the augmented rules appears to significantly reduce the social loss, even if most of the optimized exchange rate reactions are different from zero. The welfare improvement of incorporating the nominal exchange rate change or one of the two real exchange rate terms is in most pass-through cases practically zero. The only case where a real exchange rate response

[18] For empirical estimates of the Taylor rule, see, e.g., Clarida et al. (2000) for the US, and Gerlach and Schnabel (2000) for the EMU countries.

[19] Another way of measuring the additive value of the exchange rate is to simultaneously optimize all reaction coefficients and then measure the welfare loss when excluding the exchange rate. Leaving out the exchange rate in

(footnote continues on next page)

enhances welfare by more than 1% (or, equivalently, decreases inflation by more than 0.05%, see Footnote 17) is when pass-through (PT) is very low (PT = 0.09). Further, note that the optimized reactions on the nominal exchange rate change and the terms of trade are increasing in the degree of pass-through, as expected. However, the response to deviations from PPP does not appear to increase monotonically with larger pass-through. Note, though, that these PPP deviations are larger when pass-through is low, which is the distortion that the policy maker wants to mitigate.

The exchange rate channel of transmitting monetary policy can perhaps explain the negative reaction coefficients that turn up in some cases. It follows from equation (3) that a positive domestic-foreign interest rate differential implies an expected future depreciation, which, in turn, induces an inflationary impulse that raises the interest rate even further. A negative policy response to the exchange rate mitigates the interest rate adjustment when the exchange rate depreciates. All policy effects are thus internalized, which eases this goal conflict. Note also that the volatility in the endogenously determined exchange rate is decreasing in the degree of pass-through.[20] Low pass-through consequently induces larger exchange rate variability, which causes a more negative policy reaction to the exchange rate. However, the overall interest rate response to a depreciation is still positive, since the policy reaction to CPI inflation raises the interest rate.

Table 3a: Optimized reaction rule coefficients ($\hat{b}_\pi, \hat{b}_y, \hat{\rho}$); equation (7a)

Pass-through	equation (7a)		
	$\hat{b}_\pi$	$\hat{b}_y$	$\hat{\rho}$
0.99	3.7	2.8	0.8
0.66	3.5	2.6	0.8
0.33	3.4	2.6	0.8
0.09	3.8	3.2	0.8

that case does, however, present a different, and sub-optimal, relation between the inflation and output reactions why the marginal loss of excluding the exchange rate is more difficult to assess.

[20] In this model, lower pass-through is induced by larger structural import price stickiness, why the required relative price adjustment is accomplished through larger exchange rate fluctuations (see Table A1 in the Appendix for unconditional variances).

Table 3b: Social loss (L^S) and optimized exchange rate coefficients ($\hat{b}_{\Delta e}$, $\hat{b}_{(pm-pd)}$, $\hat{b}_{(p^*+e-p)}$), using optimized reaction rule coefficients $\hat{b}_\pi, \hat{b}_y, \hat{\rho}$

	$\hat{b}_\pi$, $\hat{b}_y$, $\hat{\rho}$ optimized (see Table 3a)						
	equation (7a)	equation (7b)		equation (7c)		equation (7d)	
Pass-through	L^S	$\hat{b}_{\Delta e}$	Rel. L^S	$\hat{b}_{(pm-pd)}$	Rel. L^S	$\hat{b}_{(p^*+e-p)}$	Rel. L^S
0.99	17.574	0.1	1.0	0.1	1.0	0.2	1.0
0.66	17.286	0.1	1.0	0	1.0	0.1	1.0
0.33	16.775	0	1.0	-0.2	0.999	0.2	1.0
0.09	15.065	-0.1	1.0	-0.6	0.988	0.9	0.989

Note: b_π, b_y, ρ are optimized separately (see Table 3a) in order to reflect the marginal advantage of incorporating an exchange rate term. The optimized exchange rate responses are established by a grid search over –1 to 1, with step 0.1.

Altogether, the results thus indicate that social welfare might possibly be improved by adding an exchange rate term to the *non-optimized* policy rule, but not to the *optimized* policy rule. These contrasting findings are simply explained from the optimized responses to, for example, inflation and output. The optimized responses to inflation and output are larger than the ones suggested by Taylor (1993), which implies a more aggressive interest rate adjustment. Inclusion of an exchange rate term (i.e., a positive exchange rate reaction) precisely implies a larger interest rate response to inflationary impulses reflected in the exchange rate. This more forceful interest rate adjustment does, in turn, result in an implicit development towards the optimized policy rule *without* the exchange rate.

3.3. Responding to domestic inflation

Another reason for why the exchange rate augmented rules are only marginally welfare improving, if at all, could be that the instrument rule already contains an implicit response to the exchange rate, realized through the reaction to CPI inflation. Consequently, Taylor (2001) suggests that the CPI inflation-interest rate rule includes a sufficient exchange rate response. If, in contrast, the policy maker adjusts the interest rate to domestic inflation (π^D), most of the direct exchange rate impact is excluded.[21] Hence, if the exchange rate does play an explicit role in the policy rule, its emphasis ought to be higher when responding to domestic inflation

[21] Note, however, that the exchange rate still indirectly affects domestic inflation in this model, through imported inputs and expenditure switching effects via aggregate demand.

compared to reacting to CPI inflation. To test this hypothesis, the exchange rate augmented rules are analyzed using domestic inflation as a reaction variable.

