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Report: Multi-country model validation and policy evaluation

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Abstract

Several macroeconomic models developed in the early 1990s were designed and estimated as open economy models. By and large, policy experiments within these models support the conclusion that it is optimal for monetary policy to respond very little to exchange rate fluctuations, see, for instance, Coenen and Wieland (2002). It is not clear whether this conclusion holds true in the latest generation of open economy models designed at central banks for policy analysis. Building on an approach by Levin, Wieland, and Williams (2003) we minimize a loss function of inflation variation, output gap variation and interest rate variation and compute the optimal reaction of the central bank to inflation, output gap and a measure of the exchange rate. We find that the results in Coenen and Wieland (2002) also hold in open economy DSGE models with two exceptions. The small open economy model of the swedish central bank estimated on the swedish economy and the model of the International Monetary Fund calibrated on euro area and data from the Czech Republic show significant improvements in welfare, if the central bank responds to the exchange rate. We also find that the change in the nominal exchange rate is overall the preferred exchange rate measure in terms of loss improvements.

Keywords: Optimal monetary policy, exchange rate, model uncertainty,

JEL-Codes: E52, F41

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1 Introduction

Recently, tremendous progress has been made in the design of optimal policies in dynamic macro models, with the focus shifting to fully microfounded general equilibrium models. Yet, little effort has been made to contrast both the predictions and the empirical validity of this class of models with those of macroeconomic models developed in the early 1990s. By and large, policy experiments within the latter models support the conclusion that it is optimal for monetary policy to respond very little to exchange rate fluctuations, see, for instance, Coenen and Wieland (2002). It is not clear whether this conclusion holds true in the latest generation of multi-country models designed in institutions like the Swedish Riksbank or the International Monetary Fund among others for policy analyis and forecasting.

There is a wide literature dealing with optimal monetary policy in open economies. In the classical view the policy problem of the central bank was thought to be isomorphic in a closed economy model or an open economy model. Clarida, Galï¿$\frac{1}{2}$, and Gertler (2001) show that an open economy DSGE model can be characterized by a New Keynesian Phillips Curve, an Aggregate Demand Curve and a Taylor Rule and that it is optimal for a central bank to react to domestic inflation (PPI inflation) and domestic GDP only to stabilize inflation and output dynamics. This result called divine coincidence only holds under certain conditions. Paoli (2009) points out that three prerequisites are needed for this divine coincidence. First, markup shocks are absent. Second, the steady state level of output is efficient. This can be ensured through a proper government subsidy if monopolistic competition is present in the firms market. And finally the trade elasticity equals the intertemporal elasticity of substitution. With this parameter constellation in place the income and substitution effect of a change in relative prices on domestic output cancel each other out. Faia and Monacelli (2008) emphasize the importance of home bias in consumption. They find that if the share of domestic intermediate goods in the final consumption basket outweights the share of imported goods this is a sufficient condition for inducing the monetary policy maker of an open economy to deviate from a strategy of strict markup stabilization and contemplate some degree of exchange rate stabilization. In the case of real country-specific shocks and sticky prices a flexible exchange rate regime is preferable, following Devereux and Engel (2003), in order to allow relative prices of domestic and foreign goods to adjust to neutralize the country specific shocks, the so called Friedman prescription. On the other hand, a fixed exchange rate regime can be favourable if one country lacks a stable currency and therefore can gain credibility by fixing its currency to a country with stable prices.

Adolfson (2007) shows the importance of the exchange rate pass through into import prices for monetary policy in open economies. She optimizes the parameters of a monetary policy rule given a loss function including the variance of inflation and output and finds it optimal for the central bank to react to consumer price inflation instead of producer price inflation if the exchange rate pass through into import prices is incomplete. But according to her results it is not welfare improving to react to the exchange rate independent of the degree of exchange rate pass through and the measure of the exchange rate. Corsetti, Dedola, and Leduc (2010) in the Handbook of Monetary Economics also point out the importance of producer currency pricing, which induce a high degree of exchange rate pass through, for the isomorphism in open and closed economies. With local currency pricing the exchange rate cannot adjust to correct potential misalignments in relative prices across countries. Additionally they show that incomplete asset markets and therefore the lack of insurance across countries breaks down the isomorphism.

Complementary to the studies above some papers do a positive analysis and investigate whether central banks adjusted their policy instrument with respect to movements in the exchange rate. Lubik and Schorfheide (2007) estimate a small open economy DSGE model with Bayesian techniques on Canadian, Australian, UK and New Zealand data and estimate among others the parameter on the nominal exchange rate in the monetary policy rule. They find that the central banks of the UK and Canada increased the policy rate slightly after a depreciation of the currency and vice versa but the central banks of Australia and New Zealand did not. Analogously Dong (2008) did the exercise for the four countries but allowing the real interest rate in the model to be endogenous and pass through of exchange rate movements into import prices to be incomplete. With these adjustments he finds that only the central bank of New Zealand was not reacting to the real exchange rate. The backward-lookingness of the New Zealand economy and different shocks in the sample period could be a reason for this result.

In this report we compute optimal monetary policy experiments by minimizing a loss function of inflation variation, output gap variation and interest rate variation, building on an approach by Levin et al. (2003), and computing the optimal reaction of the central banks policy rate to inflation, output gap and a measure of the exchange rate. We account for model uncertainty by using a large set of different macroeconomic models, which vary in terms of size -some models are small open economy models and some are multi country models-, country data, they are estimated on, and frictions. To facilitate the analysis we are using the macroeconomic modelbase, which was designed to perform such model comparison exercises and which hosts a variety of macroeconomic models.[1] Thereby we want to analyse if an adjustment of the monetary policy instrument to the exchange rate helps the central bank to improve domestic welfare given by inflation and output variance. Or in other words is the exchange rate a good predictor for inflation and output variability in the different models?

The remainder of this report proceeds as follows. Section 2 provides a brief overview of the properties of the six different macroeconomic models we engage in the analysis. Section 3 explains the optimization problem for monetary policy. Section 4 contains in detail the optimization results for

[1]The macroeconomic model archive is described in more detail in Wieland, Cwik, Mueller, Schmidt, and Wolters (2011).

different specifications of the loss function, the instrument rule and different exchange rate measures. Section 5 concludes.

2 The models

We consider a wide range of macroeconomic models in the analysis, which vary in terms of size, microfoundation or country they represent. Four models out of the six models are New-Keynesian DSGE models, which assume forward-looking behavior of indiviuals and firms and some form of price rigidity. They are also microfounded in the sense that the model equations are derived from optimization decisions of representative households and firms. The first model of IMF researchers Laxton and Pesenti (2003), we will refer to as "Small IMF model", includes two countries, the euro area and the Czech republic. Its parameters are calibrated with artificial pre-EMU data. We will optimize the parameters of the policy rule for the Euro area and the Czech republic and report the results separately. The second model was developed by researchers at the European Commission and is described in Ratto, Roeger, and in't Veld (2009). We refer to it as the "EU-Quest" model. This model is estimated with quarterly euro area data from 1981Q1 to 2006Q1 thereby including a large part of EMU history. The third model was derived by researchers from the Swedish Riksbank. It is a small open economy model of the euro area and estimated with Bayesian techniques on euro area data from 1970Q1-2002Q4. The derivation and estimation is described in Adolfson, Laséen, Lindé, and Villani (2007) and we will call it "SR-EU model". The last DSGE model is also brought forward by the Swedish Riksbank. Is has a similar model structure than the "SR-EU model" and was estimated on Swedish data from 1980Q1-2007Q3. We will refer to it as the "SR-Sweden model".[2]

The two other models are multi-country models. The Taylor model is a G7 model. Households and firms are assumed to be forward-looking and are forming rational expectations, but Ricardian equivalence is not enforced. It is also New-Keynesian in the sense that is has sticky prices and wages through staggered price and wage contracts. The multi-country model is estimated on data up to 1993.[3] We will perform optimal monetary policy experiments for the US in this model. The second multi-country is a model of the US, Japan and EU called "CW 2003 model" with similar model features than the Taylor model. It is described in Coenen and Wieland (2002). Wie will optimize the parameters of the policy rule for the US, but the results hold also for the EU.

[2] See Adolfson, Laséen, Lindé, and Svensson (2008) for more details on the model and the estimation.
[3] See Taylor (1993) for more information.

3 The optimization problem

In this section we set-up the optimization problem of the policy maker. We assume that the policy maker wants to minimize variations in prices and wants to stabilize the economy. He also wants to adjust the policy rate slowly. The loss function $\mathcal{L}$ has the form

$$\mathcal{L} = Var(\pi) + \lambda Var(y) + \chi Var(\Delta i) \tag{1}$$

where Var(.) stands for the unconditional variance, π for Q4-Q4 inflation, y for the output gap and Δi for the change in the annualized interest rate. We use the output gap measure derived by the authors of the models and used as output gap measure in the original monetary policy rules. In all models except the "EU-Quest" model the output gap is defined as the deviation of output from its trend in percent. λ and χ indicate the weight the policy maker places on reducing output variability and interest rate variability relative to inflation variability. When the loss function of the central bank is derived from the households utility function in models with microfoundation, the weight on output stabilization varies with the structure of the model and the deep parameters. Therefore we will consider 3 different values of λ in the analysis namely $\lambda = (0, 0.5, 1)$. We will also vary the weight the policy maker places on the stabilization of the interest rate, $\chi = (0.5, 1)$, which reflects different preferences of policy makers on the speed of adjusting the policy rate.

Given the different structure of the economies in the macroeconomic models, we optimize the parameters of the instrument rule in (2) to minimize the value of the loss function of the policy maker in (1):

$$i_t = \rho i_{t-1} + (1-\rho)(r^* + \pi_t) + \alpha(\pi_t - \pi^*) + \beta y_t + \beta_1 y_{t-1} + \gamma x_t \tag{2}$$

where r^* denotes the natural real rate of interest and π^* the inflation target of the central bank, if defined in the models. x_t stands for the respective exchange rate measure, we will vary during the analysis. More precisely we will use the real exchange rate, the change in the nominal exchange rate and the change in the real exchange rate as candidates for x_t in the analysis. ρ expresses the degree of interest rate smoothing and α, β, β_1 and γ measure how much the policy rate reacts with respect to inflation, contemporaneous output gap, lagged output gap and the exchange rate.

4 Is it optimal for monetary policy to respond to the exchange rate?

In the following section we present the optimization results for various specifications of the loss function, the instrument rule and the exchange rate measure. We start in the next subsection by optimizing a five parameter rule, given by (2). Thereafter we show the optimization results for a four parameter rule, where $\beta_1 = 0$ and in the last subsection we will abstract from interest rate smoothing and will also set $\rho = 0$.

4.1 The five parameter rule

Table (1) shows the baseline optimization results without an exchange rate response ($\gamma = 0$) to compare it with the subsequent results. One can see that it is optimal to adjust the interest rate very slowly. The ρ coefficient is close to one or slightly above one in all models and for all weights (λ) on the output gap variability in the loss function. Although the degree of interest rate smoothing is slightly higher in DSGE models than in the Taylor model or the CW 2003 model.

Table 1: Optimized rules without exchange rate response

Model	λ	ρ	α	β	β_1	$\mathcal{L}$
	0	0.98	0.26	0.57	-0.54	0.40
Small IMF model	0.5	1.08	0.15	1.00	-0.96	0.87
	1	1.09	0.16	1.52	-1.45	1.26
	0	0.97	0.62	0.73	-0.65	2.24
Small IMF Czech model	0.5	1.02	0.56	1.90	-1.75	4.06
	1	1.05	0.50	2.65	-2.49	5.62
	0	1.03	1.12	0.11	-0.11	0.40
EU-Quest model	0.5	1.03	0.97	0.45	-0.29	1.80
	1	1.03	0.88	0.73	-0.47	3.04
	0	1.03	0.72	-0.03	0.01	0.23
SR-EU model	0.5	1.08	0.12	1.70	-1.73	2.66
	1	1.06	0.09	2.60	-2.63	4.21
	0	1.01	0.80	0.16	-0.14	1.43
SR-Sweden model	0.5	1.03	0.56	1.02	-0.91	4.94
	1	1.04	0.34	1.60	-1.48	7.53
	0	0.98	0.51	0.09	0.02	1.68
Taylor model	0.5	0.96	0.32	0.41	0.18	5.83
	1	0.95	0.24	0.60	0.26	8.79
	0	0.93	0.69	0.10	-0.04	1.01
CW 2003 model	0.5	0.92	0.49	0.71	-0.40	3.28
	1	0.89	0.52	0.98	-0.47	4.70

Notes: For each model and each value of the preference parameter λ, this table indicates the optimal coefficient values (ρ, α,β,β_1) in a four parameter instrument rule without a reaction of the interest rate to an exchange rate measure and $\chi = 0.5$.

The coefficient on Q4-Q4 inflation (α) varies across the models. In the Small IMF model it is lowest with a value of 0.26 in the scenario with no weight on output gap variability (λ=0), whereas in the EU Quest model it is optimal for monetary policy to have a tight monetary stance and $\alpha = 1.12$.

There is also a lot of variation in the parameters on the contemporaneous and lagged ouput gap. The coefficient on the former is almost zero in all models except of the Small IMF model and the Small IMF Czech model in the scenario with $\lambda = 0$. Not surprisingly the optimal coefficient on inflation in the policy rule decreases and the coefficients on the output gap increase with a higher weight on output variability in the loss function. Interestingly all DSGE models seem to prefer output growth in the policy rule. The coefficient on the lagged output gap (β_1) is of almost equal size but shows a negative sign as opposed to the coefficient on the contemporaneous output gap. This does not hold in the Taylor model or the CW 2003 model.

Table 2: Optimized rules with response to the real exchange rate

Model	λ	ρ	α	β	β_1	γ	$\mathcal{L}$
	0	0.97	0.25	0.50	-0.48	0.00	0.40
Small IMF model	0.5	1.04	0.14	0.85	-0.81	0.00	0.87
	1	1.08	0.15	1.43	-1.36	0.00	1.26
	0	0.93	0.55	0.35	-0.29	0.03	2.23
Small IMF Czech model	0.5	0.99	0.53	1.67	-1.55	0.02	4.06
	1	1.04	0.48	2.54	-2.39	0.01	5.62
	0	1.03	1.12	0.11	-0.11	0.00	0.40
EU-Quest model	0.5	1.03	0.96	0.45	-0.29	0.00	1.80
	1	1.03	0.87	0.73	-0.46	0.00	3.04
	0	1.03	0.73	-0.03	0.02	0.00	0.23
SR-EU model	0.5	1.08	0.12	1.70	-1.73	0.00	2.66
	1	1.06	0.09	2.59	-2.63	0.00	4.21
	0	1.00	0.65	-0.01	0.00	0.04	1.27
SR-Sweden model	0.5	1.01	0.47	0.82	-0.74	0.03	4.81
	1	1.02	0.29	1.40	-1.29	0.02	7.39
	0	0.98	0.51	0.09	0.02	0.00	1.68
Taylor model	0.5	0.96	0.32	0.41	0.18	0.00	5.83
	1	0.95	0.24	0.60	0.26	0.00	8.79
	0	0.93	0.69	0.10	-0.04	0.00	1.01
CW 2003 model	0.5	0.93	0.51	0.72	-0.39	0.01	3.28
	1	0.90	0.56	0.98	-0.42	0.01	4.70

Notes: For each model and each value of the preference parameter λ, this table indicates the optimal coefficient values (ρ, α,β,β_1,γ) in a five parameter instrument rule and $\chi = 0.5$.

If one compares the findings in table (1) with the one in table (2), where we include the real exchange rate in the policy rule, all the findings in the former table still hold. One can also see that the result of Coenen and Wieland (2002) still holds for almost all models. The coefficent γ is zero in four out of six models in all scenarios and furthermore including the real exchange rate in the policy rule does not lead to any welfare improvements. The two exceptions are the Small IMF Czech model, where γ is slighly positive and there is a small decrease in the loss and the SR-Sweden model, where the welfare improvement is more pronounced.

Table 3: Optimized rules with response to the change in the nominal exchange rate

Model	λ	ρ	α	β	β_1	γ	$\mathcal{L}$
	0	0.98	0.26	0.56	-0.53	0.00	0.40
Small IMF model	0.5	1.07	0.14	0.95	-0.90	0.00	0.87
	1	1.09	0.16	1.52	-1.45	0.00	1.26
	0	0.97	0.63	0.79	-0.71	-0.01	2.24
Small IMF Czech model	0.5	1.02	0.63	2.31	-2.16	-0.07	4.04
	1	1.05	0.59	3.28	-3.10	-0.09	5.57
	0	1.03	1.13	0.11	-0.11	0.01	0.40
EU-Quest model	0.5	1.03	0.97	0.45	-0.29	0.00	1.80
	1	1.04	0.85	0.72	-0.47	-0.01	3.04
	0	1.03	0.72	-0.04	0.02	0.01	0.23
SR-EU model	0.5	1.08	0.12	1.71	-1.75	0.01	2.66
	1	1.06	0.08	2.60	-2.64	0.01	4.21
	0	1.08	0.78	0.07	-0.04	0.22	1.28
SR-Sweden model	0.5	1.08	0.36	0.99	-0.91	0.25	4.71
	1	1.07	0.16	1.49	-1.42	0.25	7.13
	0	0.98	0.51	0.09	0.02	0.00	1.68
Taylor model	0.5	0.96	0.32	0.41	0.18	0.00	5.83
	1	0.95	0.24	0.60	0.27	0.00	8.79

Notes: For each model and each value of the preference parameter λ, this table indicates the optimal coefficient values (ρ, α,β,β_1,γ) in a five parameter instrument rule and $\chi = 0.5$.

