The Riksbank and International Interest Rate Dynamics

UNIVERSITY OF GOTHENBURG
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Master Thesis in Economics, 30 HEC

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Abstract

Based on the case of Sweden, this thesis studies the relationship between the nominal interest rate in a small open economy and the interest rates of the country's trading partners. Cross-country interest rate differentials affect domestic economic conditions through two channels; the exchange rate channel and via capital flows. This means that interest rate differentials can have both expansionary and contractionary effects, depending on the circumstances. Contrary to common theoretical monetary policy frameworks, which model international aspects only through its effect on domestic conditions, there are good arguments that interest rate differentials affect a central bank's considerations in a small open economy. This thesis presents empirical support suggesting a significant positive relationship between the Swedish Repo Rate and a trade-weighted foreign interest rate. The positive relationship is robust through different estimation techniques. Based on the empirical results, the thesis proposes a theoretical framework for modelling such a dependency structure using a DSGE model. The thesis concludes that international dynamics should be considered in macroeconomic models that analyze the interest rates of small open economies.

Keywords: Interest Rate; International Dynamics; Capital Flows; Small Open Economies; DSGE; Riksbank; Sweden

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1 Introduction

This Master Thesis in Economics studies the relationship between the interest rate of a small open economy and a trade-weighted interest rate of its trading partners. The underlying hypothesis is that common theoretical monetary policy frameworks, which only capture international dynamics through its indirect impact on inflation and economic activity, underestimate the effect of cross-country interest rate differentials for small open economies. This hypothesis is evaluated using data for Sweden, covering the period from 1993 to 2018.

Interest rate changes coming from abroad can affect the domestic economy through mainly two channels. Firstly, the interest rate differential between two countries affects the exchange rate between the countries' currencies. A positive interest rate differential between the home country and the foreign country suggests that the exchange rate will appreciate, making imports cheaper and exports more expensive (Engel et al., 2018). This will in turn deteriorate the current account and have a negative impact on economic activity. The second channel captures the effect of interest rate differentials on capital flows between the countries. Here a negative interest rate differential will lead to an inflow of capital to the home country. These two channels illustrate why a central bank in a small open economy has reasons to consider its interest rate differential towards other countries. Assuming that the central bank strives to minimize this differential, there would be a significant positive effect between the domestic and the foreign interest rate if the hypothesis stated above holds true.

The purpose of this thesis is to investigate the impact of interest rate differentials on central bank's interest rate decisions in small open economies. The empirical question raised here is studied using Swedish data from 1993 to 2018. That is the complete period of Swedish inflation targeting and flexible exchange rate. Sweden is a small open economy, where the value of its exports and imports in nominal terms correspond to about half the size of GDP (Statistics Sweden, 2019). Since Sweden is not a member of the Economic and Monetary Union it has sovereign control of its monetary policy. Also, the institutional framework for Swedish monetary policy has been relatively stable since 1993. Altogether this makes Sweden a suitable choice for evaluating the hypothesis that international interest rates matter for the domestic interest rate decision of a small open economy.

The results presented in the thesis are in line with the underlying hypothesis. Impulse responses generated from *local projections (LP)* and a *structural VAR (SVAR)* model show a significant positive effect of a foreign monetary policy shock on the Riksbank's most important interest rate, the *Repo Rate*. This relationship is robust through different choices of lag lengths and different estimation techniques. Based on Bayesian analysis, the *Dynamic Stochastic General Equilibrium (DSGE)* model estimates a positive response from the Riksbank to a foreign interest rate change, which in magnitude is equivalent to its response to an inflation change. The results thereby suggest that the differentials between domestic and foreign interest rates should be considered in both empirical analysis and in theoretical modelling.

The empirical analysis provides policy relevant results that contribute to the understanding of how the interest rate in a small open economy is determined. While economic outcomes of the effects of interest rate differentials, such as exchange rate movements and capital flows, are well-researched topics, the same is not true for the direct impacts of interest rate differentials. If such differentials are important for a central bank's interest rate decision, it suggests the need for an analytical framework that gives importance international dynamics. The incorporation of a foreign monetary policy rule and an interest rate differential in the domestic monetary policy rule in the presented DSGE model, facilitate theoretical modelling of international interest dynamics.

The rest of the thesis is structured as follows. Section 2 contains a literature review that describes previous research on this topic, while Section 3 presents the data used for the empirical analysis. Section 4 focuses on the empirical relationship between the foreign interest rate and the Riksbank's Repo Rate. Additionally, this section describes the methodological frameworks. In Section 5 a DSGE model that incorporates a foreign monetary policy rule is presented. This framework is used for estimating the key parameters of the derived Riksbank's reaction function, leading to more evidence of a positive relationship between the foreign interest rate and the Repo Rate. Finally, in Section 6, conclusive remarks are presented.

2 Literature Review

There are mainly two channels through which foreign interest rates can affect domestic economic conditions; the exchange rate channel and through capital flows. This section discusses these two channels based on previous research as well as additional important aspects of Swedish monetary policy.

The exchange rate channel in the monetary transmission mechanism captures the effect of monetary policy on the exchange rate. The interest rate affects the real exchange rate, which in turn impacts net-exports and thereby economic activity (Mishkin, 1995). The exchange rate channel emerges from the fact that interest rate differentials leads to capital flows between countries. Under the assumption that domestic and foreign assets are perfect substitutes and flexible exchange rates, the Mundell-Fleming model predicts that expansionary monetary policy will create an outflow of capital that depreciates the exchange rate. The depreciation will continue until a new equilibrium is reached. Hence, in contrary to a scenario with a fixed exchange rate, with a floating exchange rate monetary policy can be used to affect economic activity (Mundell, 1963). In another well-known macroeconomic model, Dornbusch (1976) states that a monetary expansion under perfect capital mobility leads to an expected long-run depreciation, which creates an outflow of capital and depreciates the current exchange rate.

Cross-country capital flows can in themselves be a reason for why central banks should consider interest rate differentials. Capital will leave the low-interest country in favor of the high-interest country and the inflow of capital has an ambiguous effect on GDP. It can raise investments and thereby have a positive impact on economic activity, but it can also increase the demand for the home country's currency, which will cause an appreciation that affects output negatively through the exchange rate channel (Blanchard et al., 2017). Additionally, large inflows of capital can lead to the creation of asset price bubbles and can also, through their volatility and unpredictability, create a balance of payment crisis (Reinhart & Reinhart, 2008). Rey (2014) states that credit flows are pro-cyclical and is positively related to asset price inflation.

Most of the research concerning capital flows and balance of payments crises are centered around emerging economies, see for instance Calvo (1998) and Blanchard (2017). However, large capital inflows can also have a destabilizing effect in more advanced economies. Reinhart and Reinhart (2008) states that while emerging economies are more sensitive to "capital flow bonanzas", that is periods with high capital inflows, these periods also increase the uncertainty of macroeconomic outcomes in advanced economies. Raza et al. (2019) describe how the dynamics of capital inflows can destabilize a small open economy. A positive interest rate differential towards the rest of the world, leads to an inflow of capital, which in turn causes rapid growth, increased debt, trade balance issues and an overvalued exchange rate. The external debt can eventually reach such high levels that questions regarding the possibility of repaying loans are raised. This could then lead to a sudden stop of inflow, which will transmit itself into a balance of payment crisis, a financial crisis and a crisis for the real economy.

During the global financial crisis of 2008 capital movements played an important role in the dynamics of the crisis. Using the framework described above, Zoega (2016) and Raza and Zoega (2019) illustrate the dynamics of the Icelandic financial crisis in 2008, where a sudden stop of capital inflows created financial turmoil and a crisis for the real economy. International capital flows also played an important role in creating financial bubbles, that later burst during the crisis, for countries in the Economic and Monetary Union, such as Ireland and Spain. Macroeconomic asymmetries together with financial and external imbalances led to capital flows from the center to the periphery in the Eurozone, which in turn created a credit boom that caused asset prices to rise (Lane, 2012, 2013). In the aftermath of the crisis there has been a discussion in many countries of whether central banks should (could) consider financial stability and the health of the fiscal system (King, 2014; Yellen, 2014). Sweden is no exception to this, see for instance Svensson (2012).

In general, theoretical monetary policy rules, such as the well-known Taylor Rule, defined in Taylor (1993), only captures international dynamics through its effect on domestic variables. However, there are good arguments for why a central bank in a small open economy should consider the differential between its interest rate and the interest rate of its main trading partners. Even so the theoretical predominant assumption has been that central banks should mainly consider domestic factors. They should aim for stabilizing inflation and output and thereby reach the best possible economic results (Mishkin, 2017). Foreign interest rates can have an indirect effect on a central bank's policies even if it follows a strict inflation targeting framework and relies only on domestic conditions. There is a pass-through of higher import prices on domestic inflation through the exchange rate (McCarthy, 2007).

Despite what theory predicts, there are arguments that central banks consider international dynamics. Amador et al. (2017) argue that many central banks, either explicitly or implicitly, attempts to impact the exchange rate and Bini Smaghi (2014) states that central banks pay too much attention to the exchange rate. Frankel (2016) discusses the possibility that countries used the interest rate to depreciate its currency with the purpose of receiving competitive advantages in the aftermath of the financial crisis. International interest dynamics could with such a strategy be considered in the scope of modern beggar-thy-neighbour policies.[1]

During 1990s Sweden together with many other western countries adopted inflation targeting as the institutional framework of monetary policy-making (Bernanke & Mishkin, 1997; Svensson, 2015). Svensson (1997) defines the crucial components of an inflation targeting regime as having a quantitative inflation target, in the case of Sweden the goal is two percent on a yearly basis, and sometimes also a tolerance interval stating that inflation can deviate from its target with a certain percentage point. Among the benefits of inflation targeting Svensson mentions that such a target functions as a commitment mechanism, which will decrease the risk for inflation bias.[2] The Riksbank's most important policy instrument is the Repo Rate, and the central bank uses open market operations to direct the overnight rates towards the Repo Rate (De Rezende, 2017).

[1]The term beggar-thy-neighbor refers to a country gaining competitive advantages by keeping its currency undervalued. See for instance McKinnon (2011).

[2]Inflation bias arises from discretionary monetary policy. The public anticipates the government to push down unemployment and there expects higher inflation in the future, which translates into higher inflation today (Kydland & Prescott, 2004). With a stated target inflation, this level would be the rational expectation of future inflation (Barro & Gordon, 1983).

3 Data

The following section describes the data used for the empirical study. It presents the definition of the variables, descriptive statistics as well as a discussion of the data's time series properties.

3.1 Definition of Variables

The empirical investigation is based on quarterly data of macroeconomic variables, mainly from Sweden, during the period between 1993 and 2018. This is appropriate due to the fact that the time horizon of quarterly data matches a central bank's considerations. Altogether this means that there are 104 observations of each variable in the relevant data set.

