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Negative Interest Rates in Sweden: An SVAR Approach

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Negative Interest Rates in Sweden:

An SVAR Approach

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Preface

This is a master`s thesis in economics at BI Norwegian Business School, as part of the study program Master of Science in business, with major in Economics. The work in this thesis has been carried out during our last year of our five-year degree. We are very grateful to our supervisor Professor Tommy Sveen for recommending the topic of negative interest rates, and thereby waking our interest for the subject. We also want to thank him for guidance, and constructive criticism during this process. Further we want to thank PhD Candidate Thomas S. Gundersen for help and guidance regarding use of MATLAB, and the development of our model. We also want to thank those who have prof-red and given feedback on this thesis. Finally, we want to thank our classmates, for much good company and support during our time here at BI.

Oslo 02.09.2018



Magnus Rennemo



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Summary

Following the financial crisis of 2008, several central banks have experimented by setting negative policy rates. In this master thesis, we want to examine the effect of negative interest rates on the Swedish economy. Sweden has since 2015 had policy rates below zero, which has raised many interesting questions. We are particularly interested in whether negative interest rates are expansionary.

To answer this, we look at the general development in the Swedish economy and compare this to the economic developments of other countries adapting to negative interest rates. We find that Sweden have over the last years experienced positive developments in its economy, with raising inflation, decreasing unemployment and increased output. To examine if this is due to monetary policy shocks or not, we establish two empirical SVAR-models. One model examining monetary policy when policy rates are positive and the other when policy rates are negative.

By simulating an expansionary monetary policy shock, we find that the Cholesky model using data when policy rates were positive show overall expansionary effects, which is in line with SVAR literature. On the other side, our Cholesky model using data after policy rates became negative shows contractionary effects on industrial production and no effect on CPI. However, on impact real effective exchange rate depreciates more under negative policy rates, than under positive policy rates.

This lead us to conclude that the major driver for the economic developments in Sweden has been other factors than monetary policy alone. Hence, at least for the case for Sweden are irrelevant or even contractionary.

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List of Abbreviations

This page poses as a summary over the abbreviations used in our thesis.

AIC:	Akaike Information Criteria
BIC:	Bayesian Information Criteria
BIS:	Bank of international Settlement
BOJ:	Bank of Japan
CB:	Central Bank
CDS:	Certificate of Deposits
CPI:	Consumer Price Index
CPIF:	Consumer Price index with Fixed mortgage rates
DSGE:	Dynamic Stochastic General Equilibrium
ECB:	European Central Bank
FED:	Federal Reserve
FEVD:	Forecast Error Variance Decomposition
FRED:	The Federal Reserve Bank of St. Louis
GDP:	Gross Domestic Product
HFI:	High Frequency Approach
HFI1W:	one-week STIBOR instrument
HFI3M:	three-month STIBOR instrument
HFI6M:	six-month STIBOR instrument
HICP:	Harmonized Index of Inflation
IP:	Industrial Production
IV:	Instrument Variable
KIX:	Krona Index
LIBOR:	London Interbank Offered Rate
MSPE	Mean Square Prediction Error
NEER:	Nominal Effective Exchange Rate
NIBOR:	Norwegian Interbank Offered Rate
NIRP:	Negative Interest Rate Policy
OLS:	Ordinary Least Squares
QE:	Quantitative Easing
R:	Policy Rate
REER:	Real Effective Exchange Rate
SNB:	Swiss National Bank
STIBOR:	Stockholm interbank Offered Rate
SVAR:	Structural Vector Autoregressive
VAR:	Vector Autoregressive
ZLB:	Zero Lower Bound

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1 Introduction

In the aftermath of the financial crisis in 2008, several countries experienced deep economic recessions. In addition, the central banks (CB) also struggled to counteract the negative effects set in motion by the crisis, hampering their credibility to keep stable inflation. To mediate this, the CBs started to lower interest rates, and some also initiated quantitative easing (QE)¹ at the same time to increase the availability of capital in the economy (International Monetary Fund, 2017).

However, these measures insufficient, and further cuts in the interest rates was needed to counteract the recession to the point where interest rates started to reach the zero-lower bound (ZLB)². Furthermore, when rates reach zero, QE can be welfare improving since it relaxes the liquidity constrain for some agents (Boel & Waller, 2015). In addition, if the CB can credibly state that policy rates will be kept zero for longer periods, it can stimulate aggregate demand by promising cheap funding for longer periods (Campbell, Evans, Fisher, Justiniano, Calomiris & Woodford, 2012).

Furthermore, fiscal policy after the crisis in 2008 has been expansionary, including large scale stimuli packages and increasing public debt levels. This have for many governments exhausted the possibility of expansionary fiscal policy because the goal to control budget deficits have taken precedence. Therefore, it has fallen on the central banks to influence the economy through monetary policy. This led some CBs to break the ZLB by implementing negative rates in hope of fuelling the economy. The countries who have implementing negative interest rates policies in the recent years are: Sweden, Denmark, Japan, Switzerland, Bulgaria and the euro area, each with different motivations.

¹ Unconventional monetary policy where the CB buys government bonds to lower short-term interest rate and increase money supply by flooding the financial affiliations with capital (Walsh, 2017).

² The Zero-lower bond is the situation where nominal interest rates reach Zero, or close to Zero (Walsh, 2017).



Retrieved from IMF (2017, pp.4) | Haver Analytics

In this thesis we have chosen to focus on the Swedish economy's experience with negative interest rate policies (NIRP). The reason why we have chosen Sweden is because they have been the ones experiencing the greatest increase in output since implementing NIRP.

Embarking into unknown territory for Sweden highlighted some important questions that we will try to answer in this thesis. Does expansionary monetary policy below ZLB have any impact on the real economy? And is expansionary monetary policy less responsive in negative territory than in positive territory? Formally our research question is:

Does monetary transaction mechanisms in Sweden work differently when policy rates are negative compared to when they were positive?

Particularity we are interested in whether monetary policy under negative interest rates are more, or less expansive than under positive interest rates.

To answer this question, we first do a descriptive analysis of the Swedish economy, comparing this to other countries where negative interest rates have been tried. After this we develop an empirical SVAR-model, where we look at the effects of monetary policy shocks to the Swedish economy, both under negative and positive policy rates.

2 Overview of literature

NIRP has only been implemented for a few years now, and the amount of literature on the subject is limited. Particularly, this is the case when it comes to theoretical literature, which might be surprising considering the radical nature of the policy experiment pursued by several central banks³. As our paper examine the effect of NIRP on the wider economy, literature on this is particularly interesting, however lacking.

Eggertsson, Juelsrud & Wold (2017) set up a new Keynesian dynamic stochastic general equilibrium (DSGE) model, to examine whether NIRP are expansionary. In the paper, the authors model how an exogenous decrease in marginal utility of consumption affect the policy rates set by the central bank. By including money storing costs⁴ and central bank reserves, the authors capture the disconnect between the policy rate and the deposit rate at the lower bound. In the paper the authors show that negative policy rates are at best irrelevant and can potentially be contractionary due to a negative effect on bank profit.

Contrary to what Eggertsson, Juelsrud & Wold finds, in a speech held at a conference on the credit channel of monetary policy, at the Federal Reserve Bank of Georgia in (2007), the chairman of the Federal Reserve at the time, Ben Bernanke discusses whether banks should lend more and take less risk when policy rates are reduced. When interest rates are lowered, banks net worth increases. This is because the lower policy rates are translated into the debt side of the balance sheet of banks. By increasing the debt value in present value terms, the difference between the asset side and the debt side increases their net worth. This in turn relaxes the banks financial constraint, and consecutively increase lending and reduce risk taking.

In an empirical paper on the pass-through of negative policy rates Heider, Saidi & Schepens (2016) recognize that after ECB set deposit facility rates below zero to negative 0.1% in June 2014, banks with high deposits focused their lending to

³ However, there is a large amount of literature on the zero-lower bound. Krugman (1998) and Eggertsson & Woodford (2006) are two early contributions to this.

⁴ There is more literature on the subject of storing cost for money. Gesell (1916) proposes a direct tax on paper currency, which is further discussed by Goodfriend (2000) and Buiter & Panigirtzoglou (2003). Another possibility is abolishing paper currency altogether. This is discussed among other, by Agarwal & Kimball (2015), Rogoff (2017b) and Rogoff (2017a).

more riskier firms in the form of syndicated loans (i.e group of lenders cooperate to form a single loan to one borrower). Lowering of the policy rate should increase net worth of the banks. However, when it goes into negative territory it lowers the banks net worth. The reason according to the authors, are that banks are reluctant to impose negative rates to their depositors in fear of cash withdrawals, thus lowering of short-term debt no longer occur. Consequently, banks find it more difficult securing funding from outside options, thus lending decrease.

Jackson (2015) and Bech & