Do Central Banks Respond to Exchange Rate Movements? A Markov-Switching Structural Investigation

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Abstract

Do central banks respond to exchange rate movements? According to Lubik and Schorfheide (2007) who estimate structural general equilibrium models with monetary policy rules, the answer is "Yes, some do". However, their analysis is based on a sample with multiple regime changes, which may bias the results. We revisit their original question using a Markov switching set up which explicitly allows for parameter changes. Fitting the data from four small open economies to the model, we find that the size of policy responses, and the volatility of structural shocks, have not stayed constant during the sample period (1982-2011). In particular, central banks in Sweden and the UK switched from a high response to the exchange rate in the 1980s and early 1990s, to a low response some time after inflation targeting was implemented. Canada also observed a regime change, but the decline in the exchange rate response was small relative to the increase in the response to inflation and output. Norway, on the other hand, did not observe a shift in the policy response over time, as the central bank has stayed in a regime of high exchange rate response prior and post implementing inflation targeting.

JEL-codes: C68, E52, F41

Keywords: Monetary policy, exchange rates, inflation targeting, markov switching, small open economy

1 Introduction

Do central banks respond to exchange rate movements? According to Lubik and Schorfheide (2007) who estimate structural general equilibrium models with interest rate rules for monetary policy in small open economies, the answer is "Yes some do". In particular, they find that the interest rate rules in Canada and the UK include responses to the nominal exchange rate, in addition to direct responses to the output gap and the inflation rate. Corroborating findings have been documented for Canada, New Zealand, Norway and Sweden in Bjørnland (2009) and Bjørnland and Halvorsen (2013) using structural vector autoregression (SVAR) models that allow for simultaneous responses between monetary policy and exchange rate changes.

During the period that Lubik and Schorfheide (2007) analyse (1983 to 2002), many countries went from having a formal exchange rate target to inflation targeting, either directly or via a period of informal exchange rate stabilisation (inside a band). Therefore, their analysis may be based on samples with multiple regime changes. Furthermore, different policy responses may also imply changes in volatility. In particular, one would expect that domestic business cycle fluctuations in open economies, especially those that are rich in natural resources, are likely to have a substantial international relative price component. Some inflation targeting central banks therefore may, in specific periods, have a specific interest in explicitly reacting to and smoothing exchange rate movements as a predictor of domestic volatility. Hence, assuming a time-invariant parameter reaction function as well as constant volatility during the sample period may bias the results.

Against this background, we analyse the importance of regime changes to the monetary policy responses and the shocks that hit small open economies. Our main focus is to explore whether inflation targeting central banks put the same weight on stabilising the exchange rate throughout the period independent of the known regime changes and the volatility of shocks. Furthermore, given that we observe a regime change, we analyse how this may have impacted the responses of output and inflation to structural shocks, and how the unconditional variances of endogenous variables have changed. A strong or weak response to the exchange rate may imply larger or smaller volatility of endogenous variables, depending on the cocktail of disturbance hitting the economy.

To answer these questions, we estimate a small open economy dynamic stochastic general equilibrium (DSGE) model, similar to the one put forward in Lubik and Schorfheide (2007), using Bayesian methods but allowing for independent Markov switching in the shocks that hit the economy and in the monetary policy responses.[1] The analysis is applied to four small-open-economy countries: Canada, Norway, Sweden and the UK, all of which have adopted inflation targeting during the period analysed, 1982 to 2011. Of these, Canada and the UK were included in the analysis of Lubik and Schorfheide (2007), while Norway and Sweden are new.

We contribute to the literature in the following ways. First, to the best of our knowledge, this is the first paper to address the specific question of regime shifts in the monetary

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[1] The DSGE model put forward in Lubik and Schorfheide (2007) is a simplified version of Galí and Monacelli (2005).

policy responses and volatility in small open economies. While Liu and Mumtaz (2011) also analyse regime shifts in the UK using a Markov switching open economy DSGE model, their focus is more general, analysing shifts in parameters and shocks to the whole DSGE model. Second, we use new solution algorithms, see Maih (2012). The algorithms rely on Newton methods developed in Maih (2012) and which extend Farmer et al. (2011). Third, in contrast to Lubik and Schorfheide (2007) who treat foreign output and inflation as unobservable (latent) variables, we include foreign (global) output and inflation explicitly as observables in the model in order to better identify the effects of foreign shocks. This helps to tie the dynamics of the small open economies model more explicitly to the global shocks. Finally, unlike Lubik and Schorfheide (2007), we do not detrend the data prior to the analysis.[2] We believe that non-filtered data are important to let the Markov-switching framework inform about medium-term changes in the dynamics of the data, which detrending effectively eliminates. Our maintained hypothesis is that the variables can be stationary but from different distributions reflected by different regimes.

We have two main findings. First, we find strong evidence that deep structural parameters and the volatility of structural shocks do not remain constant through the sample period in any of the four countries. Our results give a more nuanced picture of the weight that central banks give to stabilizing the nominal exchange rate. In particular, we find that the central banks in Sweden and the UK put less weight on stabilising the exchange rate, as measured by the response to the nominal effective exchange rate, when inflation targeting was adopted in the early 1990s. Canada also observed a regime switch, but a few years later. The switch implied a decline in the exchange rate response, but only relative to the increase in response to inflation and output. The change corresponds well with the time the Bank of Canada abandoned the systematic intervention in the foreign exchange market. For Norway, which formally adopted inflation targeting as late as 2001, we do not observe a systematic change in the response to the nominal effective exchange rate, which has remained high throughout the period analysed.

Second, we show that preceding the switch in policy response, Sweden and the UK in particular observed several episodes of high volatility, which may have contributed to the policy switch. During the last 15 years, however, while the periods of high volatility have been less common, they have also been more synchronised across countries.

The remainder of the paper is structured as follows. Section 2 describes the New Keynesian model for SOE, while the algorithms and the estimation procedure are described in Section 3. Data and priors are presented in section 4, and the results are reported in section 5. Section 6 discusses robustness, and Section 7 concludes.

2   A structural small open economy model

Our model is a simplified version of Galí and Monacelli (2005) which is adapted from Lubik and Schorfheide (2007).[3]. The model consist of a forward-looking (open economy)

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[2]Lubik and Schorfheide (2007) detrend the data using the Hodrick- Prescott (HP) filter.
[3]See also Del Negro and Schorfheide (2009) for a similar exposition.

IS equation, a Phillips curve, an exchange rate equation and a monetary policy (interest rate) rule.

Following Lubik and Schorfheide (2007), we rewrite the (consumption) Euler equation as an open economy IS-curve:

$$y_t = E_t y_{t+1} - (\tau + \lambda)(r_t - E_t \pi_{t+1}) - \rho_z z_t - \alpha(\tau + \lambda) E_t \Delta q_{t+1} + \frac{\lambda}{\tau} E_t \Delta y_{t+1}^*, \qquad (1)$$

where $0 < \alpha < 1$ is the import share (that measures the degree of openness), τ is the intertemporal substitution elasticity and we define $\lambda = \alpha(2 - \alpha)(1 - \tau)$. Note that the equation reduces to its closed economy variant when $\alpha = 0$. The endogenous variables are output y_t, the CPI inflation rate π_t and the nominal interest rate r_t. q_t is the terms of trade, y_t^* is world output, while z_t is the growth rate of an underlying non-stationary world technology process A_t. In order to obtain stationarity of the model, domestic and foreign output are both expressed in terms of percentage deviations from A_t.[4] We will assume that y_t^* and z_t are exogenous variables that evolve as AR processes with autoregressive coefficients ρ_{y^*} and ρ_z respectively.

Optimal price setting of domestic firms, together with an assumption of perfect risk-sharing across countries that links domestic potential output to foreign output, leads to the open economy Phillips curve

$$\pi_t = \beta E_t \pi_{t+1} + \alpha \beta E_t \Delta q_{t+1} - \alpha \Delta q_t + \frac{\kappa}{(\tau + \lambda)}(y_t - \bar{y}_t), \qquad (2)$$

where $\bar{y}_t \equiv -\alpha(2 - \alpha)(1 - \tau)/\tau y_t^*$ is domestic potential output in the absence of nominal rigidities. Again this reduces to the closed economy variant with $\alpha = 0$. In a standard New-Keynesian model, κ is the slope coefficient. It is related to the price stickiness, the degree of competition and the representative firm's cost function parameters. Like Lubik and Schorfheide (2007), we treat κ itself as structural, but we do not model the underlying structure of the production side of the economy.

Finally, when estimating the model, we add a demand shock ε_y to the IS equation and a cost push shock ε_π to the Phillips curve.

We introduce the nominal exchange rate (e_t) via the definition of consumer prices. Assume that relative Purchasing Power Parity (PPP) holds, we have:

$$\Delta e_t = \pi_t - (1 - \alpha)\Delta q_t - \pi_t^*, \qquad (3)$$

where π_t^* is world inflation. In our setup, the nominal exchange rate, domestic inflation, the terms of trade and foreign inflation are observable variables. Of these, the exchange rate and the domestic inflation rate are endogenous, while the other variables will be exogenous and follow AR-processes. The restriction underlying the PPP condition is

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[4]This implies that observed domestic and foreign output growth correspond to respectively Δy_t and Δy_t^* adjusted by productivity growth z_t.

therefore quite tight, and we allow for measurement errors in these variables. Since all variables are demeaned, equation 3 allow for a trend in the real exchange rate.

Monetary policy is described by an interest rate rule where we assume that the central bank can adjust its instrument in response to inflation, output and possibly also due to a nominal exchange rate depreciation:

$$r_t = \rho_r r_{t-1} + (1 - \rho_r)(\gamma_\pi \pi_t + \gamma_y y_t + \gamma_e \Delta e_t) + \epsilon_{r,t}, \tag{4}$$

We assume that the policy coefficients γ_π, γ_y and $\gamma_e \geq 0$. We also allow for a smoothing term in the rule, with $0 < \rho_r < 1$. $\epsilon_{r,t}$ is the exogenous monetary policy shock, which can be interpreted as the unsystematic component of monetary policy (deviation from rule). With this setup, the policy coefficients γ_π, γ_y, and γ_e should be interpreted as long-run responses - with high interest rate persistence, the estimated $\gamma's$ may be quite large, and still entail small immediate responses.

Finally, instead of solving endogenously for terms of trade, we follow Lubik and Schorfheide (2007) and add a law of motion for their growth rate to the system:

$$\Delta q_t = \rho_q \Delta q_{t-1} + \epsilon_{q,t}$$

3 The Markov-Switching DSGE model

In this section, we describe a general framework for the Markov switching DSGE or rational expectations model. Then we briefly discuss the solution method and the estimation approach. All the algorithms used for the computations in this paper are done using RISE, an object-oriented Matlab toolbox for solving and estimating Markov switching rational expectations (MSRE) models.[5]

3.1 The general framework

For a linear model like the one considered in this paper, the general Markov-switching rational expectations model can be written as [6]:

$$E_t \left\{ A_{s_{t+1}}^+ x_{t+1} (\bullet, s_t) + A_{s_t}^0 x_t (s_t, s_{t-1}) + A_{s_t}^- x_{t-1} (s_{t-1}, s_{t-2}) + B_{s_t} \varepsilon_t \right\} = 0 \tag{5}$$

x_t is a $n \times 1$ vector including all the endogenous (predetermined and non-predetermined) variables; $\varepsilon_t \sim N(0, I)$, is the vector of structural shocks. The regime index s_t, which could be a composite of states from different Markov chains, switches between a finite number of possibilities with cardinality h. And so, $s_t = 1, 2, ..., h$. (s_t, s_{t-1}) denotes the state today s_t and the state in the previous period s_{t-1}.

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[5]RISE is the acronym for "Rationality In Switching Environments". It is available free of charge at `https://github.com/jmaih/RISE_toolbox` and is being developed by Junior Maih.

[6]See Maih(2012) for the general nonlinear case.

The Markov transition probabilities are summarized by a matrix $Q = [p_{s_t,s_{t+1}}]$, where $p_{s_t,s_{t+1}} = prob(s_{t+1}|s_t)$, with $s_{t+1} = 1, 2, ..., h$. In other words, $p_{s_t,s_{t+1}}$ denotes the probability of going from state s_t in the current period to state s_{t+1} next period. This allows us to define the expectation

$$E_t A_{s_{t+1}} x_{t+1} (\bullet, s_t) \equiv \sum_{s_{t+1}=1}^{h} p_{s_t,s_{t+1}} A_{s_{t+1}} E_t x_{t+1} (s_{t+1}, s_t) \qquad (6)$$

3.2 Solution and stability

Solving the type of systems above is not straightforward and the traditional solution methods for constant-parameter DSGE models cannot be used. As can be seen from the problem, the solution in each state will be a function of the solution in all other states and vice-versa. To solve the system we rely on Newton methods developed in Maih (2012) and which extend Farmer et al. (2011).

The Newton method in Maih (2012) concentrates on minimum state variable (MSV) solutions of the form:

$$x_t (s_t, s_{t-1}) = T_{s_t} x_{t-1} (s_{t-1}, s_{t-2}) + R_{s_t} \varepsilon_t \qquad (7)$$

The traditional stability concepts for constant-parameter linear rational expectations models do not extend to the markov switching case. Following the lead of Svensson and Williams (2005) and Farmer et al. (2011), we characterize stable solutions using the concept of Mean Square Stability (MSS), borrowed from the engineering literature. See for instance, Gupta et al. (2003) or Costa et al. (2005).

Consider the MSRE system whose solution is given by equation (7) and with transition probability matrix Q. This system is MSS if for any initial condition x_0, there exist a vector μ and a matrix Σ independent of x_0 such that $\lim_{t \longrightarrow \infty} \|Ex_t - \mu\| = 0$ and $\lim_{t \longrightarrow \infty} \|Ex_t x_t' - \Sigma\| = 0$. A necessary and sufficient condition for MSS is that matrix Υ, has all its eigenvalues inside the unit circle.

$$\Upsilon \equiv (Q \otimes I_{n^2 \times n^2}) \begin{bmatrix} T_1 \otimes T_1 & & \\ & \ddots & \\ & & T_h \otimes T_h \end{bmatrix}$$

3.3 Estimation

In order to estimate the model, the likelihood has to be computed. Because of the presence of unobserved variables and unobserved states of the Markov chains, the likelihood has to be computed using a filtering procedure. The standard Kalman filter is not appropriate in this case because the information up to time t includes all the history of the states of the Markov chains. The most accurate filtering procedure should take into account

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all possible paths, which are multiplied by a factor of h (the number of states) at each iteration. This is infeasible. Kim and Nelson (1999) propose an approximation that makes filtering possible. Their strategy is to limit the number of states that are carried forward at each iteration of the Kalman filter. This is done through an operation called "collapse", which, essentially, averages across states.

Even when carrying forward only a few states, this filtering procedure is still expensive. Waggoner and Zha (2008)[7] exploit Kim and Nelson's idea and propose a variant in which the collapse occurs right after the prediction step of the Kalman filter, rather than right after the updating step as in Kim and Nelson (1999). The two approaches lead to numerically similar results and the Waggoner-Zha approach, which we follow, achieves those results with substantial computational savings. In both cases, the calculation of the probabilities is done using the Hamilton (1994) filter.

For the smoothing step, we adapt the Durbin and Koopman (2012) smoother for constant-parameter models. Our adaptation has the advantage of giving the same results as the Kim and Nelson (1999) smoothing procedure and also allowing smoothing based on the Waggoner-Zha filtering procedure.

The paper uses a Bayesian approach for estimating the models. In particular, we combine the likelihood, described above, with the prior density of the parameters, thereby forming the posterior kernel which we maximize to get the mode of the posterior distribution. While the estimate of the mode represents the most likely value, it also serves as a starting point for initializing the Markov chain Monte Carlo (MCMC) procedure aimed at constructing the full posterior distribution and computing the marginal data density (MDD).