The key response variable is the policy rate of the Swedish Riksbank, that is the Repo Rate. For this data compiled by Bank of International Settlements, BIS (2018a), is used. Each data point describes the level of the interest rate on the last day of each quarter. Additionally, inflation data for Sweden collected by the OECD (2018) is used. The considered inflation measure is CPI and this series measure the change in price of a basket of goods from quarter to quarter. Using this data and the inflation target of two percent a variable that captures the deviation of inflation from its target is created. Data describing the output gap is based on quarterly data for real GDP from Statistics Sweden (2018). A Hodrick-Prescott filter[3] is used to decompose the time series into a trend and a cyclical component. This cyclical component, converted to percentages, measures the output gap. A positive output gap means that GDP is higher than its trend value, while a negative output gap suggests the opposite. Using weights from BIS' narrow index (BIS, 2018b), the foreign interest rate is defined as a trade-weighted average of the policy rates for Denmark, ECB (after 1999), Germany (until 1999), Norway, United Kingdom and

[3]A Hodrick-Prescott filter makes it possible to distinguish between a time series' trend and cyclical components. Here the difference between the trend and the actual value is used as a proxy for the output gap. The calibration parameter is set to 1600, which is recommended for quarterly data (Hodrick & Prescott, 1997).

United States. Since the BIS' weights are updated seven times between 1993 and 2018 an average weight is calculated for each country. For Germany between 1993 and 1999 the calculated weight of the Eurozone is used.

3.2 Descriptive Statistics

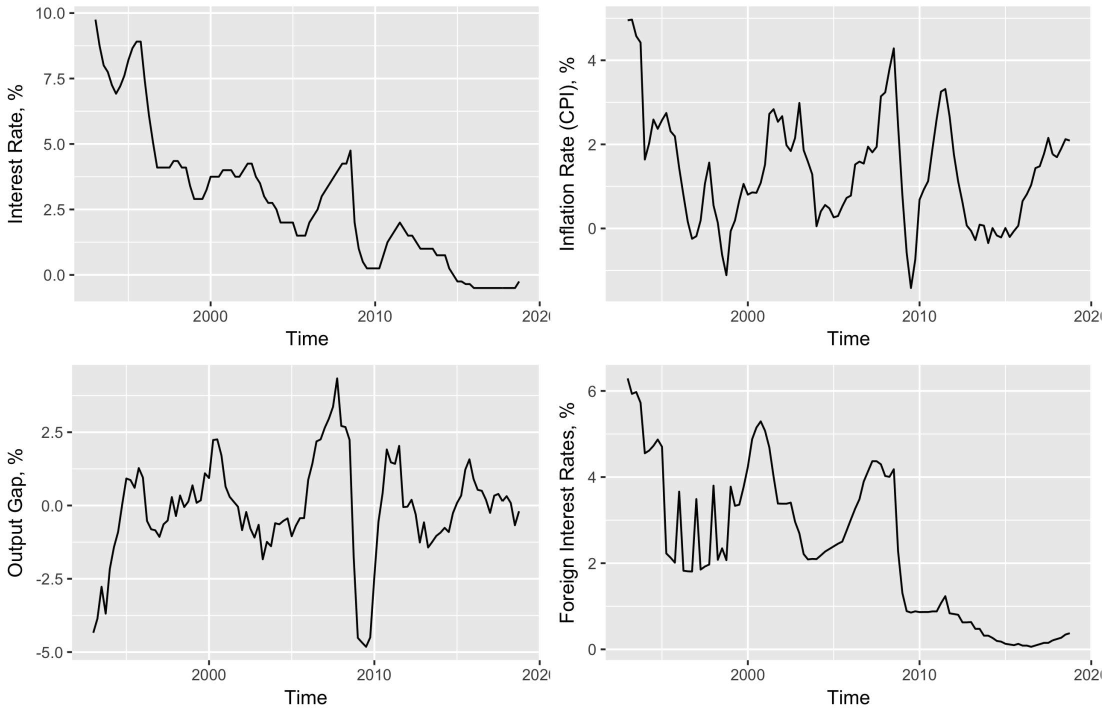
Table 1 and Figure 1 present summary statistics for the variables used in the empirical investigation. The average Repo Rate has been 2.83 percent during the period of interest. This is somewhat higher than the average foreign interest rate. The average output gap is close to zero, as expected. Its minimum value is caused by the recession following the financial crisis in 2008, while the maximum value occurred during the preceding boom. It is interesting to notice that the average inflation is substantially lower than the target rate of two percent.

Table 1: Descriptive Statistics, 1993-2018

	Obs.	Mean	Std. Dev	Min	Max
Repo Rate	104	2.83	2.61	-0.50	9.75
Inflation (CPI)	104	1.34	1.33	-1.42	4.97
Output Gap	104	-0.12	1.71	-4.82	4.34
Foreign Interest Rate	104	2.31	1.74	0.06	6.29

Descriptive statistics for the variables used in the empirical study. Data on the Swedish and the foreign interest rates comes from BIS (2018a). The foreign interest rate is a weighted average of the interest rates of Sweden's main trading partners. The output gap is calculated using data from Statistics Sweden (2018) and the inflation rate is retrieved from OECD (2018).

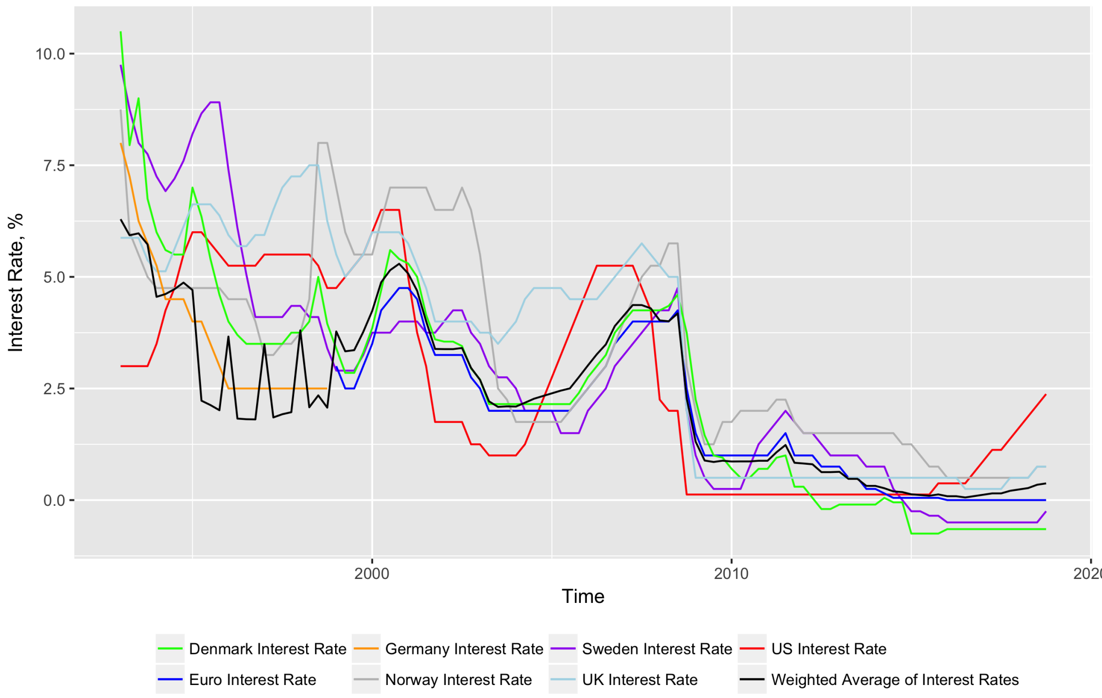
Figure 1: Descriptive Statistics, 1993-2018



Descriptive statistics for the variables used in the empirical study. Data for the Swedish and the foreign interest rates comes from BIS (2018a). The foreign interest rate is a weighted average of the interest rates of Sweden's main trading partners. Output gap is calculated using data from Statistics Sweden (2018) and the inflation rate is retrieved from OECD (2018).

To facilitate comparisons, Figure 2 graphs the Swedish and all the foreign interest rates in the same figure. Judging from the figure the trajectories of the different interest rates follow each other closely.

Figure 2: Evolution of Interest Rates, 1993-2018



Comparison of all the relevant interest rates. The underlying data is retrieved from BIS (2018a).

3.3 Time Series Properties

Empirical work using time series data must take the concept of stationarity into account. Granger and Newbold (1974) argues that estimated relationships between non-stationary variables might be spurious, since the autocorrelated residuals affect the estimates and can invalidate significance testing. A stochastic process is defined as strictly stationary if its probability distribution does not change over time. A stochastic process is weakly stationary if its mean, variance and covariance are independent over time (Stock & Watson, 2015).

Augmented Dickey-Fuller (ADF) and *Kwiatkowski-Phillips-Schmidt-Shin (KPSS)* tests are used to examine whether the four time series are stationary. Since ADF tests can misinterpret a structural break as a presence of a unit root, also *Zivot-Andrews (ZA)* tests, allowing for one endogenous structural break, are performed for those variables that the other tests find to be non-stationary (Glynn et al., 2007). For the ADF and ZA tests the appropriate number of lags is determined using *Akaike's information criterion (AIC)*.[4] The results of the tests are reported in Table 2.

Table 2: Results from Tests of Unit Root and Stationarity

	Lags	ADF Statistic	KPSS Statistic	ZA Statistic
Repo Rate	1	-2.754*	1.799***	-6.146***
Inflation Deviation	6	-3.569***	0.199	-
Output Gap	3	-6.085***	0.096	-
Foreign Interest Rate	6	-2.570*	1.466***	-4.963**

*** Significant 1 % level, ** Significant 5 % level, * Significant 10 % level.
Results from the ADF, KPSS and ZA tests where the optimal number of lags is determined using AIC. The integration order is determined using a qualitative assessment of the test results.

The ADF test has the null hypothesis of a unit root, that is non-stationarity. As the test indicates this null hypothesis cannot be rejected at a 5 percent level for the Repo Rate and the foreign interest rate. The KPSS test, having a null hypothesis of stationarity, point in the same direction for these two variables. However, the ZA test rejects the null hypothesis of a unit root for both variables. These tests indicate a structural break at q4 in 1995 for the Repo Rate, at the recovery after the Swedish financial crisis in the early 1990's and at q3 in 2008, the outburst of the global financial crisis for the foreign interest rate. This will be accounted for in the models by generating two binary variables, $D_{90,t}$ and $D_{08,t}$, that equals one for the observations in question. Taking the estimated structural breaks into account, this means that it is possible to estimate our model in levels.

[4]Details on these procedures are omitted for spacing reasons. For more information see Dickey and Fuller (1979), Kwiatkowski et al. (1992), Zivot and Andrews (2002) and Akaike (1974).