Table 4 presents the social loss and the optimized response coefficients when the policy rule consists of domestic inflation, output, the interest rate, and the various exchange rate terms. Comparing the social loss under the domestic inflation rules and the CPI inflation rules indicates that implementing monetary policy through a rule based on CPI inflation yields a better outcome in terms of social welfare (see column 5 in Table 4). Furthermore, the results in Tables 3b and 4 show that inclusion of any exchange rate term is *relatively* more welfare enhancing under a domestic inflation rule than under a CPI inflation rule, although the differences are very small. This reflects the fact that some of the exchange rate reaction, in fact, is inherent in the CPI inflation response, as discussed above. Still, there is no strong indication that a *direct* exchange rate response should be added to the optimized policy rule even if it is based on domestic inflation.

Table 4: Relative social loss and optimized reaction rule coefficients, policy rule based on domestic inflation (π_t^D)

Pass-through	equation (7a)				equation (7b)		equation (7c)		equation (7d)	
	$\hat{b}_\pi$	$\hat{b}_y$	$\hat{\rho}$	L_d^S / L^S	$\hat{b}_{\Delta e}$	Rel. L_d^S	$\hat{b}_{(pm-pd)}$	Rel. L_d^S	$\hat{b}_{(p^*+e-p)}$	Rel. L_d^S
0.99	3.8	3.0	0.8	1.013	0.2	0.999	0.3	0.999	0.4	0.999
0.66	3.4	2.6	0.8	1.01	0.1	0.999	0.1	1.0	0.4	0.999
0.33	5.5	4.6	0.9	1.0	0.2	1.0	-0.1	1.0	0.7	0.998
0.09	3.3	2.9	0.8	1.024	0	1.0	-0.7	0.982	1.0	0.980

Note: L_d^S / L^S denotes the relative loss from following policy rule (7a) based on domestic inflation compared to basing it on CPI inflation. Rel. L_d^S represents the relative loss between the respective exchange rate augmented rule and equation (7a) based on domestic inflation (i.e., the loss reduction from exchange rate stabilization under domestic inflation targeting). b_π, b_y, ρ are optimized separately in order to reflect the marginal advantage of incorporating an exchange rate term.

4. Robustness issues

4.1. Social preferences

As seen above, the question of whether to incorporate the exchange rate in the open economy-policy rule is related to the issue of what inflation measure the interest rate adjustment optimally is based on. This in turn might, however, be dependent on the society's particular welfare

function. What is the appropriate objective function of an open economy? In a model with nominal rigidities, where deviations between sticky and flexible prices occur, unnecessary variation in the relative price of goods (which, in turn, generates inflationary impulses) can be avoided by keeping the *general* price level stabilized (Woodford (2001)). The effects of nominal rigidities, that is the relative price distortions, can thereby be neutralized.

Some authors have argued that domestic inflation stabilization, rather than CPI inflation stabilization, characterizes the open economy welfare criterion (see, for example, Sutherland (2001)). However, this reasoning builds on an assumption of full pass-through, such that import prices are fully flexible. In this case, the distortion can be alleviated, and the flexible price outcome restored by stabilizing domestic inflation, to which the price stickiness pertains. On the other hand, in the model used here, *both* domestic and import prices are sticky, given incomplete pass-through. This implies that the distortion applies to both foreign and domestic producers, why the *general* price level translates into the consumer price index to which the producers relate their own price. Consequently, this suggests that CPI inflation should be stabilized when pass-through is incomplete.

The results presented above are however robust to evaluating the exchange rate augmented rules using a social loss function including domestic inflation, that is $L_t^D = \text{var}(\pi_t^D) + \lambda^S \text{var}(y_t)$, also in the cases with incomplete exchange rate pass-through.[22] This is shown in Tables 5a and 5b, which display the social loss (L_t^D), and the optimized policy reactions, from policy rules based on either CPI inflation or domestic inflation. Note in particular that the implicit exchange rate reaction achieved through targeting CPI inflation is beneficial for the outcome, even if society values domestic inflation stabilization (see column 5 in Table 5b). The reason is that exchange rate volatility is lower under a policy rule based on CPI inflation (see Table 1 in the Appendix). This, in turn, is helpful also for stabilizing domestic inflation, since domestic inflation is affected by exchange rate fluctuations through imported intermediate inputs. The lower exchange rate volatility improves the variance trade-off between domestic inflation and output, which thus is more favourable than if the policy maker would respond to domestic inflation (see Figure 4). Consequently, interest rate rules based on CPI inflation are welfare enhancing relative to the rules reacting to domestic inflation.

[22] Note, moreover, that the results are not (qualitatively) affected by whether an interest rate smoothing-objective is included in either of the two social loss functions.

Table 5a: Social loss ($L^D = \text{var}(\pi^D) + \lambda^S \text{var}(y)$), and optimized reaction rule coefficients, policy reaction to CPI inflation (π_t)

Pass-Throug	equation (7a)				equation (7b)		equation (7c)		equation (7d)	
	$\hat{b}_\pi$	$\hat{b}_y$	$\hat{\rho}$	L^D	$\hat{b}_{\Delta e}$	Rel. L^D	$\hat{b}_{(pm-pd)}$	Rel. L^D	$\hat{b}_{(p^*+e-p)}$	Rel. L^D
0.99	3.5	2.7	0.8	17.750	0.1	1.0	-0.1	1.0	-0.1	1.0
0.66	3.3	2.5	0.8	17.629	0.2	1.0	-0.2	1.0	0	1.0
0.33	3.4	2.6	0.8	17.364	0	1.0	-0.3	0.998	0.1	1.0
0.09	3.9	3.1	0.8	16.254	-0.2	0.999	-0.7	0.988	0.8	0.991

Table 5b: Social loss ($L^D = \text{var}(\pi^D) + \lambda^S \text{var}(y)$), and optimized reaction rule coefficients, policy reaction to domestic inflation (π_t^D)

Pass-Throug	equation (7a)				equation (7b)		equation (7c)		equation (7d)	
	$\hat{b}_\pi$	$\hat{b}_y$	$\hat{\rho}$	L_d^D / L^D	$\hat{b}_{\Delta e}$	Rel. L_d^D	$\hat{b}_{(pm-pd)}$	Rel. L_d^D	$\hat{b}_{(p^*+e-p)}$	Rel. L_d^D
0.99	3.5	2.8	0.8	1.01	0.2	0.998	0.1	1.0	0.1	1.0
0.66	3.3	2.6	0.8	1.009	0.2	0.999	-0.1	1.0	0.3	0.986
0.33	5.5	4.6	0.9	1.0	0.2	1.0	-0.4	0.999	0.5	0.999
0.09	3.4	2.8	0.8	1.023	0	1.0	-0.7	0.984	1.0	0.983

Note: L_d^D / L^D denotes the relative loss from following policy rule (7a) based on domestic inflation compared to basing it on CPI inflation. Rel. L_d^D represents the relative loss between the respective exchange rate augmented rule and equation (7a) based on domestic inflation (i.e., the loss reduction from exchange rate stabilization under domestic inflation targeting). b_π , b_y , ρ are optimized separately in order to reflect the marginal advantage of incorporating an exchange rate term.

4.2. Parameterization

Does the exchange rate play an explicit role in monetary policy if the economy becomes more open in terms of larger import and export shares? In this case, foreign disturbances have a larger impact on the domestic economy, and one might think that this also should affect the policy rule. Nonetheless, Table 6 shows that adding an exchange rate term to the (re)optimized policy rule does not notably improve welfare. The welfare gain is less than 1.6%, which is equivalent to a permanent decline in inflation by 0.04% (see also Footnote 17). The reaction coefficients on inflation and output do, however, appear to be increasing in the degree of openness (cf. Tables 3a and 6). This may well reduce the need for an additional exchange rate reaction.

Table 6: Social loss (L^S) and optimized reaction rule coefficients, greater openness

Pass-through	equation (7a)				equation (7b)		equation (7c)		equation (7d)	
	$\hat{b}_\pi$	$\hat{b}_y$	$\hat{\rho}$	L^S	$\hat{b}_{\Delta e}$	Rel. L^S	$\hat{b}_{(pm-pd)}$	Rel. L^S	$\hat{b}_{(p^*+e-p)}$	Rel. L^S
0.99	4.5	3.6	0.8	17.577	0.1	1.0	0.1	1.0	0.3	1.0
0.66	4.4	3.6	0.8	17.076	0.1	1.0	-0.2	1.0	0.7	1.0
0.33	4.6	3.9	0.8	16.014	-0.1	1.0	-0.5	0.999	1.3	0.998
0.09	3.9	3.7	0.7	12.511	-0.3	0.997	-0.7	0.987	1.0	0.984

Note: The size of the import and export shares, and the share of imported inputs are doubled (i.e. 60% and 20%, respectively, in contrast to the benchmark case; 30% and 10%). b_π, b_y, ρ are optimized separately in order to reflect the marginal advantage of incorporating an exchange rate term.

Do the size and persistence of fluctuations in the exchange rate affect the exchange rate's policy role? If the persistence in the risk premium shock increases, it induces larger and more prolonged exchange rate movements, which thus have a larger effect on the economy. Consequently, there are reasons for a more aggressive and long-lasting policy reaction. As shown in Table 7, social loss is reduced somewhat when the central bank follows a rule that incorporates a real exchange rate response. However, neither in this case do the exchange rate augmented rules imply any greater welfare improvements compared to the fully optimized policy rule. Note moreover that the larger reactions on inflation and output compensate for the lack of an explicit exchange rate term, so that the resulting policy rule in any case is more vigorous.

Table 7: Social loss (L^S) and optimized reaction rule coefficients, larger risk premium persistence

Pass-through	equation (7a)				equation (7b)		equation (7c)		equation (7d)	
	$\hat{b}_\pi$	$\hat{b}_y$	$\hat{\rho}$	L^S	$\hat{b}_{\Delta e}$	Rel. L^S	$\hat{b}_{(pm-pd)}$	Rel. L^S	$\hat{b}_{(p^*+e-p)}$	Rel. L^S
0.99	7.5	5.9	0.9	18.109	0.4	0.999	0.9	0.982	1.2	0.982
0.66	6.7	5.2	0.9	17.685	0.3	0.999	0.7	0.981	1.1	0.98
0.33	6.5	5.1	0.9	17.091	0.2	1.0	0.7	0.982	1.0	0.981
0.09	7.5	6.6	0.9	15.400	-0.1	1.0	0.4	0.996	1.1	0.977

Note: The risk premium persistence is τ_ϕ = 0.95. b_π, b_y, ρ are optimized separately in order to reflect the marginal advantage of incorporating an exchange rate term.

The same applies if the relative variances of the foreign disturbances are larger (see Table 8). For example, increasing the relative importance of risk premium disturbances does not change the main results. In this case, the welfare improvement of adding an exchange rate term to the

standard Taylor rule is somewhat larger, but the exchange rate augmented rules outperform the fully optimized rule only to a small extent. It is only in the case with very low pass-through (PT = 0.09) that a real exchange rate response seems to enhance social welfare. The social loss of 0.9 relative to the rule without the exchange rate is though comparable to a permanent decrease in inflation of a mere 0.1% (see also Footnote 17).

Table 8: Social loss (L^S) and optimized reaction coefficients, larger risk premium variance

Pass-through	equation (7a)				equation (7b)		equation (7c)		equation (7d)	
	$\hat{b}_\pi$	$\hat{b}_y$	$\hat{\rho}$	L^S	$\hat{b}_{\Delta e}$	Rel. L^S	$\hat{b}_{(pm-pd)}$	Rel. L^S	$\hat{b}_{(p^*+e-p)}$	Rel. L^S
0.99	7.3	6.8	0.8	18.339	0.5	0.998	1.1	0.996	1.5	0.996
0.66	6.8	6.3	0.8	18.013	0.4	0.999	0.8	0.998	1.5	0.995
0.33	6.5	6.1	0.8	17.434	0.3	0.999	0	1.0	1.7	0.991
0.09	7.0	7.2	0.8	15.568	-0.1	1.0	-1.8	0.981	2.6	0.900

Note: The risk premium variance is five times larger than in the basecase parameterization; $\sigma_\phi^2 = 2.0$. b_π, b_y, ρ are optimized separately in order to reflect the marginal advantage of incorporating an exchange rate term.

Consequently, the results do not seem to be sensitive to the particular parameterization chosen here. Note, moreover, that the results are not contingent upon the fully forward-looking model specification. The results are qualitatively robust to using a model with some backward-looking components in the demand and supply relations.[23]

5. Conclusions

This paper analyzes the performance of various open-economy policy rules within a forward-looking aggregate supply-aggregate demand model, adjusted for incomplete exchange rate pass-through. The results show that policy rules with direct exchange rate reactions only yield marginal improvements relative to an optimized Taylor rule. Neither nominal, nor real, exchange rate responses enhance stabilization of the economy. Given optimized policy reactions to inflation and output, there do not seem to be any sizeable welfare improvements from using exchange rate augmented rules, irrespective of the degree of pass-through.

However, an indirect, or implicit, exchange rate response is welfare improving. A policy rule responding to CPI inflation does better in social welfare terms than a rule based on domestic

[23] Results from this model are available upon request.

inflation, in all pass-through cases. The inherent exchange rate reaction included in the CPI inflation response appears to be one of the reasons why a direct exchange rate response is redundant. This result is not contingent upon social preferences for either CPI inflation stabilization or domestic inflation stabilization. Consequently, in this model, it is better for the policy maker to base her policy rule on CPI inflation, since this induces lower exchange rate volatility, which, in turn, also reduces domestic inflation variability.

The only case where social welfare improves from inclusion of a *direct* exchange rate reaction is when a real exchange rate response is added to the *non-optimized* Taylor rule with standard reaction coefficients on inflation, output, and the lagged interest rate (i.e., 1.5, 0.5, and 0.8, respectively). Adding a real exchange rate response to this Taylor rule makes the interest rate adjustment somewhat more aggressive. This reduces the sub-optimality of the resulting overall policy reaction, which thus enhances welfare. The exchange rate reaction, as well as the welfare gain, is increasing in the degree of pass-through.

Consequently, an exchange rate response can be a substitute for optimizing the Taylor rule coefficients, but once these other policy responses have been optimized there are no additional welfare gains from inclusion of an exchange rate term in the policy rule.

Appendix

A.1 State-space representation, model dynamics, and asymptotic variances

To formulate the model (i.e., equations (1) – (6)) in state-space form, the following inflation components, shock processes, and identities are used:

$$\text{(A1a)} \quad \pi_t^M = \alpha_\pi \mathrm{E_t}\pi_{t+1}^M + \frac{\alpha_p}{\kappa_M}\left(p_t^* + e_t - p_t^M\right),$$

$$\text{(A1b)} \quad \pi_t^D = \alpha_\pi \mathrm{E_t}\pi_{t+1}^D + \frac{1}{(1-\kappa_M)}\left(\alpha_y y_t + \alpha_q (p_t^M - p_t^D) + \varepsilon_t^\pi\right),$$

$$\text{(A2a)} \quad \varepsilon_{t+1}^\pi = \tau_\pi \varepsilon_t^\pi + \upsilon_{t+1}^\pi,$$

$$\text{(A2b)} \quad \varepsilon_{t+1}^y = \tau_y \varepsilon_t^y + \upsilon_{t+1}^y,$$

$$\text{(A2c)} \quad \varepsilon_{t+1}^\phi = \tau_\phi \varepsilon_t^\phi + \upsilon_{t+1}^\phi,$$

$$\text{(A3a)} \quad (p_t^M - p_t^D) = (p_{t-1}^M - p_{t-1}^D) + \pi_t^M - \pi_t^D,$$

$$\text{(A3b)} \quad (p_t^* + e_t - p_t^M) = (p_{t-1}^* + e_{t-1} - p_{t-1}^M) + \pi_t^* + \Delta e_t - \pi_t^M.$$

The state-space representation is

$$\text{(A4)} \quad \widetilde{A}_0 \begin{bmatrix} x_{1,t+1} \\ \mathrm{E_t} x_{2,t+1} \end{bmatrix} = \widetilde{A} \begin{bmatrix} x_{1,t} \\ x_{2,t} \end{bmatrix} + \widetilde{B}\, i_t + \widetilde{\upsilon}_{t+1},$$

$$x_{1,t} = \left[\, i_{t-1} \quad y_t^* \quad i_t^* \quad \pi_t^* \quad \varepsilon_t^\pi \quad \varepsilon_t^\phi \quad \varepsilon_t^y \quad (p_{t-1}^M - p_{t-1}^D) \quad (p_{t-1}^* + e_{t-1} - p_{t-1}^M) \,\right]',$$

$$x_{2,t} = \left[\, y_t \quad \pi_t^D \quad \pi_t^M \quad \Delta e_t \,\right]',$$

$$\widetilde{\upsilon}_{t+1} = \left[\, 0 \quad u_{t+1}^{y*} \quad u_{t+1}^{i*} \quad u_{t+1}^{\pi*} \quad u_{t+1}^{\pi} \quad u_{t+1}^{\phi} \quad u_{t+1}^{y} \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \,\right]',$$

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 $\widetilde{\upsilon}_{t+1}$ is a 13×1 vector of disturbances,

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

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

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

Premultiplying (A4) with $\widetilde{A}_0^{-1}$, and inserting the monetary policy reaction, $i_t = -F\begin{bmatrix} x_{1,t} & x_{2,t} \end{bmatrix}'$, yields

$$\text{(A5)} \qquad \begin{bmatrix} x_{1,t+1} \\ \mathrm{E}_t x_{2,t+1} \end{bmatrix} = (A - BF)\begin{bmatrix} x_{1,t} \\ x_{2,t} \end{bmatrix} + \begin{bmatrix} \upsilon_{1,t+1} \\ 0_{4\times 1} \end{bmatrix},$$

where $A = \widetilde{A}_0^{-1}\widetilde{A}$, $B = \widetilde{A}_0^{-1}\widetilde{B}$, and $\begin{bmatrix} \upsilon_{1,t+1} & 0_{4\times 1} \end{bmatrix}' = \widetilde{A}_0^{-1}\widetilde{\upsilon}_{t+1}$. Provided that the policy rule, *F*, implies a unique equilibrium, the dynamics of the model is given by

$$\text{(A6a)} \qquad x_{1,t+1} = M^s x_{1,t} + \upsilon_{1,t+1},$$

$$\text{(A6b)} \qquad x_{2,t+1} = H^s x_{1,t+1},$$

where M^s and H^s can be found using a Schur decomposition of $(A - BF)$, see Söderlind (1999).

Given the system's dynamics in equation (A6), the variance-covariance matrix of the predetermined variables results from

(A7a) $\Sigma_{x1} = M^s \Sigma_{x1} M^{s'} + \Sigma_{\upsilon 1}$,

(A7b) $\text{vec}(\Sigma_{x1}) = \left[I_{n1^2} - (M^s \otimes M^s)\right]^{-1} \text{vec}(\Sigma_{\upsilon 1})$,

where the unconditional variance-covariance matrix of the disturbance vector, υ_{t+1}, is given by $\Sigma_\upsilon = \left(\Sigma_{\upsilon 1} \quad 0_{9\times 4}\right)$, where $\Sigma_{\upsilon 1}$ is defined as

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

The variables of interest (z_t) can be expressed as a function of the predetermined variables,

$$\begin{aligned} z_{t+1} &= T_x x_{t+1} + T_i i_{t+1} \\ &= \begin{bmatrix} T_{x1} & T_{x2} \end{bmatrix} \begin{bmatrix} x_{1,t+1} \\ x_{2,t+1} \end{bmatrix} + T_i i_{t+1} \\ &= \begin{bmatrix} T_{x1} & T_{x2} \end{bmatrix} \begin{bmatrix} x_{1,t+1} \\ H^s x_{1,t+1} \end{bmatrix} - T_i \begin{bmatrix} F_1 & F_2 \end{bmatrix} \begin{bmatrix} x_{1,t+1} \\ H^s x_{1,t+1} \end{bmatrix} \\ &= T^s x_{1,t+1} \ , \end{aligned}$$

yielding the following variance-covariance matrix for (z_t):

(A12) $\Sigma_z = T^s \Sigma_{x1} T^{s'}$.

Table A1a: Unconditional variances and social loss, using standard reaction coefficients on (b_π, b_y, ρ)

	$b_\pi = 1.5,\ b_y = 0.5, \rho = 0.8$ equation (7a); $i_t = (1-\rho)(b_\pi \pi_t + b_y y_t) + \rho i_{t-1}$						
Pass-through	var (π)	var (y)	var (p^M-p^D)	var (Δe)	var (i)	var (π^D)	var (π^M)
0.99	9.037	27.180	7.162	12.191	4.325	8.759	12.061
0.66	8.533	25.576	5.984	12.930	4.10	8.67	9.259
0.33	7.938	24.756	5.865	13.925	3.764	8.448	7.308
0.09	6.688	24.678	11.315	15.575	3.106	7.754	4.979

Table A1b: Unconditional variances and social loss, using optimized reaction coefficients

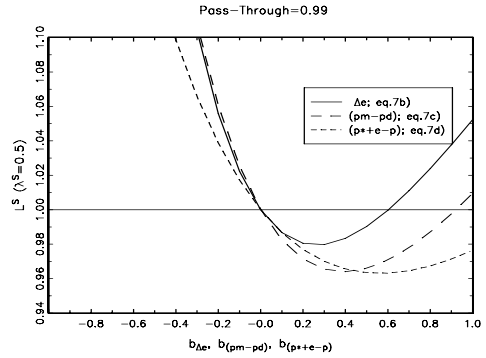
	optimized reactions; see Table 3a equation (7a); $i_t = (1-\rho)(b_\pi \pi_t + b_y y_t) + \rho i_{t-1}$						
Pass-through	var (π)	var (y)	var (p^M-p^D)	var (Δe)	var (i)	var (π^D)	var (π^M)
0.99	11.852	11.443	5.426	12.853	8.458	12.034	12.726
0.66	11.555	11.461	5.04	13.398	8.031	11.902	11.542
0.33	11.36	10.831	5.314	14.501	7.754	11.948	10.539
0.09	10.508	9.113	12.37	16.295	7.735	11.708	8.487

Table A1c: Unconditional variances and social loss, policy rule based on domestic inflation (π_t^D)

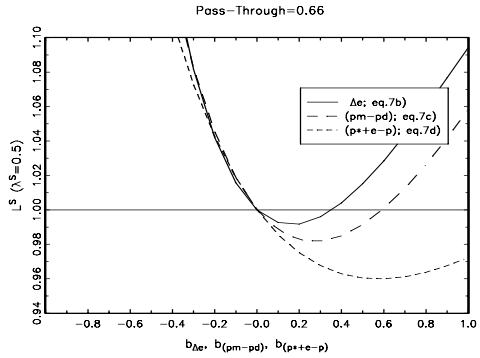
	optimized reactions; see Table 4 equation (7a); $i_t = (1-\rho)(b_\pi \pi_t^D + b_y y_t) + \rho i_{t-1}$						
Pass-through	var (π)	var (y)	var (p^M-p^D)	var (Δe)	var (i)	var (π^D)	var (π^M)
0.99	12.214	11.164	5.57	13.487	8.747	12.363	13.348
0.66	11.885	11.147	5.091	14.058	8.257	12.213	11.976
0.33	11.143	11.266	5.355	14.784	7.142	11.722	10.350
0.09	11.042	8.784	12.473	17.128	8.123	12.257	8.986

Figure 1: Social loss under varying degrees of exchange rate reactions added to the Taylor rule

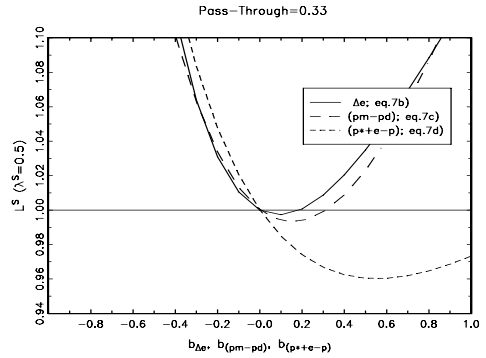
a) Pass-Through = 0.99



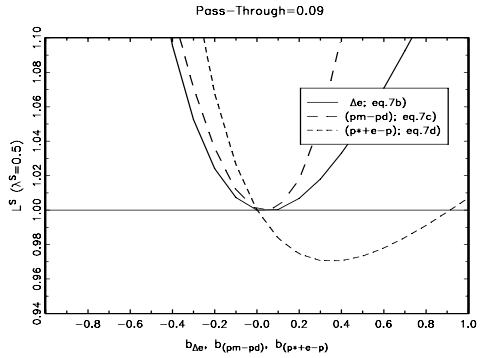
b) Pass-Through = 0.66



c) Pass-Through = 0.33



d) Pass-Through = 0.09



Note: Relative social loss compared to the social loss under the Taylor rule *without* the exchange rate.
Truncated y-axis.

Figure 2: Impulse responses for the case with full pass-through (99%; solid) and with incomplete pass-through (33%; dashed), using optimized rules

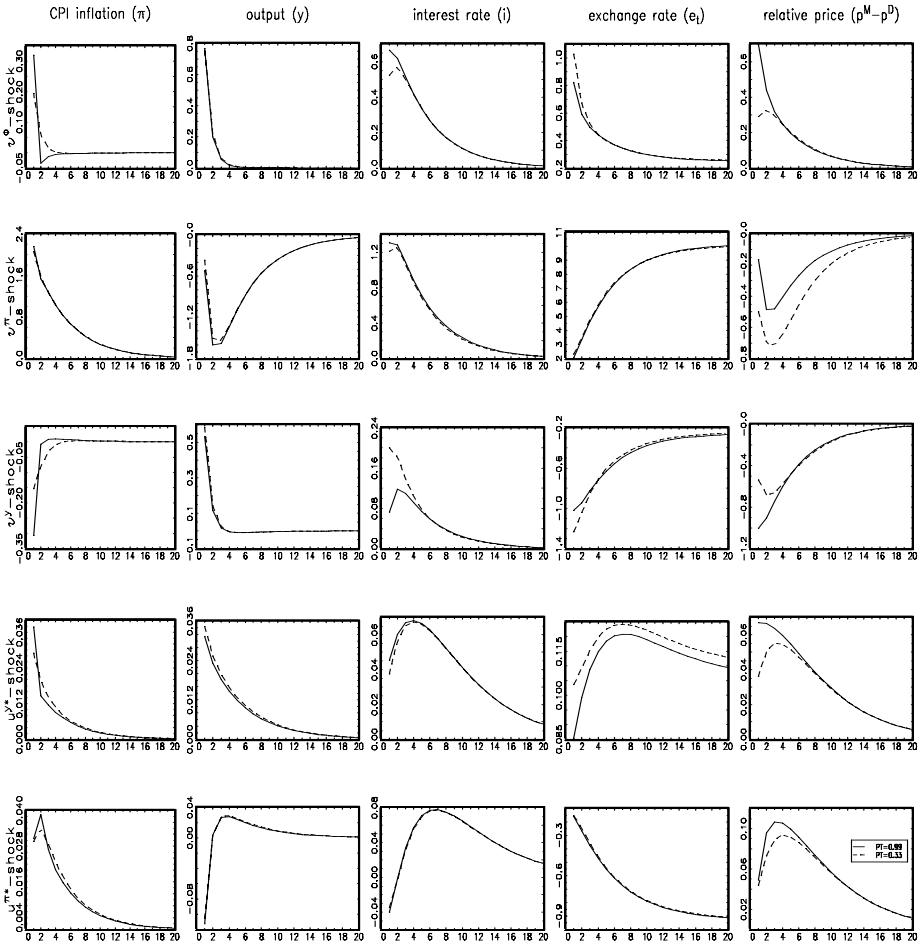
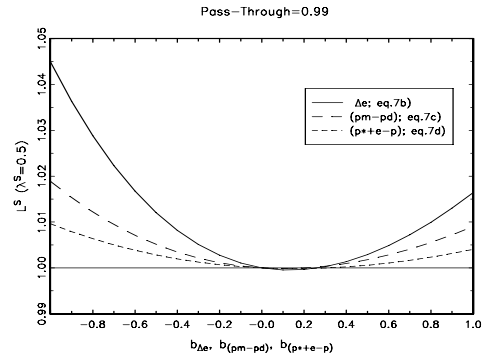
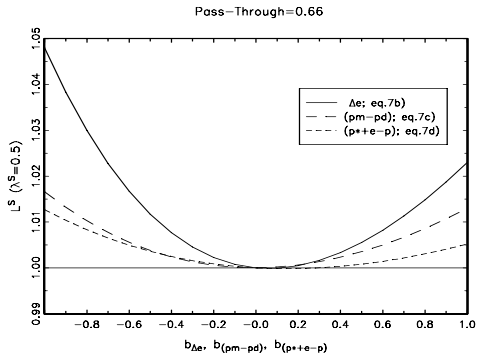


Figure 3: Social loss under varying degrees of exchange rate reactions added to the optimized rule

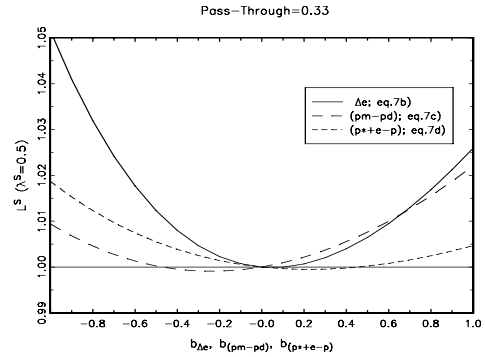
a) Pass-Through = 0.99



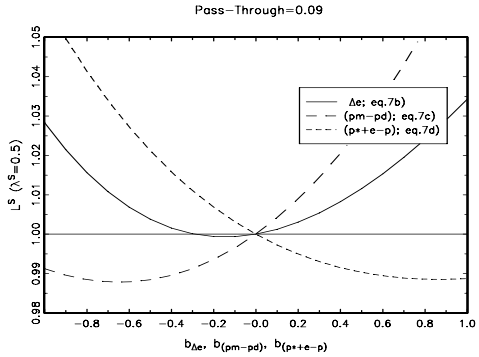
b) Pass-Through = 0.66



c) Pass-Through = 0.33



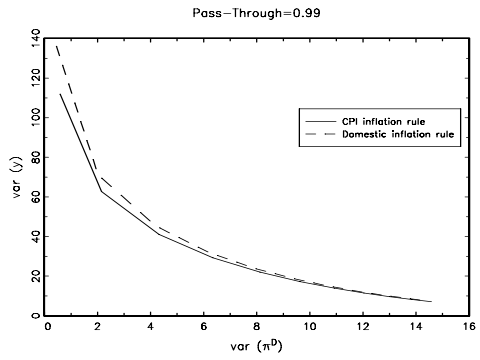
d) Pass-Through = 0.09



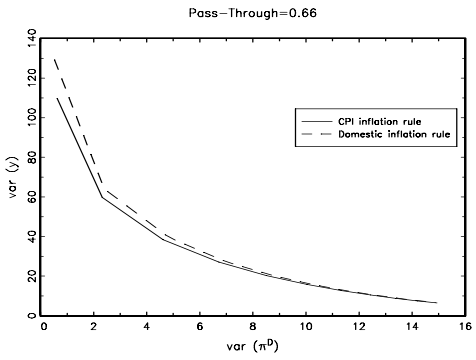
Note: Relative social loss compared to the social loss under the optimized rule *without* the exchange rate.

Figure 4: Domestic inflation-output variance trade-off, CPI inflation based rule (solid) vs. domestic inflation based rule (dashed)

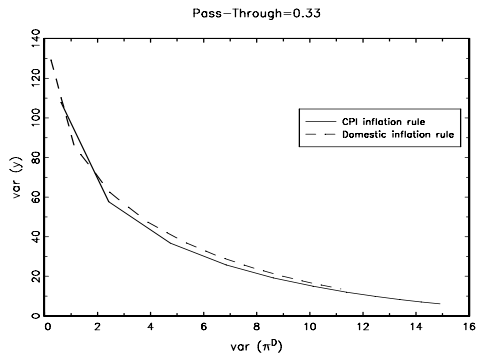
a) Pass-Through = 0.99



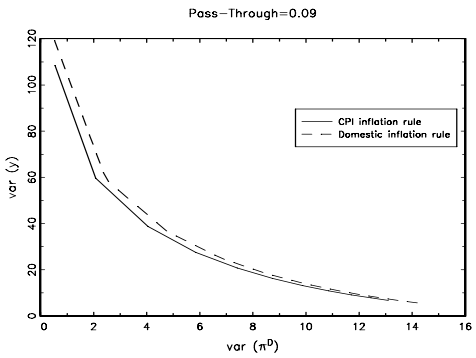
b) Pass-Through = 0.66



c) Pass-Through = 0.33



d) Pass-Through = 0.09



Note: Optimized policy rules, varying the degree of output response between 0-4, step 0.4. For inflation and interest rate reactions, see Tables 3a and 4, respectively.