Even for simple models as the one considered here, finding the mode is computationally challenging given that the posterior kernel has many peaks. Our optimization strategy is to use a stochastic grid search algorithm, which is derivative-free, to locate areas of the parameter space in which the global peak may lie and then use a Newton-based optimization procedure to climb to that peak.

4 Empirical implementation

We proceed with a discussion on the data, the choice of prior distribution for the Bayesian analysis and a description of the choice of parameters that are allowed to switch. We also discuss briefly the timing of policy changes that has actually taken place in history, such as when the central banks adopted inflation targeting.

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[7]See Zha (2011) for reference.

4.1 Data

We use quarterly data for the period 1982:2-2011:4.[8] For each country, there are seven observable variables: domestic real GDP, inflation, nominal effective exchange rate, terms of trade and short term interest rate, foreign output and inflation. In this respect, we differ from Lubik and Schorfheide (2007) as they do not use foreign observables in their estimations. All data except the nominal interest rate and the exchange rate are seasonally adjusted.

Output growth rates are computed as log differences of GDP and multiplied by 100 to convert them into quarter to quarter percentages. Inflation rates are defined as log differences of the consumer price indices and multiplied by 400 to obtain annualised percentage rates. We approximate foreign output and inflation based on US GDP and CPI inflation respectively.[9] We use the log differences (multiplied by 100) of the trade-weighted nominal effective exchange rate to obtain depreciation rates.[10] Percentage changes in the terms of trade are computed as log differences and multiplied by 100 while the nominal interest rate is measured in levels. All series are demeaned prior to analysis. For further details on data and the sources, see Appendix A.

4.2 Choice of priors and Markov switches

The choice of prior distribution for the structural parameters are presented in Table 1 along with the estimated posterior mode for a model with constant regime as a benchmark. With the exception of the parameter α, we allow for loose priors to entertain the idea that there has been multiple regime changes in the sample. α, which is the import share, is tightly centered around 0.2, as in Lubik and Schorfheide (2007).

For each country, we will allow for four competing Markov switching models; Time invariant (constant) regime, markov switch in volatilities only, switch in parameters in the policy rule only, and (independent) markov switch in volatility and parameters in the monetary policy rule. With four countries this implies that we will estimate a total of 16 models.

In the model that allows for regime switching in the open economy interest rate rule, we allow the parameters $\rho_r, \gamma_\pi, \gamma_y$ and γ_e to follow an independent two-state Markov process, where we denote the low response regime as $(coef, 1)$ and the high response regime as $(coef, 2)$. To compare systematically across countries, we normalize the high response regime $(coef, 2)$ to be the regime where the central bank responds strongly to the exchange rate, i.e. $\gamma_e(coef, 1) < \gamma_e(coef, 2)$.

In the model that allows for regime switching in the shocks, we let volatility of all structural and foreign shocks $\sigma_r, \sigma_z, \sigma_{y^*}, \sigma_{\pi^*}$ and σ_q to follow an independent two-state Markov

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[8]The start date reflects data availability for the interest rate series in Sweden.

[9]As an alternative, we constructed a global index calculated from the principal component of the GDP based on 27 different countries throughout the world. The results were robust to this change and can be obtained at request.

[10]Note that for an increase to correspond to a depreciation rate, we invert the exchange rate.

process, where we denote the low volatility regime as $(vol, 1)$ and the high volatility regime as $(vol, 2)$. Again, to compare systematically across countries, we normalize the high volatility regime $(vol, 2)$ to be the regime where the volatility (in productivity) is highest, i.e. $\sigma_z(vol, 1) < \sigma_z(vol, 2)$

4.3   Known policy changes - Inflation targeting

Before estimating the model, it is useful to acknowledge the periods of known policy changes that has taken place, such as when the central banks switched from a regime of exchange rate targeting to inflation targeting.

Canada adopted an inflation target in February 1991, but has changed the explicit target and range several times since then. However, since the end of 1995, the target for the annual rate of total consumer price inflation has been the 2 percent midpoint of a 1 to 3 per cent range. Until September 1998, the Bank of Canada intervened in the foreign exchange market in a systematic and automatic fashion to avoid significant upward or downward pressure on the Canadian dollar. Since September 1998, the policy has been to intervene only in exceptional circumstances.

Sweden and the UK switched to inflation targeting in the early 1990s after currency crises and the collapse of their fixed exchange rate regimes (to the ECU in the fall of 1992). The countries have adhered to a policy of not intervening systematically in the foreign exchange market since then.

In Norway, interventions to fix the exchange rate were abandoned in December 1992, and the foreign exchange regime thereafter became more flexible. Monetary policy was still oriented towards maintaining a stable exchange rate in relation to European currencies, although without defining a central exchange rate with fluctuation margins that should be defended by interventions. Eventually, in early 2001, a formal inflation targeting framework was adopted. However, the new framework in Norway was not communicated by policymakers as a regime change.[11]

We investigate whether empirical evidence of regime shifts and spurs of volatility can be extracted from the data, given our model framework.

5   Results

We start by comparing the parameter estimates in a time invariant model for Canada with the results in Lubik and Schorfheide (2007) before turning to our preferred multiple regime switching model.

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[11]The Norwegian central bank Governor at the time, Svein Gjedrem, stated in a speech in the fall of 2001 that "The new guidelines for monetary policy did not entail any significant change in the conduct of monetary policy. Quantifying an inflation target, in line with international practice, has made it easier to explain and understand Norwegian monetary policy.", see Gjedrem (2001).

5.1 Parameter estimates - Time invariant Rational Expectation Model

The estimation result for the posterior mode, along with the prior mode distribution[12] for Canada using a time invariant (constant) model is reported in Table 1.

Table 1: Canada: Constant model - Prior and posterior mode

Param	Prior distr	Prior prob	low	high	mode	mode_std
τ	Beta	0.9	0.17	0.83	0.62	1.81e-08
k	Gamma	0.9	0.12	0.87	0.32	1.48e-08
α	Beta	0.9	0.12	0.28	0.13	1.71e-08
ρ_q	Beta	0.9	0.1	0.8	0.36	0.0090
ρ_{y^*}	beta	0.9	0.4	0.8	0.95	0.0009
ρ_{π^*}	beta	0.9	0.1	0.8	0.41	0.0138
ρ_z	Beta	0.9	0.4	0.8	0.49	0.0052
ρ_r	Beta	0.9	0.05	0.948	0.89	0.0019
γ_π	Gamma	0.9	0.9	3	0.97	0.0001
γ_y	Gamma	0.9	0.1	3	3.00	0.0001
γ_e	Gamma	0.9	0.05	3	0.001	0.0001
σ_r	InvGam	0.9	0.005	1	0.002	0.0002
σ_q	InvGam	0.9	0.005	1	0.020	0.0011
σ_z	InvGam	0.9	0.005	1	0.005	0.0005
σ_{y^*}	InvGam	0.9	0.005	1	0.005	0.0004
σ_{π^*}	InvGam	0.9	0.005	1	0.019	0.0009
σ_y	InvGam	0.9	0.005	1	0.002	0.0005
σ_π	InvGam	0.9	0.005	1	0.012	0.0009

The table suggests structural parameters that are broadly aligned with the model parameters reported in Lubik and Schorfheide (2007), with the exception of the parameters on the policy reaction function, which suggests a higher weight on output and lower weight on the exchange rate. However, given that we allow for loose priors, include observable foreign variables and use a longer sample (9 years of extra data including the financial crisis at the end) this is not very surprising. In fact, we would argue that if the data are generated by different distributions reflected by different regimes, forcing a time invariant distribution to the data should potentially yield different results depending on the sample analysed.