4 The Riksbank and the Foreign Interest Rate

This section provides an empirical assessment of whether the foreign interest rate impacts the Riksbank's interest rate decision. This question is analyzed using impulse responses created from *local projections (LP).* As a robustness test the relationship between these time series are also estimated using a *structural VAR (SVAR)* model.

4.1 Local Projections

The local projection approach to impulse response functions was first presented by Jordà in 2005. Compared to the VAR framework, see Section 4.2, Jordà argues that this approach has several advantages. The main benefit emerges from the fact that impulse responses from a VAR model are functions of forecasts made for increasing distances, while the impulse responses from local projections are based on estimations where the variables are sequentially shifted ahead to future horizons. This procedure makes impulse responses from local projections less sensitive to misspecification. Also, compared to VAR models, this approach is more flexible and does for instance facilitate estimations of non-linear models. Local projections serve two purposes for the empirical analysis in this thesis. Firstly, interest rate decisions are complex procedures which makes them hard to model. A technique less sensitive to specification errors could therefore be expected to give more credible results. Secondly, the impulse responses from the local projections serve as benchmarks for which the structural VAR results can be compared against.

Jordà (2005) defines the projection of $\boldsymbol{y}_{t+s}$, where $s = 0, 1, 2, ..., h$, on the linear space spanned by $[\boldsymbol{y}_{t-1}, \boldsymbol{y}_{t-2}, ..., \boldsymbol{y}_{t-p}]'$ as local projections. Such a projection can be expressed as a linear regression

$$\boldsymbol{y}_{t+s} = \boldsymbol{\alpha}^s + \boldsymbol{B}_1^{s+1}\boldsymbol{y}_{t-1} + \boldsymbol{B}_2^{s+1}\boldsymbol{y}_{t-2} + ... + \boldsymbol{B}_p^{s+1}\boldsymbol{y}_{t-p} + u_{t+s}^s, \tag{1}$$

where s represents each horizon and h the total number of horizons.

In Equation (1) $\boldsymbol{y}_t$ and $\boldsymbol{u}_t$ are in the scope of this thesis defined as

$$\boldsymbol{y}_t = \begin{bmatrix} i_t^f \\ \tilde{y}_t \\ \tilde{\pi}_t \\ i_t \\ D_{90,t} \\ D_{08,t} \end{bmatrix} \quad \text{and} \quad \boldsymbol{u}_t = \begin{bmatrix} u_{t,i^f} \\ u_{t,\tilde{y}} \\ u_{t,\pi} \\ u_{t,i} \\ u_{t,D_{90}} \\ u_{t,D_{08}} \end{bmatrix}, \tag{2}$$

where t is a time index describing discrete time, i_t^f is the foreign interest rate, $\tilde{y}_t$ is the output gap, $\tilde{\pi}_t$ is inflation deviation from its target and i_t is the domestic nominal interest rate. The variables D_{90} and D_{08} are defined as presented earlier. The vector $\boldsymbol{u}_t$ contains the residuals for each of the six equations. The matrices $\boldsymbol{B}_j^{s+1}$, where $j = 1, 2, ..., p$, are 6×6 matrices containing the coefficients for each lag of the six variables and $\boldsymbol{\alpha}^s$ is a 6×1 vector with intercepts. Additionally, p represents the lag length and is here determined to be equal to five using a trade-off between the AIC and a wish to restrict the number of estimated parameters.

Impulse responses can be defined as the difference between two forecasts, where only one of them is affected by a structural shock captured by the 6×1 vector $\boldsymbol{d}$.

$$IR(t, s, \boldsymbol{d}) = E[\boldsymbol{y}_{t+s}|\boldsymbol{v}_t = \boldsymbol{d}; \boldsymbol{X}_t] - E[\boldsymbol{y}_{t+s}|\boldsymbol{v}_t = \boldsymbol{0}; \boldsymbol{X}_t] \tag{3}$$

Here $\boldsymbol{X}_t$ is defined as $\boldsymbol{X}_t = [\boldsymbol{y}_{t-1}, \boldsymbol{y}_{t-2}, ..., \boldsymbol{y}_{t-p}]'$. By combining Equations (1) and (3) it is possible to show that the impulse responses can be defined as

$$IR(t, s, \boldsymbol{d}) = \boldsymbol{B}_1^s \boldsymbol{d}, \tag{4}$$

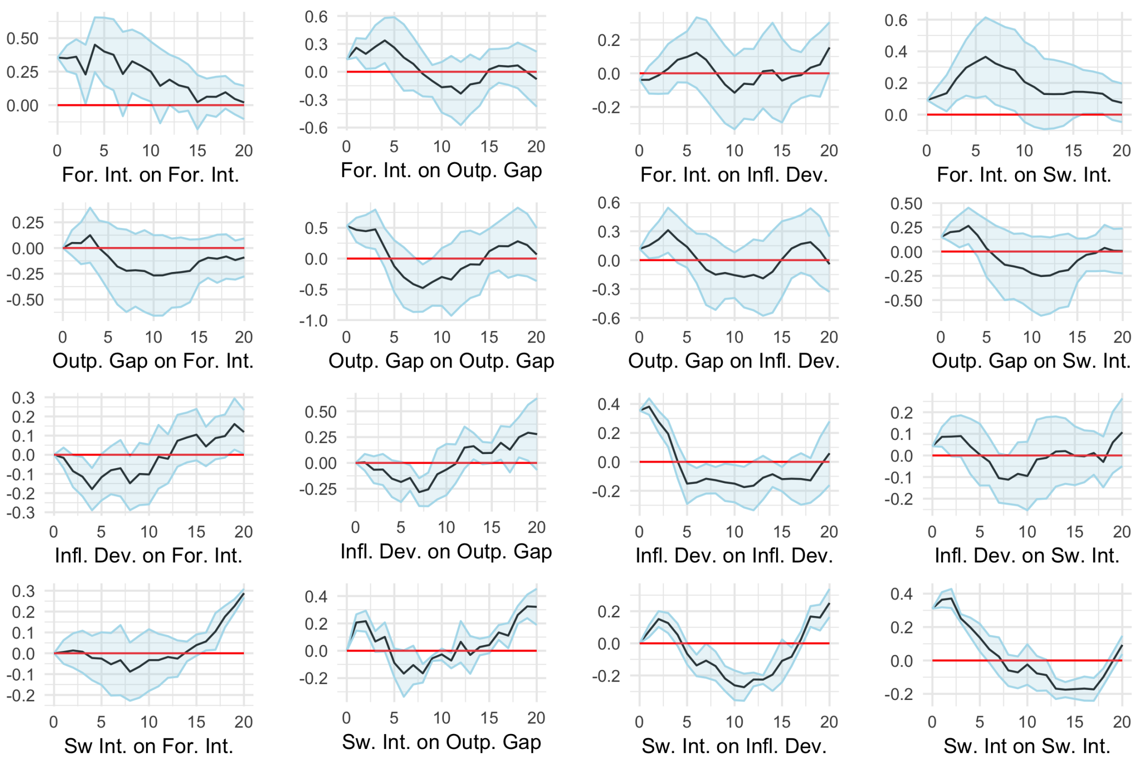
where $\boldsymbol{B}_1^0 = \boldsymbol{I}$.

Figure 3 presents the estimated impulse responses from orthogonal shocks for each of the four variables, here disregarding the two dummy variables. The size of the shocks are set to be one standard deviation. The bands around the solid line represents 95 percent bootstrapped confidence intervals.

As suggested by the figure there is a significant positive effect on the domestic nominal interest rate from a one standard shock to the foreign interest rate. The effect lasts for about two years (eight quarters) and thereafter the reaction to go towards zero over time. At its maximum is the size of the response equal to the size of the shock itself. The result presented here suggests that the Riksbank considers the effect of the foreign interest rate when determining the Repo Rate. Additionally, the results illustrate that a foreign monetary policy shock has a positive impact on the output gap that lasts for about one year after the shock. This result means that a foreign monetary policy shock increases economic activity in Sweden and is likely driven by an exchange rate effect that increases net-exports. Such effects can in the long-run be neutralized by an outflow of capital from Sweden to the rest of the world, which arises from the created interest rate differential. There is no clear evidence of an effect from a foreign monetary policy shock on inflation. If there would be one, it could be explained by the fact that the created interest rate differential would transmit itself into higher import prices. There are some evidence that inflation and output shocks lead to a short-term positive effect on the Repo Rate. This is what would be expected from standard economic theory. As can be seen from the last row of Figure 3 the results implicate that domestic monetary policy impacts the Swedish output gap and inflation with a lag. These reactions are also what is expected from economic theory. The estimated impulse responses, not displayed here, suggest a large and significant negative effect of an orthogonal shock on D_{08} to the foreign interest rate. It also suggests short-term negative impacts on the output gap and inflation, while the effect on the Repo Rate emerges with a lag. A surprising result is the significant positive effect after four years of a domestic monetary policy shock on the foreign interest rate. This result is contrary to what is expected from a relationship between a small open economy and an exogenous foreign interest rate and is likely caused by the fact that both interest rates has a common trend.

For all the estimated impulse responses it is necessary to underline that longer series of available and appropriate data would decrease the standard errors and could lead to stronger and more credible results. Impulse responses from foreign monetary policy shocks on the Repo Rate for different choices of lag lengths can be found in Appendix A.

Figure 3: Estimated Impulse Responses from Orthogonal Shocks



Estimated impulse responses from orthogonal shocks on the foreign interest rate, output gap, inflation deviation from its target and domestic nominal interest rate. The impulse responses are generated from local projections. The bands around the solid line represents a 95 percent confidence interval.

4.2 Structural Vector Autoregression Model

The purpose of this section is to investigate whether the results presented in the previous section are robust to a change in estimation technique. Structural VAR (SVAR) models have traditionally been a dominant tool for analyzing monetary policy. The VAR framework was presented by Sims (1980) and constitutes a method to capture the dynamic evolution of a set of variables from its history (Verbeek, 2017). Studying a VAR model can be understood as examining how an autoregressive system reacts to random shocks (Sims, 1980). The difference between a reduced VAR, where each variable is explained by its past values and the past values of the other variables, and a SVAR model is that the latter uses economic theory to establish contemporaneous links between the variables (Stock & Watson, 2001).

In a SVAR model the ordering of the variables matter for the Choleski decomposition necessary for restricting the contemporaneous links (Enders, 2015). Here is the foreign interest rate ordered as the first variable. This variable affects the output gap and inflation through its impact on the exchange rate and on capital flows, which translates into changes in net-exports, investments and the prices of imported goods. It is further assumed that the foreign interest rate only affects the domestic interest rate with a lag, hence there is no contemporaneous link between these two variables. Given the DIS equation, see Equation (7), the output gap has a contemporaneous effect on inflation. Through this reasoning the output gap is ordered before the deviation of inflation from its target. Neither the output gap nor inflation are assumed to have a contemporaneous impact on the interest rate. The interest rate is ordered last of the main variables, and will as a consequence not have a contemporaneous effect on any other variable. This is reasonable since it is unlikely that the Swedish interest rate affects the American or the ECB policy rates and because a change of interest rate would not have instantaneous impact on inflation or output.