References

Adolfson, M. (2002), "Implications of Exchange Rate Objectives under Incomplete Exchange Rate Pass-Through", *Sveriges Riksbank Working Paper*, No. 135.

Adolfson, M. (2001), "Monetary Policy with Incomplete Exchange Rate Pass-Through", *Sveriges Riksbank Working Paper*, No. 127.

Adolfson, M. (1997), "Exchange Rate Pass-Through to Swedish Import Prices", *Finnish Economic Papers*, Vol. 10, No. 2, 81-98.

Ball, L. (2000), "Policy Rules and External Shocks", *NBER Working Paper*, No. 7910.

Ball, L. (1999), "Policy Rules for Open Economies", in Taylor, J. (ed.), *Monetary Policy Rules*, University of Chicago Press.

Batini, N., Harrison, R. and Millard, S. P. (2001), "Monetary Policy Rules for an Open Economy", *Bank of England Working Paper Series*, No. 149.

Benigno, P. (2001), "Optimal Monetary Policy in a Currency Area", manuscript, New York University.

Cecchetti, S., Genberg, H., Lipsky, J. and Wadhwani, S. (2000), "Asset Prices and Central Bank Policy", *Geneva Reports on the World Economy*, No.2, ICMB/CEPR.

Clarida, R., Galí, J. and Gertler, M. (2000), "Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory", *Quarterly Journal of Economics*, Vol. 115, No. 1, 147-180.

Clarida, R., Galí, J. and Gertler, M. (1998), "Monetary Policy Rules in Practice: Some International Evidence", *European Economic Review*, Vol. 42, No. 6, 1033-1067.

Gerlach, S. and Schnabel, G. (2000), "The Taylor Rule and Interest Rates in the EMU Area", *Economics Letters*, Vol. 67, No. 2, 165-171.

Leitemo, K. and Røisland, Ø. (2000), "The Choice of Monetary Policy Regime for Small Open Economies", *Working Paper No. 5/2000*, Norges Bank.

Leitemo, K. and Söderström, U. (2001), "Simple Monetary Policy Rules and Exchange Rate Uncertainty", *Sveriges Riksbank Working Paper*, No. 122.

Levin, A., Wieland, V. and Williams, J. C. (1999), "Robustness of Simple Policy Rules under Model Uncertainty", in Taylor, J. (ed.), *Monetary Policy Rules*, University of Chicago Press.

McCallum, B. and Nelson, E. (1999), "Nominal Income Targeting in an Open-Economy Optimizing Market", *Journal of Monetary Economics*, Vol. 43, No. 3, 553-578.

Menon, J. (1996), "Exchange Rates and Prices – The Case of Australian Manufactured Imports", *Lecture Notes in Economics and Mathematical Systems*", 433, Springer-Verlag.

Monacelli, T. (1999),"Open Economy Policy Rules under Imperfect Pass-through", manuscript, Boston College.

Naug, B. and Nymoen, R. (1999), "Pricing to Market in a Small Open Economy", *Scandinavian Journal of Economics*, Vol. 98, No. 3, 329-350.

Rotemberg, J. (1982), "Monopolistic Price Adjustment and Aggregate Output", *Review of Economic Studies*, Vol. 49, 517-531.

Rudebusch, G. (2001), "Is the Fed Too Timid? Monetary Policy in an Uncertain World", *Review of Economics and Statistics*, Vol. 83, 203-217.

Rudebusch, G. and Svensson, L.E.O. (1999), "Policy Rules for Inflation Targeting", in Taylor, J. (ed.), *Monetary Policy Rules*, University of Chicago Press.

Smets, F. and Wouters, R. (2001), "Openness, Imperfect Exchange Rate Pass-Through and Monetary Policy, *Journal of Monetary Economics*, forthcoming.

Sutherland, A. (2001), "Incomplete Pass-Through and the Welfare Effects of Exchange Rate Variability", manuscript, University of St Andrews.

Svensson, L. (2001), "What is Wrong with Taylor Rules? Using Judgment in Monetary Policy through Targeting rules", manuscript, Princeton University.

Söderlind, P. (1999), " Solution and Estimation of RE Macromodels with Optimal Policy", *European Economic Review*, Vol. 43, 813-823.

Taylor, J. (2001), "The Role of the Exchange Rate in Monetary-Policy Rules", *American Economic Review*, Vol. 91, No. 2, 263-267.

Taylor, J. (1993), "Discretion versus Policy Rules in Practice", *Carnegie-Rochester Conference Series on Public Policy*, Vol. 39, 195-214.

Weerapana, A. (2000), "The Performance of Simple Monetary Policy Rules in A Large Open Economy", *Working Paper*, No. 2000-05, Wellesley College.

Woodford, M. (2001), "Inflation Stabilization and Welfare", *NBER Working Paper*, No. 8071.

Woodford, M. (1999), "Optimal Monetary Policy Inertia", *NBER Working Paper*, No. 7261.

Earlier Working Papers:

Sveriges Riksbank • Visiting address: Brunkebergs torg 11 • Mail address: se-103 37 Stockholm
Website: www.riksbank.se • E-mail: registratorn@riksbank.se • Telephone: +46 8 787 00 00 • Fax: +46 8 21 05 31