Finally, Table 2 displays the results for the coefficients on the policy function for the other three countries (Norway, Sweden and the UK).[13] The results suggest a very high weight on the exchange rate in the policy reaction function in Norway, followed by Sweden, while in the UK, there is no exchange rate response. The coefficients for output are high in all countries, while the response to inflation varies from 0.4 in Norway to 1.4 in Sweden.

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[12]"Prior prob" indicate the mass of prior distribution between "low" and "high" parameter choices.

[13]Results for the other parameters that are not switching can be obtained upon request.

Table 2: Norway, Sweden and UK: Constant model - Policy parameters

Param	Prior distr	Prior prob	low	high	Norway	Sweden	UK
ρ_r	Beta	0.9	0.05	0.948	0.94	0.88	0.86
γ_π	Gamma	0.9	0.9	3	0.40	1.36	0.94
γ_y	Gamma	0.9	0.1	3	2.71	1.97	2.99
γ_e	Gamma	0.9	0.05	3	2.15	0.09	0.00

Hence, using a constant parameter model would lead us to conclude that there is virtually no exchange rate response in Canada and the UK, while the responses in Sweden and in particular in Norway, are more substantial. However, it is evidenced herein that there is a more nuanced picture when we allow the parameters to switch between different regimes.

5.2 Parameter estimates - Switching policy rule and volatility

Table 3 displays for all countries the posterior mode of the estimated parameters in a model with both switching volatility and policy responses. We find that the size of policy responses, and the volatility of structural shocks, have not remained constant during the sample period (1982 to 2011). For all countries, there is a substantial difference between the high and low volatility regimes and between the high and low policy response regimes.

We begin by investigating the coefficients on the policy reaction function, $\rho_r, \gamma_\pi, \gamma_y$ and γ_e. There is clear evidence that the central banks have responded strongly to the exchange rate in the high response regime $\gamma_e(coef, 2)$, while the response to inflation is highest in the low response regime $\gamma_\pi(coef, 1)$. Interest rate smoothing is also more pronounced in the low response regime, with the exception of Norway. The response to output varies between the different countries, with Canada and the UK responding more strongly to output also in the low response regime, while Norway and Sweden respond more strongly to output in the high response regime.

Hence, the low response regime can be characterized by an interest rate rule that emphasises interest rate smoothing and high inflation response, while the high response regime is characterized by high exchange rate response, and for Norway and Sweden, it is also characterised by high output responses. Among the countries, we find Norway to have the strongest interest rate response to the exchange rate, followed by Canada, Sweden and the UK. The probability of moving from a low to a high response regime, is also highest in Norway. For the other countries, the probability of moving from a high to a low response regime is higher.

Regarding the Markov state processes for volatility, all shocks display the highest volatility in regime $(vol, 2)$. However, in all countries, the probability of moving from a high to a low volatility regime is greater than moving from a low to a high volatility regime. Hence, all countries remain in the low volatility regime for most of the periods. Note that Norway stands out from the other countries in two respects, though. Volatility of its terms of trade is about six times higher (in the low volatility regime), see Table 3. This is most likely due to the relative size of the petroleum sector in that country. In equation

Table 3: Regime switches - Posterior mode

Param	Prior distr	Prior prob	low	high	Canada	Norway	Sweden	UK
τ	Beta	0.9	0.17	0.83	0.93	0.48	0.78	0.58
k	Gamma	0.9	0.12	0.87	0.57	1.09	0.14	0.05
α	Beta	0.9	0.12	0.28	0.15	0.46	0.18	0.16
ρ_q	Beta	0.9	0.1	0.8	0.25	0.97	0.06	0.04
ρ_{y^*}	Beta	0.9	0.4	0.8	0.95	0.97	0.96	0.96
ρ_{π^*}	Beta	0.9	0.1	0.8	0.48	0.36	0.58	0.25
ρ_z	Beta	0.9	0.4	0.8	0.50	0.79	0.63	0.44
$\rho_r(coef,1)$	Beta	0.9	0.05	0.95	0.93	0.07	0.95	0.94
$\rho_r(coef,2)$	Beta	0.9	0.05	0.95	0.76	0.97	0.10	0.67
$\gamma_\pi(coef,1)$	Gamma	0.9	0.5	3	0.57	0.85	0.13	0.37
$\gamma_\pi(coef,2)$	Gamma	0.9	0.5	3	0.48	0.51	0.12	0.35
$\gamma_y(coef,1)$	Gamma	0.9	0.1	3	3.41	2.11	2.00	3.69
$\gamma_y(coef,2)$	Gamma	0.9	0.1	3	1.91	2.94	3.15	0.77
$\gamma_e(coef,1)$	Gamma	0.9	0.05	3	0.10	0.001	0.001	0.001
$\gamma_e(coef,2)$	Gamma	0.9	0.25	3	0.11	4.069	0.061	0.080
$\sigma_r(vol,1)$	InvGam	0.9	0.005	1	0.002	0.003	0.001	0.001
$\sigma_r(vol,2)$	InvGam	0.9	0.005	1	0.003	0.008	0.002	0.003
$\sigma_q(vol,1)$	InvGam	0.9	0.005	1	0.012	0.064	0.010	0.009
$\sigma_q(vol,2)$	InvGam	0.9	0.005	1	0.035	0.039	0.019	0.019
$\sigma_z(vol,1)$	InvGam	0.9	0.005	1	0.004	0.003	0.003	0.003
$\sigma_z(vol,2)$	InvGam	0.9	0.005	1	0.007	0.011	0.009	0.010
$\sigma_{y^*}(vol,1)$	InvGam	0.9	0.005	1	0.004	0.003	0.004	0.004
$\sigma_{y^*}(vol,2)$	InvGam	0.9	0.005	1	0.018	0.015	0.012	0.010
$\sigma_{\pi^*}(vol,1)$	InvGam	0.9	0.005	1	0.017	0.009	0.010	0.018
$\sigma_{\pi^*}(vol,2)$	InvGam	0.9	0.005	1	0.033	0.063	0.034	0.048
$\sigma_y(vol,1)$	InvGam	0.9	0.005	1	0.002	0.007	0.002	0.002
$\sigma_y(vol,2)$	InvGam	0.9	0.005	1	0.004	0.009	0.007	0.004
$\sigma_\pi(vol,1)$	InvGam	0.9	0.005	1	0.010	0.019	0.015	0.011
$\sigma_\pi(vol,2)$	InvGam	0.9	0.005	1	0.030	0.008	0.039	0.020
coef_tp_1_2	Beta	0.9	0.001	0.3	0.005	0.111	0.005	0.005
coef_tp_2_1	Beta	0.9	0.001	0.3	0.010	0.010	0.018	0.017
vol_tp_1_2	Beta	0.9	0.001	0.3	0.027	0.005	0.027	0.055
vol_tp_2_1	Beta	0.9	0.001	0.3	0.164	0.111	0.165	0.253

(3), we impose relative purchasing power parity, with domestic inflation being the only endogenous variable. Output variance is also much higher in Norway than in the other countries - 2-3 times higher, which is again most likely due to the size of the petroleum sector.

With respect to the other structural parameters (that are not switching), three features should be noted. First, the parameter α that measures the degree of openness, is estimated to be largest in Norway, followed by Sweden, the UK and Canada. Hence, Norway is the most open country. Second, the parameter κ which measures the slope coefficient

Figure 1: Smoothed probabilities - Canada
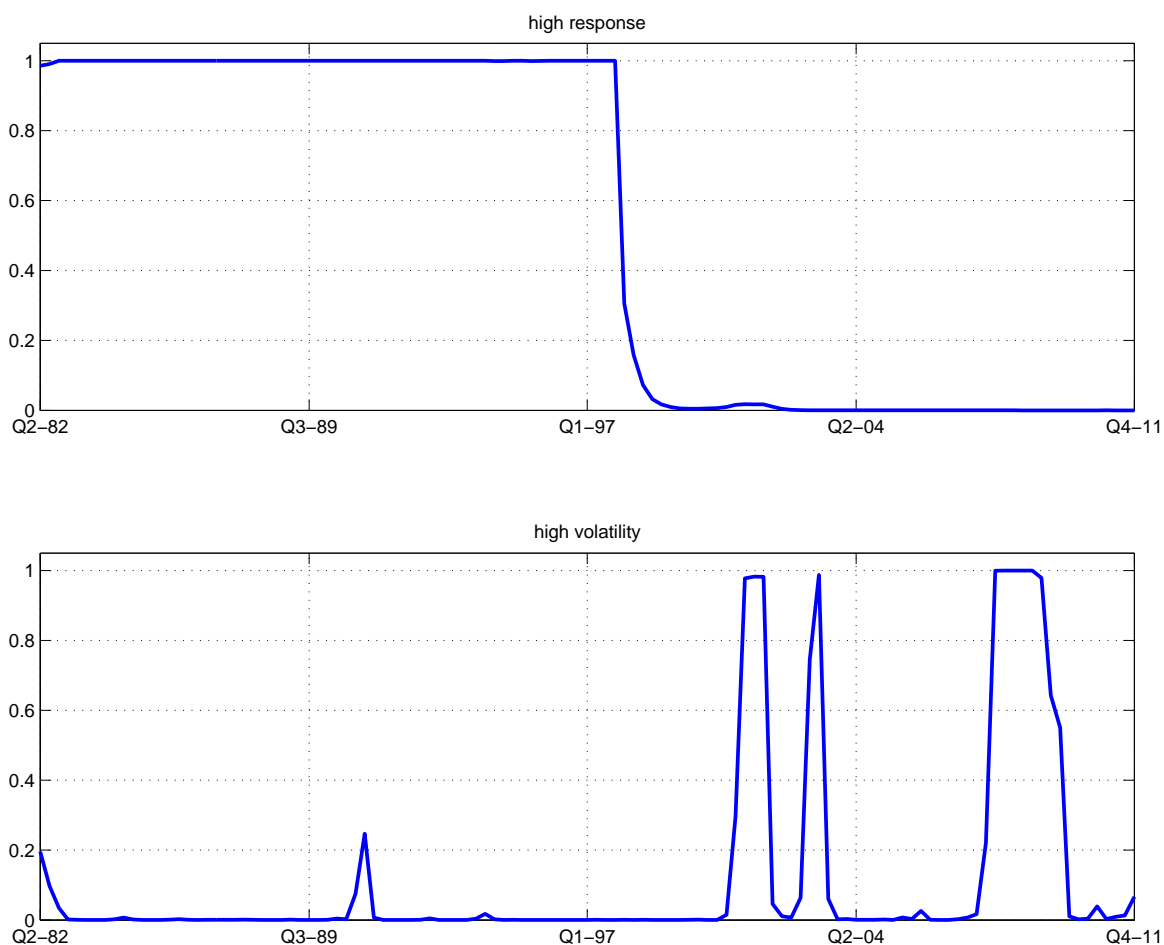
Note: The upper row displays the smoothed probabilities of being in a high policy response regime $(coef, 2)$ and the bottom row shows the probability of being in a high volatility regime $(vol, 2)$.

in the Phillips curve is estimated to be below one in all countries but Norway, where it is just above one. A high value for κ may relate to the fact that the output gap is also linked to foreign output, via the perfect risk-sharing assumption, thus implying that κ in our model reflects shocks to foreign output in addition to domestic productivity. Given that Norway is the most open of these countries, a high κ may also be reasonable. Third, the parameter τ, which measures the intertemporal elasticity of substitution, is highest in Canada. With a high elasticity, movements in foreign output does not contribute to the output gap, via the perfect risk-sharing condition. Furthermore, foreign output is dropped from the IS equation. As our measure for foreign output is US GDP growth, which may be closely correlated with Canadian output, foreign output may not give too much additional information regarding the Canadian case.

Figures 1,2, 3 and 4 display the smoothed probabilities in Canada, Norway, Sweden and the UK respectively. Each figure displays in the upper row the smoothed probabilities of being in a high policy response regime $(coef, 2)$ and in the bottom row, the probability of being in a high volatility regime $(vol, 2)$.

Figure 2: Smoothed probabilities - Norway

high response

high volatility
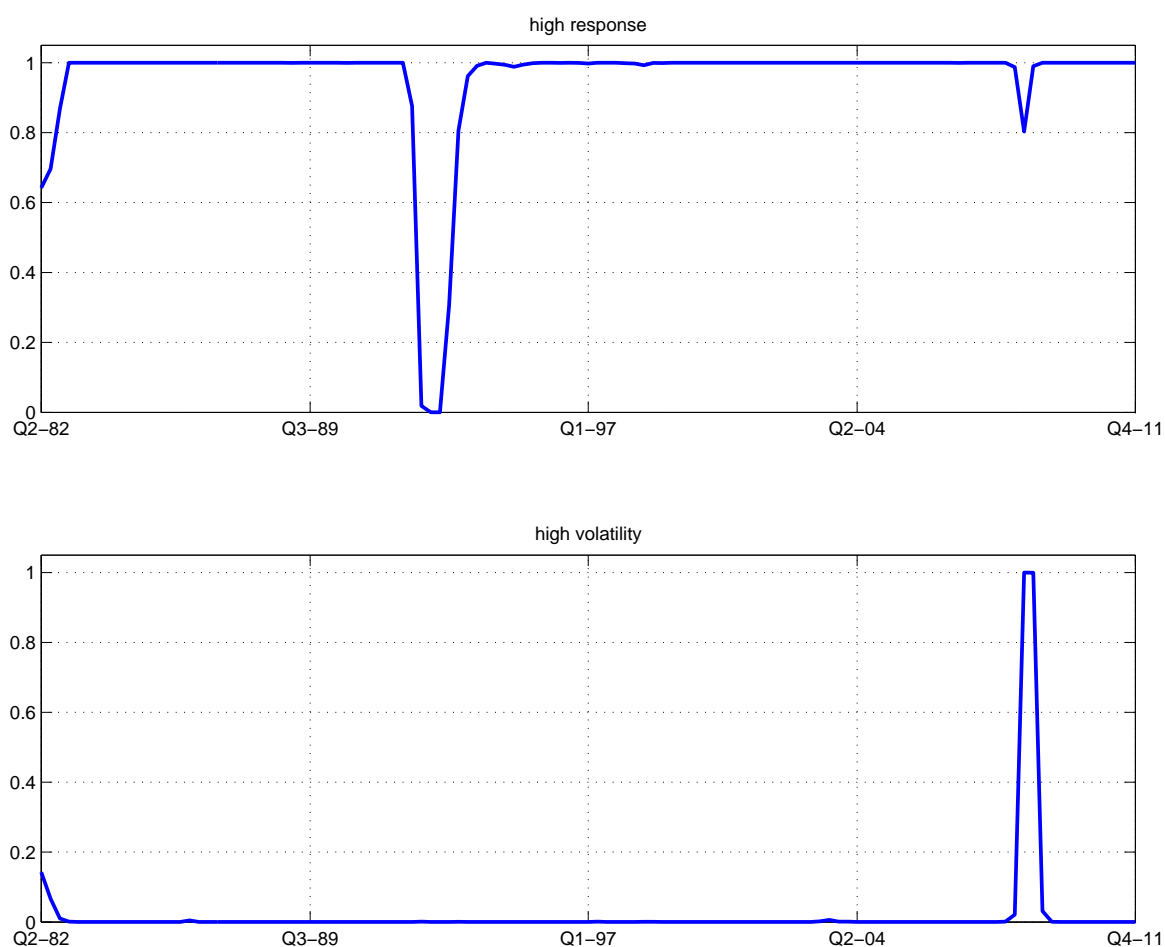
Note: See notes to Figure Figure 1 above.

The figures emphasise that the central banks in Sweden and the UK switched from primarily responding to the exchange rate in the 1980s, to responding more to inflation shortly after inflation targeting was implemented in the early 1990s. Canada also switched from a high to a low response regime throughout the sample, but the switch occurred a few years later, in 1997/1998, which corresponds to the time when the Bank of Canada stopped intervening systematically in the foreign exchange market, see the discussion in Section 4.3 and in Lama and Medina (2012).[14] Note, however, that the Central Bank in Canada still responds to the exchange rate, but the response has declined relative to the response in inflation and output, see Table 3.

The results for Norway are different. With the exception of the brief period in 1992/1993, the central bank has responded strongly to the exchange rate both prior and post implementing inflation targeting (in 2001). This regime also involves high output response.

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[14]Canada also targeted the exchange rate indirectly during periods in the 1990s by developing a monetary condition index (MCI) that encompasses both interest rate and exchange rate information as a more comprehensive indicator of the monetary stance.

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Figure 3: Smoothed probabilities - Sweden
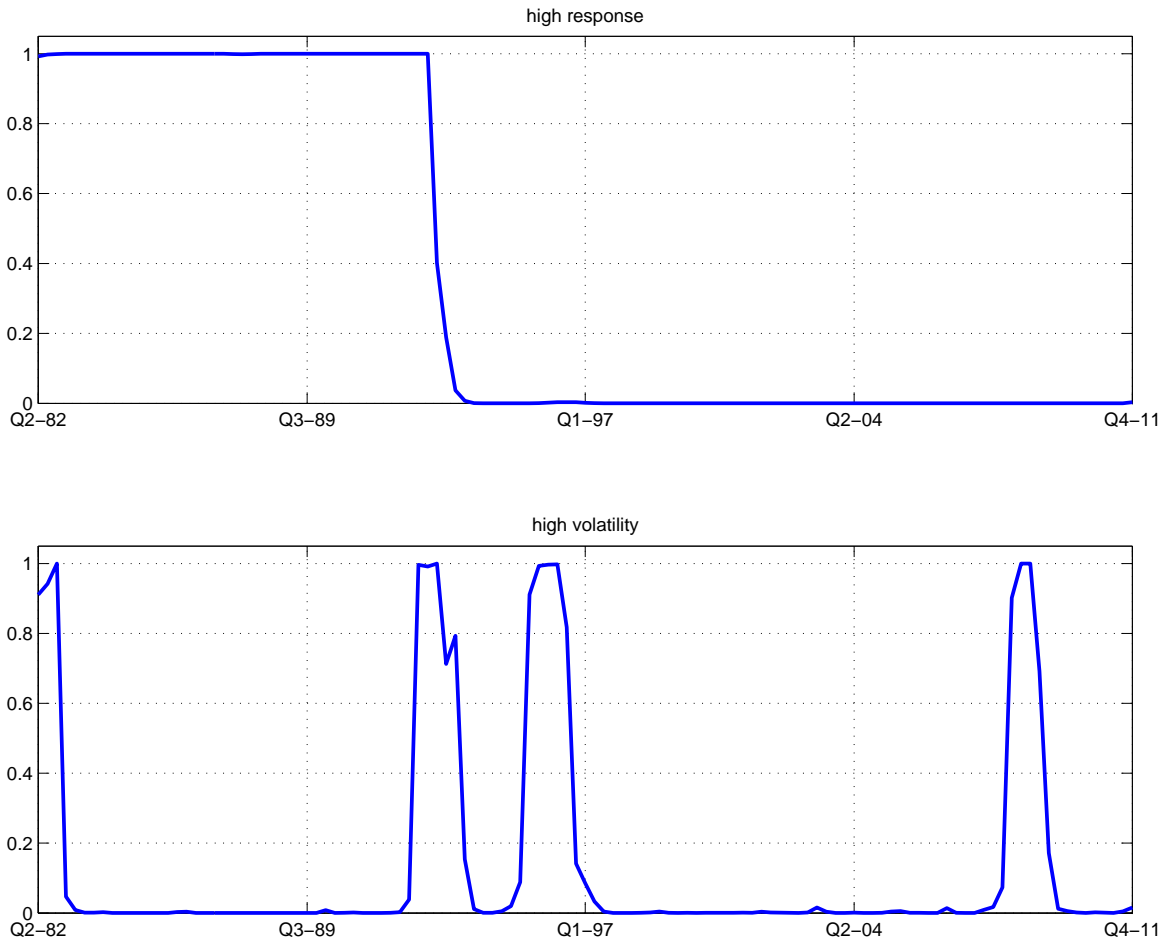
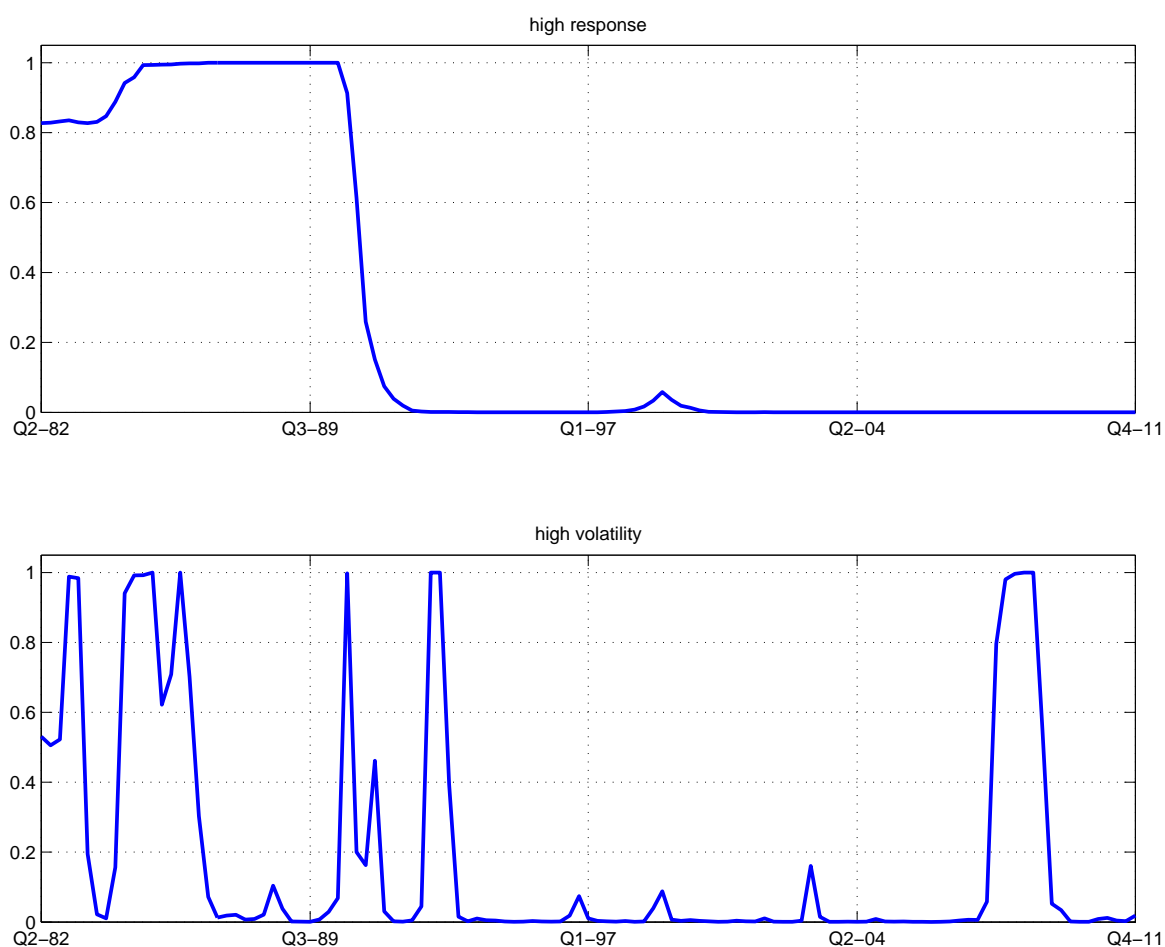*Note: See notes to Figure Figure 1 above.*

In 1992/1993 Norway stopped intervening in the foreign exchange market to defend the fixed exchange rate regime, and exited the strict exchange rate peg. This is being picked up as a regime switch by the data, and for 1-2 years, there is virtually no exchange rate response. The year after, the policy rule in Norway is again best described by a high response to the exchange rate (as well as a concern for output stabilisation).