The SVAR model is defined as

$$\boldsymbol{B}\boldsymbol{X}_t = \boldsymbol{\beta}_0 + \sum_{j=1}^{p} \boldsymbol{\beta}_j \boldsymbol{X}_{t-j} + \boldsymbol{\varepsilon}_t, \tag{5}$$

where $j = 1, ..., p$, $\boldsymbol{B}$ is a 6×6 matrix describing the contemporaneous links between the variables, $\boldsymbol{\beta}_0$ is a 6×1 vector with intercepts, p is the lag length, $\boldsymbol{\beta}_j$ are 6×6 matrices capturing the effects of the lagged values of the endogenous variables. Also $\boldsymbol{\varepsilon}_t$ is a 6×1 vector where each element describes white noise. The elements of $\boldsymbol{X}_t$ and $\boldsymbol{\varepsilon}_t$ are the same as those for $\boldsymbol{y}_t$ and $\boldsymbol{u}_t$ in Equation (2).

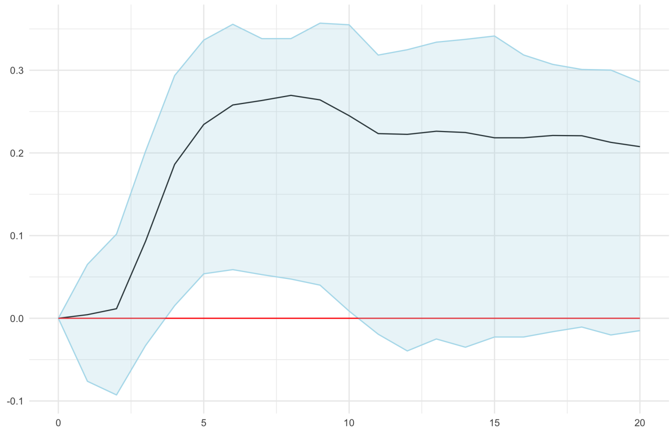
To be able to estimate the system of equations it is necessary to impose restrictions on matrix $\boldsymbol{B}$. This is done using primarily a Choleski decomposition that transforms the matrix into an upper triangular one. Additional restrictions are imposed based on the lack of contemporaneous relationships between the variables following the reasoning presented above. This is illustrated by Equation (6). To make the shocks orthogonal, that is uncorrelated with each other, restrictions are also imposed on the variance-covariance matrix of the structural shocks. This matrix will be a diagonal matrix, with the variances in the diagonal and all other elements set to zero. See Enders (2015) for a detailed description of how to transform the $\boldsymbol{B}$ matrix.

$$\boldsymbol{B} = \begin{bmatrix} 1 & b_{12} & b_{13} & b_{14} & b_{15} & b_{16} \\ b_{21} & 1 & b_{23} & b_{24} & b_{25} & b_{26} \\ b_{31} & b_{32} & 1 & b_{34} & b_{35} & b_{36} \\ b_{41} & b_{42} & b_{43} & 1 & b_{45} & b_{46} \\ b_{51} & b_{52} & b_{53} & 1 & b_{55} & b_{56} \\ b_{61} & b_{62} & b_{63} & 1 & b_{65} & b_{66} \end{bmatrix} \quad \Rightarrow \quad \boldsymbol{B} = \begin{bmatrix} 1 & b_{12} & b_{13} & 0 & 0 & 0 \\ 0 & 1 & b_{23} & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \tag{6}$$

As with the local projections methodology impulse responses are generated with the purpose of evaluating how a shock in one of the variables affects the others. These are generated using the estimated coefficients and displayed graphically as a function of the forecast horizon (Verbeek, 2017). Also the results of a *Granger causality test* is provided. This test evaluates if lagged values of one variable facilitates the forecasting of another variable (Stock & Watson, 2001). Additionally a *forecast error variance decomposition* for the Repo Rate is presented. The purpose of this is to find what proportion of the forecast error variance that depends on shocks to the variables itself or on shocks to the other five variables (Enders, 2015).

Figure 4 below presents the effect on the Repo Rate from a standard deviation shock in the foreign interest rate. The impulse response from a foreign monetary policy shock on the Repo Rate points in the same direction for both the SVAR and the LP models. A foreign monetary policy shock has a significant positive effect on the Swedish Repo Rate. However, there are two differences compared to the results from the LP model. Firstly, the magnitude of the response is smaller for the SVAR model and, secondly, there is no tendency of a movement towards zero in the result of the SVAR model. All estimated impulse responses for the SVAR model can be found in Appendix B.

Figure 4: Response of the Repo Rate from a Foreign Monetary Policy Shock



Estimated impulse responses from an orthogonal shock to the foreign interest rate on the Repo Rate. The impulse response is generated from a SVAR model. The bands around the solid line represents a 95 percent confidence interval.

The result of the Granger Causality test, presented in Table 3, does not indicate that lagged values of the foreign interest rate help to forecast the Repo Rate. This result argues against the hypothesis that there is a causal link in time between these two variables. On the other hand, with a p-value of 0.016, the test rejects the null hypothesis of no instantaneous causality between the two. The results from the Granger Causality tests indicate that the model in itself has explanatory power for the Repo Rate. According to the results lagged values of the output gap, but not of inflation deviation, cause changes in the Repo Rate. The forecast error variance decomposition indicates that after five years 30 percent of the Repo Rate's forecast error can be explained by a shock to the foreign interest rate.

Table 3: Granger Causality from the SVAR Model

	Dependent variable			
Regressor	Foreign Interest Rate	Output Gap	Inflation Deviation	Repo Rate
Foreign Interest Rate	0.007***	0.062*	0.413	0.104
Output Gap	0.034**	0.039**	0.010***	0.043**
Inflation Deviation	0.028**	0.328	0.000***	0.439
Repo Rate	0.314	0.052*	0.006***	0.032**

*** Significant 1 % level, ** Significant 5 % level, * Significant 10 % level.
Results from Granger causality test. The table displays the p-values associated with a F-test with the null hypothesis that the coefficients in question are equal to zero. The diagonal elements display the p-value from a F-test with a null where the coefficients of all other variables are equal to zero.

Table 4: Forecast Error Variance Decomposition of the Repo Rate

Horizon	Repo Rate	Output Gap	Inflation Deviation	Foreign Interest Rate	D_{90}	D_{08}
1	1.000	0.000	0.000	0.000	0.000	0.000
4	0.860	0.063	0.019	0.013	0.037	0.008
8	0.629	0.098	0.044	0.184	0.039	0.006
12	0.496	0.079	0.127	0.245	0.042	0.012
16	0.466	0.068	0.140	0.279	0.035	0.012
20	0.436	0.063	0.156	0.300	0.035	0.010

Forecast error variance decomposition of the Swedish Repo Rate. The numbers presents the proportion of the forecast error variance of the Repo Rate that can be explained by shocks to different variables, for different horizons.

In conclusion, the empirical results from both the LP model and the SVAR model support the hypothesis that the interest rate of Sweden's most important trading partners play an important role when the Riksbank determines the Repo Rate.

5 A DSGE Approach to the Foreign Interest Rate

The *Dynamic Stochastic General Equilibrium (DSGE)* framework is an approach to macroeconomic analysis where a number of equations are used to determine actions taken by economic agents, such as households, firms and policy makers. The general equilibrium is usually defined by market clearing conditions and is affected by exogenous variables, which follow a stochastic pattern and causes the economy to fluctuate. Compared to standard real business cycle models, the New Keynesian approach allows for nominal variables, price and wage rigidities as well as for price markups. The latter means that the assumption of perfect competition in the goods market is set aside (Galí, 2018). DSGE models are standard analytical tools used by policy makers and central banks. Even if they have been criticized for not helping to foresee the financial crisis of 2008 these models remain as a dominant framework for policy modeling (Galí, 2018).

5.1 The Model

The backbone of the DSGE model presented in this thesis is derived from Galí's small open economy model, described in for instance Galí and Monacelli (2005) and Galí (2018b). The world economy is modelled as a continuum of infinitely small economies. Technology, preferences and market structure are assumed to be identical for all economies. The optimality conditions for the households and the firms are derived in the same way here as in Galí and Monacelli. As will be seen, these conditions together with the necessary equilibrium conditions can be translated into two equations; the Dynamic IS curve and the New Keynesian Phillips curve. However, compared to Galí's and Monacelli's model, the model here uses another monetary policy rule, derived from a central bank's minimization problem, as well as an international monetary policy rule that determines the foreign interest rate.

This differs from the Riksbank's DSGE model, RAMSES II, in several aspects. RAMSES II is more complex, it contains more equations and structural shocks and requires more data. For the purpose of this thesis the most striking difference is that while RAMSES II does not incorporate a direct impact of international interest rates in the monetary policy rule the model presented here does (Adolfson et al., 2013). In the following subsections this DSGE model will be outlined in more detail.

5.1.1 A Representative Household

The *Dynamic IS equation (DIS)* is fundamental for the model and captures the relationship between the output gap, $\tilde{y}_t$, and the difference between the real interest rate, $i_t - E_t\{\pi_{H,t+1}\}$, and the natural interest rate, i_t^n. DIS is presented in Equation (7) below.

$$\tilde{y}_t = E_t\{\tilde{y}_{t+1}\} - \frac{1}{\sigma_\upsilon}(i_t - E_t\{\pi_{H,t+1}\} - i_t^n), \tag{7}$$

In Galí and Monacelli (2005) this relationship is derived in the context of a representative household that maximizes expected life-time utility subject to a budget constraint. The household receives utility from consumption of both domestic and imported goods and disutility from hours of work. Focusing on a given time-period t and assuming a certain functional form of the utility function, this utility maximization problem can be expressed as

$$\begin{aligned} &\underset{C_t,N_t}{\text{maximize}} \quad U(C_t, N_t) = \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi} \\ &\text{subject to} \quad P_tC_t + E_t\{Q_{t,t+1}D_{t+1}\} \leq D_t + W_tN_t + T_t, \end{aligned} \tag{8}$$

where P_tC_t is the total expenditure on both domestic and foreign goods, total consumption C_t is the sum of both domestic and imported consumption, N_t is hours of work, W_t is the hourly wage and T_t is a lump-sum tax or transfer. Additionally, D_t expresses capital income and Q_t is a discount factor. Expected utility is discounted at the rate of β, σ is the inverse of the elasticity of intertemporal substitution and φ is the elasticity of labor supply. The subscripts i and j refers to countries and goods. Solving the optimization problem in Equation (8) leads to the first order conditions

$$C_t^\sigma N_t^\varphi = \frac{W_t}{P_t} \quad \text{and} \quad \beta\Big(\frac{C_{t+1}}{C_t}\Big)^{-\sigma}\Big(\frac{P_t}{P_{t+1}}\Big) = Q_{t,t+1}, \tag{9}$$

which in log-linear form can be expressed as

$$w_t - p_t = \sigma c_t + \varphi n_t \quad \text{and} \quad c_t = E_t\{c_{t+1}\} - \frac{1}{\sigma}(i_t - E_t\{\pi_{t+1}\} - \rho). \tag{10}$$

Here i_t denotes the domestic nominal interest rate and π_t denotes CPI inflation, a function of both domestic inflation and imported foreign inflation, while $\rho = \beta^{-1} - 1$ is a time discount factor. Equilibrium in the domestic goods market requires that domestic output equals the sum of domestic consumption and demand for the products from abroad. This, together with the Euler equation in Equation (10), leads to the following equilibrium condition

$$y_t = E_t\{y_{t+1}\} - \frac{1}{\sigma_\upsilon}(i_t - E_t\{\pi_{H,t+1}\} - \rho) + \upsilon\Theta E_t\{\Delta y^*_{t+1}\}, \tag{11}$$

where $\Theta = (\sigma\gamma - 1) + (1 - \upsilon)(\sigma\eta - 1)$ and σ_υ is defined below. Here η is a parameter measuring the substitutability between domestic and foreign goods, γ captures the substitutability between goods produced in different foreign countries and υ describes the degree of openness. The parameter σ_υ is defined as $\sigma_\upsilon = \frac{\sigma}{1-\upsilon+\upsilon\omega}$, while $\omega = \sigma\gamma + (1-\upsilon)(\sigma\eta - 1)$.

The natural interest rate, i^n_t can be determined endogenously in the model by

$$i^n_t = \rho - \sigma_\upsilon\Gamma(1 - \rho_a)a_t + \upsilon\sigma_\upsilon(\Theta + \Psi)E_t\{\delta y^*_{t+1}\}, \tag{12}$$

where $\Gamma = \frac{1+\varphi}{\sigma_\upsilon+\varphi}$, $\Psi = -\frac{\Theta\sigma_\upsilon}{\sigma_\upsilon+\varphi}$, a captures the technology used and follows an AR(1) process, such that $a = \rho_a a_{t-1} + \varepsilon_a$, and y^*_t describes world output. The combination of Equations (11) and (12) leads to the definition of DIS.

Focusing on the fact that domestic output must equal domestic demand and demand from abroad, it is possible, as in Galí (2018b), to derive an expression for the relation between the output gap and the real exchange rate, q_t, such that

$$q_t = \sigma_\upsilon(1 - \upsilon)\tilde{y}_t. \tag{13}$$

5.1.2 A Representative Firm

The focus is now turned to the supply side. Here the *New Keynesian Phillips Curve (NKPC)*, presented below, captures the relationship between the output gap and domestic inflation, $\pi_{H,t}$. Assuming rational expectations, the present domestic inflation is also a function of expected future inflation.

$$\pi_{H,t} = \beta E_t\{\pi_{H,t+1}\} + \kappa \tilde{y}_t, \tag{14}$$

where $\kappa = \lambda(\sigma_v + \varphi)$ and λ is a composite parameter defined as $\lambda = \frac{(1-\beta\theta)(1-\theta)}{\theta}$.

The firms' technology and price-setting behavior is defined as in Galí and Monacelli (2005). The technology structure is given by a production function with linear technology. Nominal rigidities, such as price rigidities, play an important role in New Keynesian models. Here prices are set according to Calvo (1983), such that a share, θ, of the firms cannot change their price in a given year. Let $\bar{p}_{H,t}$ denote newly changed domestic prices, then the price-setting behavior can be expressed as

$$\bar{p}_{H,t} = \mu + (1-\beta\theta)\sum_{k=0}^{\infty}(\beta\theta)^k E_t\{mc_{t+k} + p_{H,t}\}. \tag{15}$$

Here μ captures the log of the mark-up in steady state and is defined as $\mu = \log\frac{\varepsilon}{\varepsilon-1}$, where ε is the demand elasticity of domestic goods. Also k is an index describing the time horizon of the price-setting. Since technology is common for all firms, every firm faces an identical marginal cost, mc. In equilibrium, domestic inflation can be defined as a function of expected future domestic inflation and the steady-state domestic real marginal cost, $\hat{mc}_t$, such that

$$\pi_{H,t} = \beta E_t\{\pi_{H,t+1}\} + \lambda \hat{mc}_t. \tag{16}$$

Since there is a positive relationship between the real marginal cost and the output gap, domestic inflation can be expressed as a function of the output gap instead. By this the

New Keynesian Phillips curve is derived from the price-setting behavior of a representative firm.

CPI inflation, π_t, is a function of both domestic inflation and inflation in import prices and is defined as

$$\pi_t = \pi_{H,t} + \frac{\upsilon}{1-\upsilon}\Delta q_t. \tag{17}$$

5.1.3 Monetary Policy Rules

The underlying hypothesis in this thesis is that a central bank in a small open economy also considers the interest rate differential towards the rest of the world. With such a starting point it is clear that the monetary policy rule used here cannot be a traditional Taylor Rule. Here, the monetary policy rule of interest, also considers the interest rate differential between the domestic interest rate and the foreign interest rate. The interest will, for smoothing reasons, also depend on its past level. Hence, the domestic monetary policy rule in the present model is expressed as

$$i_t = \rho_i i_{t-1} + (1-\rho_i)(\phi_\pi E_t\{\pi_{H,t+1}\} + \phi_y E_t\{\tilde{y}_{t+1}\} + \phi_{i^f} i_t^f + i_t^n) + \nu_t, \tag{18}$$

where ρ_i describes the autocorrelation of the interest rate and the parameters ϕ captures the effect of a unit change in the variables on the domestic interest rate. The variable ν_t is an AR(1) process, $\nu_t = \rho_\nu \nu_{t-1} + \varepsilon_\nu$, where $\varepsilon_\nu \sim N(0, \sigma_\nu)$ and represents the domestic monetary policy shock.

A theoretical motivation for the monetary policy rule stated above can be found by assuming that the central bank uses discretionary measures to minimize a quadratic loss function, as in for instance Clarida et al. (1999) and in Svensson (1997), with the exception that the interest rate differential is a target variable in the central bank's loss function. See Appendix C for such a derivation.

Also the foreign interest rate is determined by a monetary policy rule. This foreign monetary policy rule is stated in Equation (19) and is based on a Taylor rule. Since the country in question is a small open economy the foreign output gap, $\tilde{y}_t^*$ and foreign inflation, π_t^* are considered to be at its steady state levels, not affected by the small economy.

$$i_t^f = \phi_\pi^* \pi_t + \phi_y^* + i_t^r + \xi_t, \tag{19}$$

where ξ_t is an AR(1) process, such as $\xi_t = \rho_\xi \xi_{t-1} + \varepsilon_\xi$. Here $\varepsilon_\xi \sim N(0, \sigma_\xi)$ and corresponds to the foreign monetary policy shock.

5.1.4 The Model in Summary

The cornerstone of the model presented here consists of seven equations, log-linearized equilibrium conditions. These are summarized below and derived in the preceding subsections.

$$\begin{aligned}
\tilde{y}_t &= E_t\{\tilde{y}_{t+1}\} - \frac{1}{\sigma_\upsilon}(i_t - \pi_{H,t+1} - i_t^n) \\
\pi_{H,t} &= \beta E_t\{\pi_{H,t+1}\} + \kappa \tilde{y}_t \\
q_t &= \sigma_\upsilon (1-\upsilon)\tilde{y}_t \\
\pi_t &= \pi_{H,t} + \frac{\upsilon}{1-\upsilon}\Delta q_t \\
i_t &= \rho_i i_{t-1} + (1-\rho_i)(\phi_\pi E_t\{\pi_{H,t+1}\} + \phi_y E_t\{\tilde{y}_{t+1}\} + \phi_{i^f} i_t^f + i_t^n) + \nu_t \\
i_t^f &= \phi_\pi^* \pi_{F,t} + \phi_y^* \tilde{y^*}_t + i_t^n + \xi_t \\
i_t^n &= \rho - \sigma_\upsilon \Gamma (1-\rho_a) a_t + \upsilon \sigma_\upsilon (\Theta + \Psi) E_t\{\delta y_{t+1}^*\}
\end{aligned} \tag{20}$$

5.2 A Calibrated DSGE Model

This section presents the results of a calibrated version of the model using simulated data. The purpose of a calibrated model is to briefly discuss the dynamics of the model before estimating the key parameters in the domestic monetary policy rule. Firstly, the calibration is presented and briefly discussed, and thereafter the focus is turned to the estimated impulse responses from a domestic as well as from a foreign monetary policy shock. Here the focus is on their effect on the output gap, real exchange rate, domestic inflation, domestic nominal interest rate and the real interest rate.

In Table 5 the calibration of the relevant parameters is presented. Some of the parameter values are general for small open economies and is collected from Galí's open model (Galí, 2018). Other parameter values are specific for Sweden and is retrieved from the priors and posteriors in the description of the Riksbank's DSGE model RAMSES II in Adolfson et al. (2013). For the monetary policy rule the values of most feedback parameters are based on the Taylor Rule (Taylor, 1993). Neither RAMSES II nor Galí's open model contains a parameter in the monetary policy rule that describes the feedback of the interest rate differential to domestic interest rates in the same way as here. Therefore it has been necessary to base the calibration of this parameter on an assumption. Here it is assumed that this parameter is equal to 0.5, that is identical to the feedback of the output gap in the monetary policy rule and significantly lower than the calibrated value of the feedback of inflation. Notice that these assumptions imply a positive relationship between the foreign and domestic interest rates. Different assumptions of the value of this parameter does not impact the dynamics of the model, it only affects the magnitude of the pass-through on domestic variables of such a shock.

The autocorrelation parameter in the foreign monetary policy shock process is assumed to be equal to 0.5, which is the same value as for the autocorrelation of a domestic monetary policy shock. The assumption of the latter autocorrelation differs from the assumption in for instance Adolfson et al. (2013), where the autocorrelation of a domestic monetary policy shock is set to 0.85 instead. With such a calibration this model presents unrealistic effects and the parameter is therefore scaled down. In the process of calibrating these two parameters experiments have been made with different parameter values. For parameter values larger than 0.76 the model returns negative responses to the nominal interest rate of monetary policy shocks. These results emerge from the strong contractionary effect of such shocks on the output gap. These translate into lower inflation which feedbacks into lower nominal interest rates.

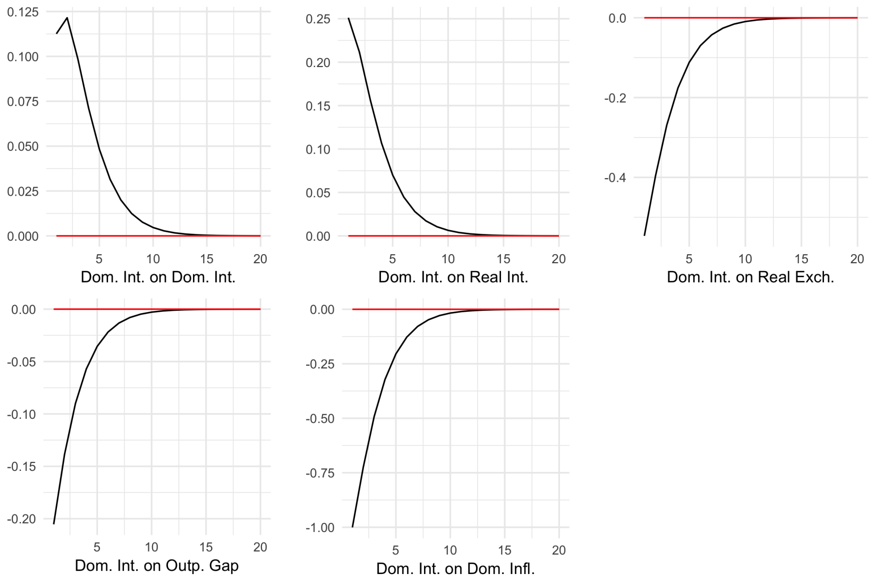
Table 5: Calibration of the Parameters

Parameter	Calibration	Description	Reference
β	0.99	Discount Factor	Adolfson et al. (2013)
η	1.41	Substitutability btw. Foreign and Domestic Good	Adolfson et al. (2013)
γ	1	Substitutability btw. Foreign Goods from Different Countries	Galí (2018b)
ϕ_π	1.5	Effect on Domestic Interest Rate from Inflation	Taylor (1993)
$\phi_{\tilde{y}}$	0.5	Effect on Domestic Interest Rate from Output Gap	Taylor (1993)
ϕ_{i_f}	0.5	Effect on Domestic Interest Rate from Foreign Interest	Own assumption
ϕ_{π^*}	1.5	Effect on Foreign Interest Rate from Inflation	Taylor (1993)
$\phi_{\tilde{y^*}}$	0.5	Effect on Foreign Interest Rate from Output Gap	Taylor (1993)
ρ_a	0.93	Autocorrelation of a Technology Shock	Adolfson et al. (2013)
ρ_ν	0.5	Autocorrelation of a Domestic Monetary Policy Shock	Own assumption
ρ_ξ	0.5	Autocorrelation of a Foreign Monetary Policy Shock	Own assumption
ρ_i	0.83	Autocorrelation of the Nominal Interest Rate	Adolfson et al. (2013)
σ	1	Elasticity of Intertemporal Substitution (Inverse)	Galí (2018b)
θ	0.75	Calvo Parameter	Adolfson et al. (2013)
υ	0.4	Degree of Openness	Galí (2018b)
φ	0.40	Elasticity of Labor Supply (Frisch, Inverse)	Adolfson et al. (2013)

Description of parameters and their calibrated values.

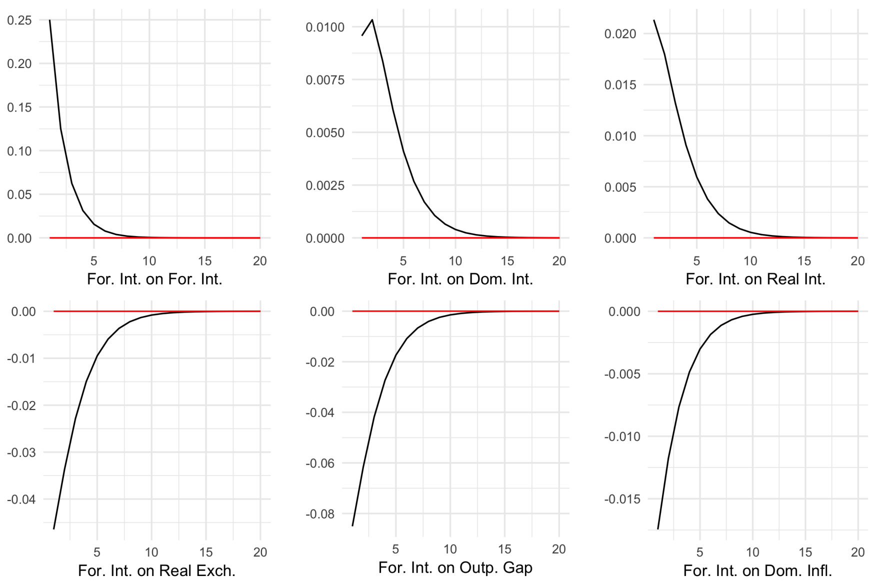
In Figure 5 and in Figure 6 estimated impulse response functions from a domestic and a foreign monetary policy shock are presented. The size of the shocks are set to 0.25, since nominal interest rates are often changed in steps of 0.25 percentage points.

Figure 5: Impulse Response from a Domestic Monetary Policy Shock



Estimated impulse responses from a domestic monetary policy shock on the nominal interest rate, real interest rate, real exchange rate, output gap and domestic inflation.

Figure 6: Impulse Response from a Foreign Monetary Policy Shock



Impulse responses from a foreign monetary policy shock on the foreign interest rate, nominal interest rate, real interest rate, real exchange rate, output gap and domestic inflation.

The impulse responses from a monetary policy shock on the output gap and on domestic inflation follows what is predicted by economic theory. A domestic monetary policy shock has a negative impact on both the output gap and on domestic inflation. Studying the figure it is evident that these two variables react strongly to such a shock. Given how the model is specified, the shock to the nominal interest rate leads to a decline in the output gap, compared to a steady state value of the output gap being zero. This means that actual GDP is below its potential value. The decline in economic activity then transfers into lower domestic inflation, through NKPC. The strong negative effects on both these variables feedback into the nominal interest rate through the domestic monetary policy rule. This means that the effect of a domestic monetary policy shock on the interest rate is smaller than the shock itself. However, as can be seen from studying the impact on the real interest rate, a domestic monetary policy shock has a strong contractionary effect on the economy. The effect of such a shock leads to a larger increase of the real interest rate in comparison to the size of the shock itself. Figure 5 also illustrates how a domestic monetary policy shock leads to a real appreciation of the currency. Such a change would likely lead to a decline of the current account and an inflow of capital to the country. How such a development would impact economic activity depends on whether the positive effect on investments from the inflow of foreign capital is larger or smaller than the deterioration of net-exports. Since there is a positive relationship between the domestic and foreign nominal interest rates, the effects of each shock point in the same direction. However, the magnitude of the responses from a foreign monetary policy shock are smaller since it is assumed that $\phi_{i^f} = 0.5$.

5.3 Bayesian Inference and Metropolis-Hastings Algorithm

In the coming section, the model described in Section 5.1 is estimated using Bayesian statistics. The purpose of this section is to give a brief introduction to Bayesian analysis and outline the methodology used.

Bayes' theorem, described in Equation (21) below, is in the center of Bayesian analysis. It states that the posterior distribution of the parameter θ, conditional on the data x, $\pi(\theta|x)$, is proportional to the product of the likelihood, $f(x|\theta)$, and the prior distribution of θ, $\pi(\theta)$. Here we can think of the presented functions as density functions, which cover both a continuous or a discrete scenario. The function $m(x)$ represents the marginal density of x. It is further assumed that the data is conditionally independent of each other (Jackman, 2009; Petris et al., 2009). In the scope of this thesis, the ambition is to find the posterior distributions of the key parameters in the domestic monetary policy rule.

$$\pi(\theta|x) = \frac{f(x|\theta)\pi(\theta)}{m(x)} \propto f(x|\theta)\pi(\theta) = \prod_{t=1}^{n} f(y_t|\theta)\pi(\theta) \tag{21}$$

In a simple univariate case where the parameters have a normal distributed prior, it would be possible to find a closed form solution for the properties of the posterior distribution, now denoted by ψ. However, in Bayesian analysis this is often not the case. Then numerical methods, generally Markov Chain Monte Carlo (MCMC) methods, is the necessary way forward. As described in Petris et al. (2009), if it would possible to draw an independent and identically distributed sample $\psi_1, \psi_2, ..., \psi_N$ from a posterior distribution, π, then the mean of any function $g(\psi)$ can be numerically approximated by

$$E_\pi\{g(\psi)\} \approx \frac{1}{N}\sum_{j=1}^{N} g(\psi_j) \tag{22}$$

as N goes to infinity.

Metropolis-Hastings algorithm, outlined in Metropolis et al. (1953) and generalized by Hastings (1970), is a way of finding a density function that fulfills the reversibility condition[5] in a Markov Chain. Based on Chib and Greenberg (1995) as well as Petris et al. (2009), the Metropolis-Hastings algorithm can be summarized in the following steps:

[5]The reversibility condition can be intuitively explained as the fact that the probability of going from a point A to point B in space should be the same as going in the reverse direction (Chib & Greenberg, 1995).

1. Generate a proposal $\tilde{\psi}_j$ from $q(\psi_{j-1}, \cdot)$, where $q(\psi_{j-1}, \tilde{\psi}_j)$ is a candidate generating density with the property $\int q(\psi_{j-1}, \tilde{\psi}_j)dy = 1$, and u is a sample from the uniform distribution $U(0, 1)$. Here the candidate generating density follows a so-called random-walk Metropolis Hastings approach.

2. If $\alpha(\psi_{j-1}, \tilde{\psi}_j) \geq u$, then let $\psi_j = \tilde{\psi}_j$, where $\alpha(\psi_{j-1}, \tilde{\psi}_j)$ denotes the probability that the candidate is accepted as a new state.

3. Otherwise let $\psi_j = \psi_{j-1}$.

4. Iterate for $j = 1, 2, ..., N$.

5. The process will generate a series $\{\psi_1, \psi_2, ..., \psi_N\}$, which can be used to approximate the properties of the posterior distribution following Equation (22).

In this study a Metropolis-Hastings algorithm is used to to approximate the posterior distribution of the parameters in the domestic monetary policy rule. Each point estimate is the mode of this posterior distribution. The number of iterations are $N = 10^6$.

5.4 Bayesian Estimation of the Domestic Monetary Policy Rule

The purpose of this section is to present estimated key parameters in the domestic monetary policy rule, that is the response of the interest rate on changes in inflation, output gap and foreign interest rate. The estimation is performed using Metropolis-Hastings algorithm, described in the previous section, and data for the Swedish Repo Rate and the foreign interest rate, as described in Section 4.[6]

The first step of Bayesian estimation is to assume prior distributions for the parameters of interest. These prior assumptions are presented in Table 6 below. As can be seen, it is assumed that these parameters follow a normal distribution, with a mean equal to the values used for calibration in Section 5.2. The presented standard deviations

[6] Since the model described in Section 5.1 only contains two exogenous shocks, only two variables can be treated as observed. Here real data is used for the two interest rates, while simulated data is used for the inflation rate and the output gap.

are appropriate choices resulting from experiments with different values. The results of the estimation are also presented in Table 6. The table presents the mean of the estimated posterior distributions and a 95 percent credible interval[7] for each parameter. Convergence statistics can be found in Appendix D.

Table 6: Priors and Estimated Posterior Mode

Parameter	Distribution	Prior Mean	Prior Std. Dev	Estimated Mean	Credible Interval	
ϕ_π	Normal	1.5	0.10	1.075	1.054	1.097
ϕ_y	Normal	0.5	0.05	0.183	0.182	0.184
ϕ_{i_f}	Normal	0.5	0.05	1.132	1.125	1.136

Priors for the three key parameters in the domestic monetary policy rule as well as the estimated mean of the posterior distribution together with a 95 % credible interval.

The results indicate that the magnitude of the response of the Repo Rate is almost equal for a change in inflation as it is for an identical change of the foreign interest rate. Since the effect of the foreign interest rate is clearly positive, these results supports the hypothesis that a central bank wants to minimize the differential between its own policy rate and the interest rate of the countries main trading partners. The size of the parameter is larger than one. Such an estimate suggests that the reaction of the Riksbank to a change in the foreign interest rate is larger than the change itself. These results support the hypothesis that traditional monetary policy frameworks underestimates the impact of international interest rate dynamics on domestic interest rates. On the other hand, this result is intuitive for a small open economy like Sweden. A small open economy with a high degree of openness is sensitive to macroeconomic changes from abroad. Thereby it would be natural that a central bank, despite an inflation targeting framework, considers the effect of foreign nominal interest rate changes when determining its own policy rate.

The estimated parameter value for the effect of domestic inflation is in line with the

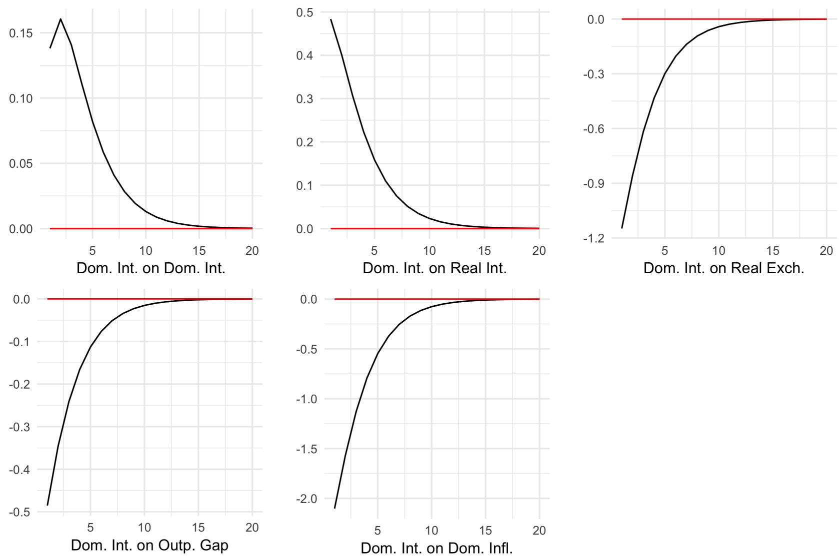
[7] The confidence interval is a so called *highest posterior density (HPD)* interval. These can be considered in the same way as confidence intervals in frequentist statistics. For more information on these, see for instance Wackerly et al. (2008)

so-called Taylor Principle, that the reaction of the interest rate to a change in inflation should be larger than one. However, the result presented here suggests a smaller reaction to a change in the output gap in comparison to what the Taylor Rule suggests. Given these results it seems likely that the Riksbank does not put weight on changes in domestic economic activity relative to inflation and international interest rate dynamics.

In Figures 7 and 8 below, impulse responses from the estimated model can be found. Naturally, the dynamics of the model does not change between the calibrated and the estimated versions. However, as seen from the figures, the magnitude of the effects differ between the two. Comparing the impulse responses from a domestic monetary policy shock between the calibrated and the estimated model, it is clear that the magnitude of the response on all variables is larger in the estimated model. Such a shock has a contractionary effect on the real interest, which in magnitude is more than twice the size of the initial shock. This is a result emerging from a larger positive impact on the nominal interest rate as well as from a larger negative impact on domestic inflation. The magnitude of the responses on all variables are larger also for a foreign monetary policy shock. The impact of such a shock on the domestic nominal interest rate is twice as large and the effect on the real interest rate is three times as large as in the calibrated version of the model.

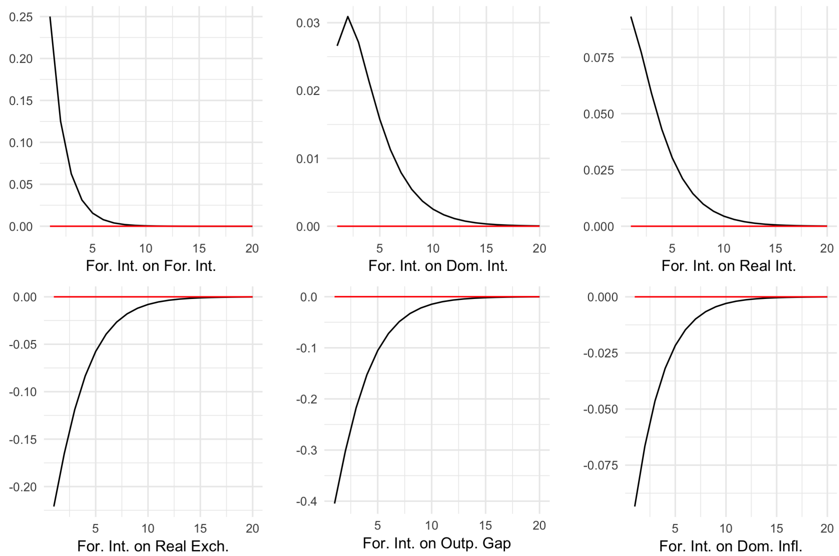
As illustrated from this section, the estimated parameters of the domestic monetary policy rule point in the same direction as the empirical analysis in Section 4. It seems that there is a positive relationship between the interest rate of Sweden's main trading partners and the Swedish Repo Rate, determined by the Riksbank. By the results presented in Section 5 it is clear that the general equilibrium effect of a foreign interest rate change is in line with the result from the local projections study and those from the SVAR model.

Figure 7: Impulse Response from a Domestic Monetary Policy Shock



Impulse response from estimated model showing the response of a domestic monetary policy shock on the nominal interest rate, real interest rate, real exchange rate, output gap and domestic inflation.

Figure 8: Impulse Response from a Foreign Monetary Policy Shock



Impulse response from estimated model showing the response of a foreign monetary policy shock on the foreign interest rate, nominal interest rate, real interest rate, real exchange rate, output gap and domestic inflation.

6 Conclusion

This thesis provides empirical support suggesting that the interest rate differential between the Swedish Repo Rate and a trade-weighted average of the interest rate of Swedens main trading partners matter for the Riksbank's policy rate decision. Impulse response functions estimated from local projections and a SVAR model, together with estimated parameters in the Riksbank's reaction function using a proposed DSGE model, illustrate how an increase in the foreign interest rate is associated with an increase of the Repo Rate. Hence, the positive relationship is robust through different estimation techniques. As described in the thesis, interest rate differentials can affect domestic economic conditions mainly through two channels; the exchange rate channel and cross-country capital flows. During the last couple of years the discussion about financial stability in Sweden has focused on the buildup of domestic private debt. With this in mind, and considering the Swedish dependency on exports and imports, it is natural that the primary focus has been on the currency rather than on the risk of destabilizing international capital flows. This could suggest that a driving force behind the Riksbank's focus on foreign interest rates can be related to the exchange rate.

The evidence presented indicates correlation between the domestic interest rate of a small open economy and the interest rates of its trading partners. From a theoretical perspective, it would be natural to assume that interest rate changes from abroad cause reactions in small open economies. More research is required to empirically distinguish between correlation and causation as wells as to identify whether the exchange rate channel or cross-country capital flows are the primary driving force.

Table 1 points to the fact that actual inflation in Sweden on average has been significantly lower than the two percent target. Together with the empirical results presented in Section 4, this could mean that the inflation target is not the guiding light of Swedish monetary policy as intended. Together with the empirical results in Section 4, this could suggest the need for a broader view of how monetary policy is conducted in Sweden. The fact that domestic conditions do not seem to fully capture the interest setting behavior of a central bank in a small open economy gives further strength to this argument. However, the interest rate differential in itself might be a hard target to use in such a framework.

One way of indirectly incorporating the importance of interest rate differentials in the conduct of monetary policy could be either through an increased focus on capital flows and financial stability or by implementing some sort of exchange rate target. The choice of a complementary target could be related to whether the driving force for considering the foreign interest rate mainly derives from current account or financial and capital account issues.

In Section 5 a DSGE model is presented, which introduces a foreign monetary policy rule that makes it possible to trace the effects on domestic variables of an exogenous foreign monetary policy shock. Altogether this model presents a simple framework that facilitates an analysis of how central banks in small open economies react to interest rate changes from abroad. In an extended model with more structural shocks, it would be possible to treat more variables as observed, which in turn would mean that real data also could be used to estimate the foreign monetary policy rule. The model could also be used when analyzing a two-country scenario, for instance how the Swedish Riksbank reacts to changes of the ECB policy rate, and thereby giving valuable insights on the dependency structure between a smaller and a larger economy. In an extended version, it would also be possible to analyze how a foreign interest rate shock affects other variables, for instance employment or foreign direct investments. It is however important to notice that the framework suggested in this thesis assumes a one-way link between the two interest rates. That is, the interest rate of a smaller economy should not affect the interest rate of a larger economy.

In conclusion, this thesis finds a positive relationship between the Swedish Repo Rate and a trade-weighted foreign interest rate. Further research is necessary to find more conclusive as well as general evidence of international interest rate dynamics for small open economies. Future theoretical contributions are also required to further develop the suggested theoretical framework. However, from the results presented here, it is clear that disregarding international dynamics when analyzing Swedish monetary policy will likely lead to false conclusions.