If one uses in table (3) the change in the nominal exchange rate instead of the real exchange rate in the policy rule, the same picture emerges. But the coefficient on the exchange rate is higher and also the welfare improvements in the Small IMF Czech model and SR-Sweden model are higher compared to the baseline results, if there is some weight on output gap variability in the loss function. By how much does the economy's welfare improve in the SR-Sweden model, if the swedish central bank would also take the change in the nominal exchange rate into account when adjusting the policy rate? We find that the loss decreases between 5-11%, which is sizeable.

Table (4) contains the optimization results, if we include the change in real exchange rate in the policy rule. We only report the findings for the Small IMF Czech model and the two Swedish Riksbank models due to no changes in the results for the other models. Again the results are very similar to the ones in the former tables. The Small IMF Czech model seems to slightly prefer this exchange rate measure, whereas in the SR-Sweden model the welfare improvements are highest for the change in the nominal exchange rate in the policy rule.

Table 4: Optimized rules with response to the change in the real exchange rate

Model	λ	ρ	α	β	β_1	γ	$\mathcal{L}$
	0	0.97	0.63	0.83	-0.75	-0.02	2.24
Small IMF Czech model	0.5	1.02	0.62	2.41	-2.27	-0.08	4.03
	1	1.05	0.59	3.44	-3.26	-0.11	5.56
	0	1.03	0.72	-0.03	0.02	0.00	0.23
SR-EU model	0.5	1.08	0.12	1.71	-1.74	0.01	2.66
	1	1.06	0.09	2.61	-2.64	0.01	4.21
	0	1.07	0.82	0.06	-0.03	0.20	1.29
SR-Sweden model	0.5	1.07	0.43	0.96	-0.88	0.23	4.74
	1	1.05	0.20	1.41	-1.35	0.27	7.16

Notes: For each model and each value of the preference parameter λ, this table indicates the optimal coefficient values (ρ, α,β,β_1,γ) in a five parameter instrument rule and $\chi = 0.5$.

Higher weight on interest rate variability in the loss function

Table 5: Optimized rules with higher weight on interest rate variability

Model	λ	ρ	α	β	β_1	γ	$\mathcal{L}$
	0	0.99	0.43	0.61	-0.55	-0.01	2.44
Small IMF Czech model	0.5	1.03	0.44	1.55	-1.44	-0.05	4.24
	1	1.05	0.42	2.20	-2.07	-0.07	5.80
	0	1.04	0.51	0.02	-0.03	0.00	0.25
SR-EU model	0.5	1.08	0.07	1.21	-1.24	0.01	2.69
	1	1.06	0.06	1.95	-1.98	0.01	4.27
	0	1.08	0.56	0.07	-0.05	0.17	1.47
SR-Sweden model	0.5	1.08	0.32	0.68	-0.60	0.21	4.92
	1	1.07	0.14	1.05	-0.97	0.22	7.45

Notes: For each model and each value of the preference parameter λ, this table indicates the optimal coefficient values (ρ, α,β,β_1,γ) in a five parameter instrument rule with the change in the nominal exchange rate as exchange rate measure and $\chi = 1$.

How do the findings change if the policy maker prefers to keep the interest rate more stable and places more weight on interest rate variability in the loss function ($\chi = 1$)? We provide the results in table (5). Not surprisingly this leads to slightly more interest rate smoothing across all models and scenarios and the coefficients on inflation and the output gap decrease. But also the policy rate reacts less to exchange rate movements. In other words the policy maker adjusts the policy rate less. [4]

Different inflation measure in the loss function

In the analysis before we used Q4-Q4 inflation in the loss function. How do the results change if we use annualized quarterly inflation instead? One would expect a higher variability of annualized quarterly inflation compared to Q4-Q4 inflation after shocks due to a lower persistence in this measure and therefore more pronounced adjustments of the policy rate with respect to movements in inflation, which translates into a higher coefficient (α) on inflation in the policy rule.

[4]We also computed the optimization results for the other scenarios in this report with a higher weight on interest variability in the loss function ($\chi = 1$). But the findings are similar to the case with a lower weight and we found the same pattern that interest rate smoothing is slightly higher and the reaction to the other variables slightly lower in this case.

Table 6: Optimized rules with annualized inflation in the loss function

Model	λ	ρ	α	β	β_1	γ	$\mathcal{L}$
	0	0.95	0.78	0.57	-0.47	0.01	9.50
Small IMF Czech model	0.5	0.98	0.78	2.08	-1.90	-0.05	11.40
	1	1.03	0.70	3.21	-2.99	-0.08	13.01
	0	1.07	1.11	-0.10	0.08	0.00	0.46
SR-EU model	0.5	1.08	0.13	1.73	-1.76	0.01	3.04
	1	1.06	0.09	2.61	-2.65	0.01	4.62
	0	1.11	1.03	0.03	0.00	0.17	4.03
SR-Sweden model	0.5	1.09	0.62	0.93	-0.80	0.21	7.73
	1	1.08	0.24	1.45	-1.36	0.24	10.41

Notes: For each model and each value of the preference parameter λ, this table indicates the optimal coefficient values (ρ, α,β,β_1,γ) in a five parameter instrument rule with the change in the nominal exchange rate as exchange rate measure and $\chi = 0.5$.

This in confirmed by the optimization results in table (6). The coefficient on inflation increases significantly compared to the results in table (3), but the other coefficients including the coefficient on the exchange rate stay more or less constant.

4.2 The four parameter rule

In this subsection we set the parameter on the lagged output gap equal to zero, when optimizing the other coefficients of the policy rule. The results are displayed in table (7).

Table 7: Optimized rules with response to the real exchange rate

Model	λ	ρ	α	β	γ	$\mathcal{L}$
	0	0.85	0.20	0.00	0.00	0.40
Small IMF model	0.5	1.00	0.04	0.01	0.00	0.88
	1	0.99	0.04	0.02	0.00	1.28
	0	0.91	0.51	0.04	0.04	2.23
Small IMF Czech model	0.5	0.89	0.46	0.09	0.05	4.21
	1	0.89	0.43	0.12	0.06	6.03
	0	1.03	1.09	0.00	0.00	0.40
EU-Quest model	0.5	1.02	0.97	0.18	0.00	1.81
	1	1.03	0.92	0.32	0.00	3.07
	0	1.03	0.74	-0.01	0.00	0.23
SR-EU model	0.5	1.09	-0.02	-0.02	0.00	2.87
	1	1.08	-0.01	-0.03	0.00	4.84
	0	1.00	0.65	-0.01	0.04	1.27
SR-Sweden model	0.5	0.98	0.50	0.11	0.04	4.98
	1	1.00	0.40	0.20	0.04	7.92
	0	0.98	0.52	0.11	0.00	1.68
Taylor model	0.5	0.97	0.35	0.53	0.00	5.92
	1	0.97	0.27	0.75	0.00	8.95
	0	0.93	0.67	0.05	0.00	1.01
CW 2003 model	0.5	0.89	0.60	0.39	0.01	3.33
	1	0.84	0.71	0.70	0.01	4.75

Notes: For each model and each value of the preference parameter λ, this table indicates the optimal coefficient values (ρ, α,β,γ) in a four parameter instrument rule and $\chi = 0.5$.

One can see that in all DSGE models the value of the coefficient on the output gap (β) drops significantly and even turns negative like in the SR-EU model, which confirms the finding that these models seem to support output growth instead of the output gap in the policy rule. When one looks on the exchange rate coefficient, there is not much of a difference. Although in the Small IMF Czech model it is higher and also the welfare improvement increase in this scenario compared to the five parameter rule.

Table 8: Optimized rules with response to the change of the nominal exchange rate

Model	λ	ρ	α	β	γ	$\mathcal{L}$
	0	0.85	0.20	0.00	0.00	0.40
Small IMF model	0.5	1.02	0.03	0.01	0.00	0.88
	1	1.01	0.04	0.02	0.00	1.29
	0	0.93	0.53	0.07	0.02	2.27
Small IMF Czech model	0.5	0.92	0.49	0.13	0.02	4.32
	1	0.93	0.46	0.18	0.03	6.18
	0	1.03	1.09	0.00	0.00	0.40
EU-Quest model	0.5	1.02	0.98	0.19	0.00	1.81
	1	1.03	0.92	0.32	0.00	3.07
	0	1.03	0.74	-0.01	0.00	0.23
SR-EU model	0.5	1.09	-0.02	-0.02	0.00	2.87
	1	1.08	-0.01	-0.03	0.00	4.85
	0	1.08	0.77	0.03	0.22	1.28
SR-Sweden model	0.5	1.07	0.42	0.14	0.25	4.95
	1	1.08	0.22	0.18	0.25	7.86
	0	0.98	0.52	0.11	0.00	1.68
Taylor model	0.5	0.97	0.35	0.53	0.00	5.92
	1	0.97	0.27	0.76	0.00	8.95

Notes: For each model and each value of the preference parameter λ, this table indicates the optimal coefficient values (ρ, α,β,γ) in a four parameter instrument rule and $\chi = 0.5$.

We also optimized a policy rule with the change in the nominal exchange rate instead of the real exchange rate in a four parameter rule and show the results in table (8). The same picture emerges like in the case of a five parameter rule. The SR-Sweden model still seems to prefer the change in the nominal exchange rate as exchange rate measure at least with some weight on output variability in the loss function but in the Small IMF Czech model the finding changes. In the case of the four parameter rule this model seems to prefer the real exchange rate in the policy rule.

Risk premium

The two models of the Swedish Riksbank and the model of the International Monetary Fund capture movements of the nominal exchange rate, which are not due to changes in the fundamentals i.e. the interest rate differential or net foreign asset positions by an autocorrelated risk premium shock.

To see how the policy rule changes if the central bank responds to the risk premium shock directly, we optimize policy rules including lagged Q4-Q4 inflation, the lagged output gap and the risk premium shock and compare the findings to an equivalent rule with the change in the nominal exchange rate, which seems to be the preferable exchange rate measure given our loss function. Table (9) contains the comparison.

Table 9: Comparison of change in the nominal exchange rate and risk premium in the policy rule

Model	λ	ρ	α	β	γ	$\mathcal{L}$
Change in nominal exchange rate						
	0	0.92	0.50	0.07	0.03	2.38
Small IMF Czech model	0.5	0.91	0.46	0.13	0.04	4.46
	1	0.94	0.41	0.18	0.05	6.35
	0	1.08	0.76	0.03	0.21	1.28
SR-Sweden model	0.5	1.07	0.43	0.14	0.24	4.99
	1	1.08	0.23	0.18	0.25	7.96
Risk premium shock						
	0	0.79	0.48	0.02	-0.14	2.25
Small IMF Czech model	0.5	0.74	0.47	0.05	-0.18	4.19
	1	0.71	0.48	0.07	-0.21	5.97
	0	0.96	0.76	0.02	0.25	1.37
SR-Sweden model	0.5	0.94	0.64	0.16	0.20	5.23
	1	0.97	0.56	0.29	0.15	8.34

Notes: For each model and each value of the preference parameter λ, this table indicates the optimal coefficient values (ρ, α,β,γ) in a four parameter instrument rule, where α indicate the coefficient on lagged Q4-Q4 inflation and β the coefficient on lagged output gap and $\chi = 0.5$.

We find the rule with a direct response to the risk premium shock to dominate the one including the nominal exchange rate in the Small IMF Czech model. The loss decreases between 5-6% compared to the scenario with the change in the nominal exchange rate in the policy rule. But this does not hold in the SR-Sweden model. Here the loss in the case with the change in the nominal exchange rate is between 4-6% lower than with a direct response to the risk premium shock.

4.3 The three parameter rule

Now we also set the parameter on the lagged interest rate (ρ) equal to zero and optimize three parameter rules. We start again by looking on a policy rule, which includes the real exchange rate as exchange rate measure. The results are displayed in table (10).

Table 10: Optimized rules with response to the real exchange rate

Model	λ	α	β	γ	$\mathcal{L}$
	0	1.00	-0.05	0.00	0.52
Small IMF model	0.5	1.00	-0.04	0.00	1.01
	1	1.00	-0.02	0.00	1.46
	0	1.51	-0.05	0.00	4.22
Small IMF Czech model	0.5	1.59	0.04	0.01	6.16
	1	1.66	0.13	0.03	7.99
	0	4.57	0.51	0.00	2.05
EU-Quest model	0.5	4.62	0.85	0.00	3.39
	1	4.50	1.15	0.00	4.66
	0	3.31	0.16	0.00	1.07
SR-EU model	0.5	3.36	0.53	0.02	5.12
	1	3.63	0.93	0.05	8.83
	0	2.32	-0.30	0.53	3.11
SR-Sweden model	0.5	2.30	0.07	0.48	6.73
	1	2.32	0.47	0.51	9.83
	0	3.01	0.23	0.01	5.21
Taylor model	0.5	3.30	0.54	0.00	11.43
	1	3.45	0.78	0.00	16.83
	0	2.73	-0.53	0.09	1.56
CW 2003 model	0.5	3.21	1.07	0.22	3.87
	1	3.52	2.18	0.39	5.36

Notes: For each model and each value of the preference parameter λ, this table indicates the optimal coefficient values (α,β,γ) in a three parameter instrument rule and $\chi = 0.5$.

The results show a very loose optimal monetary stance in the Small IMF model with a coeffcient on inflation of roughly 1. On the other hand the optimal response of the central bank with respect to inflation in the EU-Quest model is very tough. It increases the interest rate by around 4.5% if inflation increases by 1 %. We can also see significant welfare improvements in the SR-Sweden model compared to the case without exchange rate measure in the policy rule. The loss decreases between 9-21% depending on the weight on the output gap variance in the loss function. The CW 2003 model shows suprising results, too. Contrary to the cases with interest rate smoothing, optimal monetary policy suggests a considerable reaction to the real exchange rate and an welfare improvement between 6-7% compared to baseline.

Table 11: Optimized rules with response to the change in the nominal exchange rate

Model	λ	α	β	γ	$\mathcal{L}$
	0	1.00	-0.05	0.00	0.52
Small IMF model	0.5	1.00	-0.04	0.00	1.01
	1	1.00	-0.02	0.00	1.46
	0	1.51	-0.05	-0.01	4.22
Small IMF Czech model	0.5	1.58	0.04	-0.02	6.15
	1	1.64	0.13	-0.02	7.99
	0	4.68	0.57	0.05	2.04
EU-Quest model	0.5	4.64	0.92	0.06	3.37
	1	4.58	1.24	0.07	4.63
	0	3.32	0.16	0.02	1.07
SR-EU model	0.5	3.34	0.54	0.03	5.13
	1	3.60	0.94	0.03	8.85
	0	3.23	-0.11	1.10	3.31
SR-Sweden model	0.5	2.99	0.41	0.86	7.03
	1	3.00	0.99	0.84	10.26
	0	3.00	0.23	0.01	5.22
Taylor model	0.5	3.29	0.55	0.01	11.40
	1	3.45	0.80	0.02	16.77

Notes: For each model and each value of the preference parameter λ, this table indicates the optimal coefficient values (α,β,γ) in a three parameter instrument rule and $\chi = 0.5$.

Finally we look at the three parameter rule including the change in the nominal exchange rate in table (11). The findings are slightly different than in the case with the real exchange rate in the policy rule. For the EU-Quest model for example we find some response to the exchange rate in the policy rule and some welfare improvements in this case. In contrary to the case with interest rate smoothing, the welfare improvements in the Small IMF Czech model are negligible and the real exchange rate dominates the change in the nominal exchange rate as exchange rate measure in the SR-Sweden model.

5 Conclusion

Building on an approach by Levin et al. (2003) we minimize a loss function of inflation variation, output gap variation and interest rate variation and compute the optimal reaction of the central bank to inflation, output gap and a measure of the exchange rate in six different macroeconomic models, which vary in terms of size, countries they represent and frictions they include. Thereby we account for model uncertainty. We find that the result in Coenen and Wieland (2002) still holds for the majority of models we examined but not for all. Only two models, the SR-Sweden model of the Swedish Riksbank, estimated on Swedish data, and the Small IMF Czech model, derived by Researchers of the International Monetary Fund and calibrated on Czech data, show a significant reaction of the policy rate to the exchange rate and significant welfare improvements. We also showed that the change in the nominal exchange rate is the most preferred exchange rate measure in the SR-Sweden model in terms of loss improvements, if there is interest rate smoothing present. In the Small IMF Czech model the findings are more ambiguous and the real exchange rate can be dominating the change in the nominal exchange rate as preferred exchange rate measure depending on the scenario. Additionally we found that in the case of no interest rate smoothing other models like the CW 2003 model or the EU-Quest model show significant reactions to the exchange rate and welfare improvements.

For further research it would be interesting to see which frictions in the models or parameter values drive these different results. We can infer from the findings in this report that especially models, which are estimated or calibrated on data from small open economies like Sweden or the Czech Republic can generate welfare improvements through a reaction of the policy rate to the exchange rate.

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