Why is there no decline in the exchange rate response? First, and as discussed herein, of the countries analysed here, Norway adopted inflation targeting last. In doing so, policymakers also stressed that the new guidelines for monetary policy did not entail any significant change in the conduct of monetary policy, see Gjedrem (2001), and development in the exchange rate are still regularly discussed in the monetary policy reports.[15]

[15]Today Norges Bank communicates its policy intentions using forward guidance for the interest rate, and the analysis behind the interest rate path is based on optimal policy and on an ad hoc loss function, rather than on an interest rate rule. The exchange rate is not an argument of the (ad-hoc) loss function that the central bank of Norway refers to, though one would expect that optimal policy could involve some response to the exchange rate to the extent that the exchange rate affects inflation, output or other targets.

Figure 4: Smoothed probabilities - UK

Note: See notes to Figure Figure 1 above.

Second, note that the persistence of the interest rate is very high in the Norwegian high-response regime, and very low in the other regime, see Table 3. Hence, one interpretation of the data is that as the flexible exchange rate regime was visited in 1992/1993, the interest rate was established at a new and lower level. Indeed, as the peg was abandoned in 1992, there was only a limited depreciation of the exchange rate, which stands in some contrast to the Swedish experience as the Swedish krone depreciated sharply in the fall of 1992. Viewed in this way, the Norwegian case is somewhat similar to the Canadian case, with a fairly high exchange rate response in the interest rate both before and after authorities stopped intervening to peg the exchange rate. In all countries, the interest rate has stayed - or become more, persistent in the regimes that have been in place in the latter part of our sample period.

Turning to the lower panel of Figures 1,2, 3 and 4, there is a striking similarity in the timing of the switch between the high and low volatility regimes, although the weights in the policy rule vary from country to country. In particular, independent of the chosen policy rules, the probability of remaining in a regime of low volatility was high from the

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middle 1990s until 2004/2005 (the period often referred to a 'the Great Moderation'). There is also a high probability of staying in a high volatility regime during the period of the financial crisis in all countries. The period where the countries vary the most, is in the 1980s when Sweden and the UK experienced high volatility. Interestingly, these are also the two countries that first switched from a regime of high exchange rate response.

How do our results compare to the findings in Lubik and Schorfheide (2007)? Estimating a DSGE model with time invariant parameters, they find that the interest rate increases systematically following an exchange rate depreciation in all countries, but with Canada and the UK responding the most. Similar results (with the possible exception of the UK) are also found in Bjørnland (2009) and Bjørnland and Halvorsen (2013), estimating a structural VAR model with constant parameters.[16] However, when we allow for regime switches, we find that in Canada, Sweden and the UK, the response to the exchange rate was substantial early in the sample but declined sharply in the period after inflation targeting was implemented (with Canada observing the switch the latest). Hence, our results for Canada and UK modify the findings in Lubik and Schorfheide (2007), For Canada, our findings suggest that the central bank still responds to the exchange rate, but the response has declined relative to that of inflation and output.

Why would some countries still respond to the exchange rate in an inflation targeting regime? What we observe is most likely that central banks, under inflation targeting, allow the interest rate to respond to the exchange rate to the extent that it is considered important for achieving the inflation target. This may differ from country to country. It is interesting to observe, though, that the two resource rich countries are the countries that observe the highest response to the exchange rate, both in the high- and the low response regimes.

Finally, it should be noted that exchange rate targeting regimes that were in place in the countries studied herein involved targeting the dollar and the European currency unit. To the extent that such targeting was successful, there would still be movements in the nominal effective exchange rate. Given this, the identification of different regimes is all the more striking.

6   Robustness - Alternative regime switches

Our regime switching model suggests a reasonable picture of policy switches and spurs of volatility consistent with historical experience and information available from speeches and publication from the relevant Central Banks. However, to evaluate if the regime switching model gives an accurate description of the data, we could use a statistical criteria. Table 4 do this by comparing the log Marginal Data Density (MDD) Laplace approximation for the constant model with three alterative regime switching models; a model with switches in the parameters only, a model with switches in volatility only and

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[16]The SVAR models are identified with sign or long-run neutrality restrictions such that the monetary policy and the exchange rate can respond instantaneously to news.

Table 4: Model comparison - Log MDD (Laplace)

	Canada	Norway	Sweden	UK
Constant parameter model	2484	2240	2497	2525
Parameter only	2553	2218	2519	2505
Volatility only	2488	**2257**	2531	**2550**
Parameter and volatility	**2561**	2252	**2534**	2533

Table 5: Prior and poster mode, volatility only

Param	Prior distr	Prior prob	low	high	Canada	Norway	Sweden	UK
ρ_r	beta	0.9	0.05	0.948	0.87	0.95	0.90	0.90
γ_π	gamma	0.9	0.9	3	0.86	0.36	1.25	0.98
γ_y	gamma	0.9	0.1	3	2.99	1.48	1.00	2.99
γ_e	gamma	0.9	0.05	3	0.12	2.34	0.20	0.00

our chosen model with switches in volatility and parameters only.[17]

The results suggest that a model that allows for switches in both policy parameters and volatility is preferred to a constant parameter model in all countries. However, for two of the countries; Norway and the UK, a model that allows for switches in volatility (only) is marginally preferred to the model that allows for switches on both parameters and volatility. For Norway, this may come at no surprise, as Norway has been in a regime of high policy response throughout most of the sample period. Hence, a model that only allow for switches in volatility may capture well the Norwegian policy response. UK, on the other hand, had the lowest policy response of the countries analyzed here, and the period in which it responded to the exchange rate ended early in the sample. This could explain why the model which only allows for a switch in volatility is marginally favoured to a model with which allow for switches in both policy parameters and volatility.

What would the results have been if we had treated the policy parameters as constant, that is, only allowed for a switch in volatility? Table 5 displays the coefficients in the policy rule for all countries assuming a model that only allows for switches in volatility, while Figure 5 display the smoothed probabilities of being in a regime of (only) high volatility for all the countries. Both are displayed in Appendix B.

Table 5 confirms again that Norway responds the most to the exchange rate, followed by Sweden, Canada and the UK (that now has zero response like in the constant regime model). Figure 5 suggests that the model now interprets the period of known policy changes as spurs of high volatility instead, see in particular the the plots for Norway and the UK. As we know there was a formal policy switch away from fixed exchange rate regimes (characterised with interventions) to a more flexible regime, we believe our core model, that allows for switches in both policy response and volatility, provides a more accurate description of how the monetary policymakers have responded to exchange rate

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[17]Because the likelihood we work with is only approximate, we use the laplace approximation to the posterior distribution, see Christiano et al. (2011) for details on computation.

fluctuations over the sample analysed.

7 Conclusion

We analyse whether central banks in small open economies respond to the exchange rate. Using a Markov switching DSGE model that explicitly allow for parameter changes, we observe that the size of policy responses and the volatility of structural shocks, have not remained constant during the sample period (1982-2011).

In particular, central banks in Sweden and the UK switched from primarily responding to the exchange rate (and output) in the 1980s to inflation shortly after inflation targeting was implemented in the early 1990s. Canada also observed a regime switch, but the switch came a few years later, in 1997/1998. However, the decline in exchange rate response was relative to an increase in responding to inflation and output.

Such a decline in exchange rate response over time has not been observed in Norway, where the central bank has responded strongly to the exchange rate before and after implementing inflation targeting.

References

Bjørnland, H. C. (2009). Monetary policy and exchange rate overshooting: Dornbusch was right after all. *Journal of International Economics 79*(1), 64–77.

Bjørnland, H. C. and J. I. Halvorsen (2013). How does monetary policy respond to exchange rate movements? New international evidence. *Oxford Bulletin of Economics and Statistics*, Forthcoming.

Christiano, L. J., M. Trabandt, and K. Walentin (2011). DSGE models for monetary policy. In B. Friedman and M. Woodford (Eds.), *Handbook of Monetary Economics, Volume 3A*, pp. 285–367. Elsevier.

Costa, O., M. Fragoso, and R. Marques (2005). *Discrete-time Markov jump linear systems*. Springer.

Del Negro, M. and F. Schorfheide (2009). Inflation dynamics in a small open economy model under inflation targeting: Some evidence from Chile. *Central Banking, Analysis, and Economic Policies Book Series 13*, 511–562.

Durbin, J. and S. J. Koopman (2012). *Time series analysis by state space methods*. Oxford University Press.

Farmer, R., D. Waggoner, and T. Zha (2011). Minimal state variable solutions to markov-switching rational expectations models. *Journal of Economic Dynamics and Control 35*(12), 2150–2166.

Galí, J. and T. Monacelli (2005). Monetary policy and exchange rate volatility in a small open economy. *Review of Economic Studies 72*, 707–734.

Gjedrem, S. (2001). Norwegian monetary policy in the age of the euro. Speech at the conference on EMU and the euro hosted by The European Commission, Euro-Info Centre and NHO, Oslo, 30 October 2001, Norges Bank.

Gupta, V., R. Murray, and B. Hassibi (2003). On the control of jump linear markov systems with markov state estimation. In *American Control Conference, 2003. Proceedings of the 2003*, Volume 4, pp. 2893–2898. IEEE.

Hamilton, J. (1994). *The Time Series Analysis*. Princeton University Press.

Kim, C.-J. and C. R. Nelson (1999, November). Has the U.S. economy become more stable? A bayesian approach based on a markov-switching model of the business cycle. *The Review of Economics and Statistics 81*(4), 608–616.

Lama, R. and J. P. Medina (2012). Is Exchange Rate Stabilization an Appropriate Cure for the Dutch Disease? *International Journal of Central Banking 8*(1), 5–46.

Liu, P. and H. Mumtaz (2011). Evolving macroeconomic dynamics in a small open economy: An estimated markov switching DSGE model for the UK. *Journal of Money, Credit and Banking 43*(7), 1443–1474.

Lubik, T. A. and F. Schorfheide (2007). Do Central Banks respond to exchange rate movements? A structural investigation. *Journal of Monetary Economics 54*, 1069–1087.

Maih, J. (2012). New solutions to first-order perturbed markov switching rational expectations models. Mimeo, International Monetary Fund.

Svensson, L. and N. Williams (2005). Monetary policy with model uncertainty: distribution forecast targeting. Technical report, National Bureau of Economic Research.

Zha, T. (2011). Nonlinearity in markov-switching structural models. Presentation at 1 September 2011 European Central Bank Workshop on "The role of non-linear methods in empirical macroeconomics and forecasting".

Appendices

Appendix A   Data and sources

We use the trade-weighted nominal effective exchange rate, NEER, from the IMFs IFS database for all countries. Note that in order to make an increase correspond to a depreciation rate, we invert the NEER. For the other series, we use the following:

Canada:

Terms of trade data are from the OECD Economic Outlook.

The short term interest rate is the average 3-Month Treasury Bill Yield from the Bank of Canada.

The CPI is from OECD MEI. We have seasonally adjusted it.

Real GDP is from Statistics Canada, SA.

Norway

Terms of trade data are from Statistics Norway, SA.

The interest rate is three month NIBOR interest rate, Norges Bank.

CPI is from Statistics Norway, SA.

Real GDP data is from Statistics Norway, SA.

Sweden

Terms of trade data are from Statistics Sweden, SA.

The short term rate is average quarterly short term rate from the Swedish Riksbank from 1982.

The CPI data is from Statistics Sweden, SA.

Real GDP is from OECD MEI, we have seasonally adjusted it.

United Kingdom

Terms of trade data are from the Office for National Statistics, SA

The interest rate is the three month interbank rate taken from OECD MEI [OECD_MEI'GBR.IR3TIB01.

The CPI is from OECD MEI [GBR.CPALTT01.IXOB.Q]. We have seasonally adjusted it.

Real GDP data is from the Office for National Statistics, SA
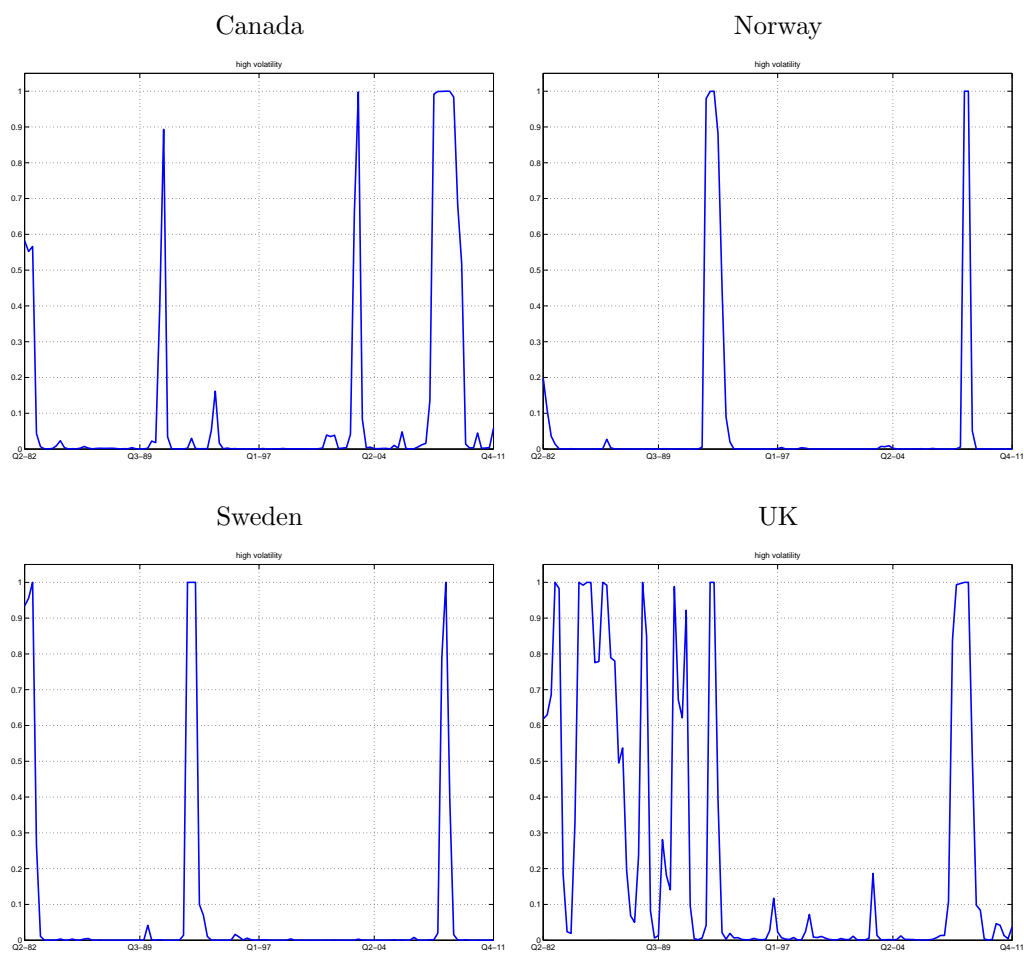
Foreign GDP and Inflation

for the foreign variables, we use US data.

Real GDP is U.S.: Gross Domestic Product (SAAR, Bil.Chn.2005$), from the Bureau of Economic Analysis, S.A.

The CPI is from the Bureau of Labor Statistics, SA.

Appendix B   Extra figures

Figure 5: Smoothed probabilities, high volatility

Canada

Norway

Sweden

UK

Note: The figures display the smoothed probabilities of being in a high volatility regime $(vol, 2)$.

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