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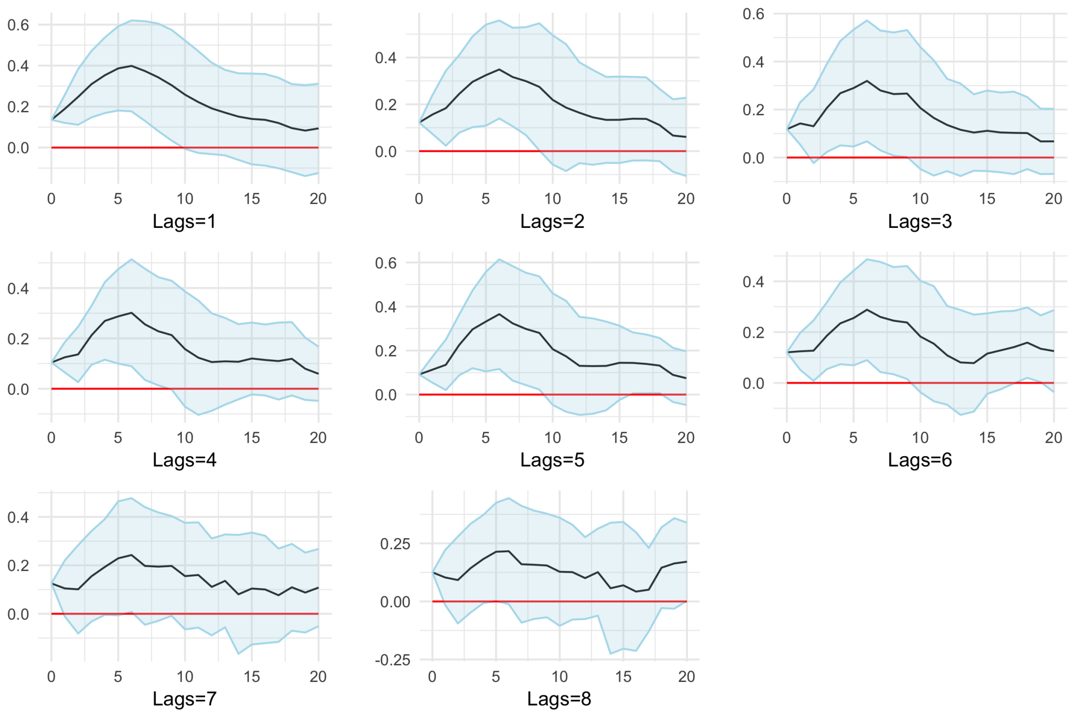
A LP Results for Different Lag Lengths

Figure 9: Reponse of the Repo Rate from a Foreign Monetary Policy Shock

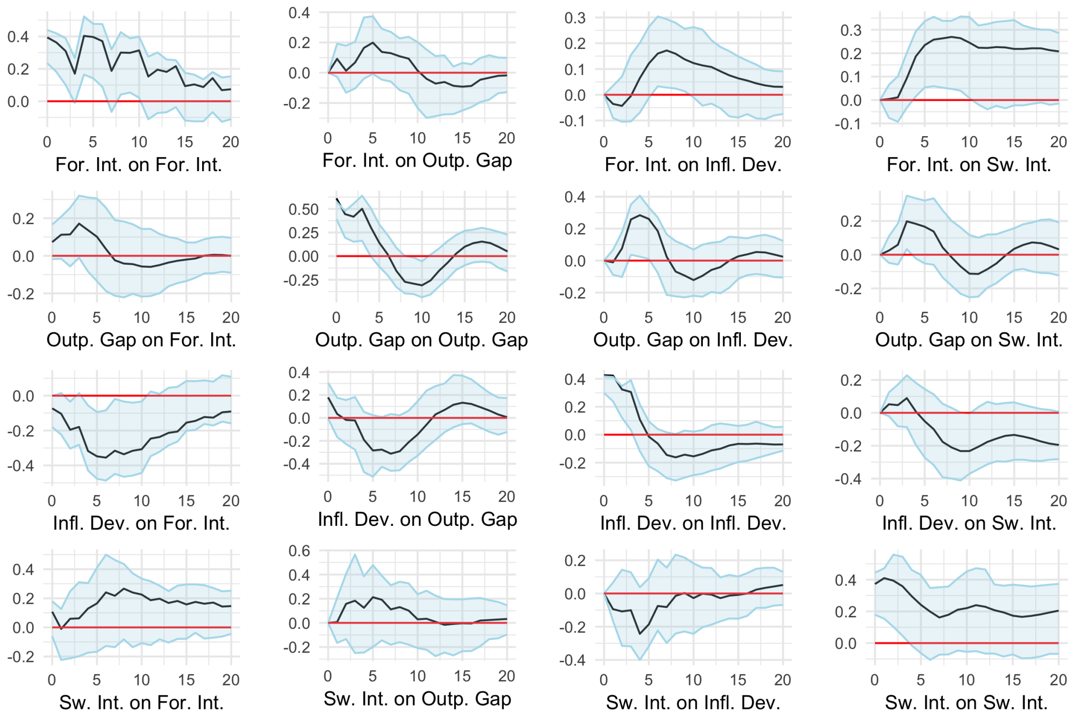


Estimated impulse responses of the Repo Rate from an orthogonal shock in the foreign interest rate for different lag lengths.

B The SVAR Model

In the figure below all estimated impulse repsonses from the SVAR model outlined in Section 4.2 are presented.

Figure 10: Estimated Impulse Response Functions from the SVAR model



Estimated impulse response functions from the SVAR model. The shocks corresponds to a standard deviation change of the variable in question.

C The Domestic Monetary Policy Rule

Consider a central bank that uses its choice of interest rate to minimize a quadratic loss function, subject to the dynamic IS equation in Equation (7) and the New Keynesian Phillips Curve in Equation (14). Assuming discretionary monetary policy, the central bank re-optimizes in every period (Clarida et al., 1999). The loss funtion of interest here is described below

$$L = \frac{1}{3}[(\pi_{H,t} - \bar{\pi})^2 + \alpha\tilde{y}^2 + c(i_t - i_t^f)^2], \tag{23}$$

where α and c are parameters that captures the importance of the output gap and the interest rate differential relative to the deviation of domestic inflation from its target. The optimization problem described above can then be expressed as

$$\begin{aligned} &\underset{i_t}{\text{minimize}} \quad L = \frac{1}{3}\big[(\pi_t - \bar{\pi})^2 + \alpha\tilde{y}_t^2 + c(i_t - i_t^f)^2\big] \\ &\text{s.t} \quad \tilde{y}_t = E_t\{\tilde{y}_{t+1}\} - \frac{1}{\sigma_\upsilon}(i_t - E_t\{\pi_{t+1}\} - i_t^n) \ \text{ and } \ \pi_{H,t} = \beta E_t\{\pi_{H,t+1}\} + \kappa\tilde{y}_t \end{aligned} \tag{24}$$

After solving the optimization problem, the central bank's reaction function is derived. This function describes how the optimal choice of interest rate reacts to changes in the target variables. Additionally, the interest rate decisions is also assumed to be a function of the interest rate in the previous period. Expressing the reaction function in terms of the composite parameters ϕ_π, ϕ_y and ϕ_{i^f}, and treating the coefficient of the natural interest as being unitary and the inflation target as a constant, the following expression is derived:

$$i_t = \rho_i i_{t-1} + (1 - \rho_i)(\phi_\pi E_t\{\pi_{H,t+1}\} + \phi_y E_t\{\tilde{y}_{t+1}\} + \phi_{i^f} i_t^f + i_t^n) + \nu_t, \tag{25}$$

Here ν_t is a AR(1) process such that $\nu_t = \rho_t\nu_{t-1} + \varepsilon_\nu$ and $\varepsilon_\nu \sim N(0, \sigma_\nu)$.

D Convergence Statistics from Bayesian Estimation

In the six graphs below convergence statistics for the three estimated parameters are presented. Since the Metropolis-Hastings algorithm performs the estimation in two blocks there are two graphs for each parameter. The lack of a clear trend in the graphs suggest convergence.

Figure 11: Trace Statistics for ϕ_π

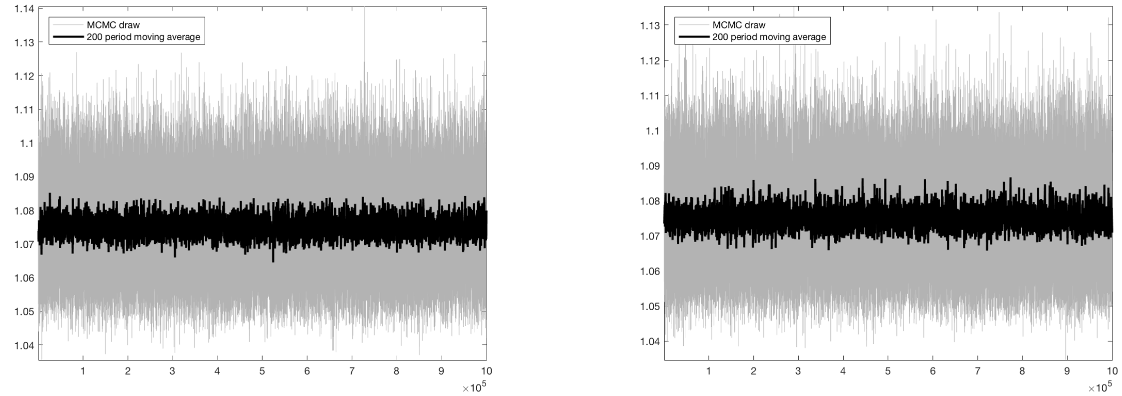


Figure 12: Trace Statistics for ϕ_y

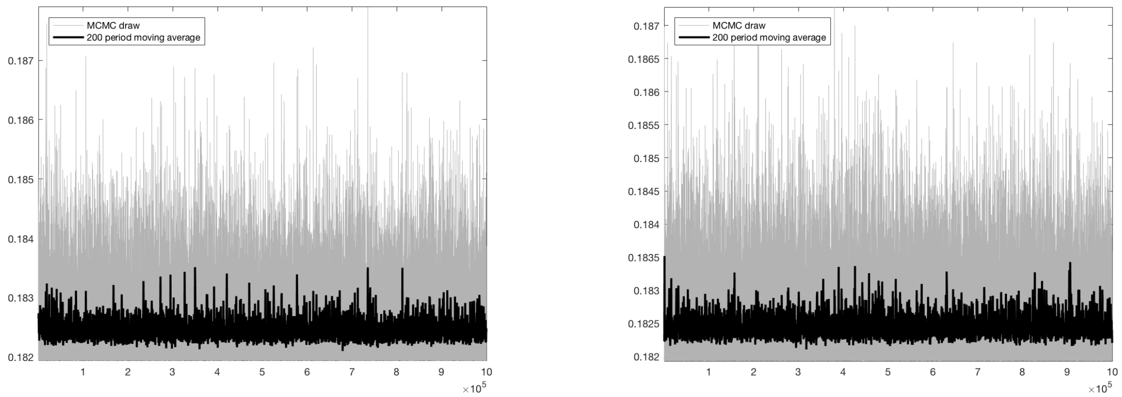


Figure 13: Trace Statistics for ϕ_{if}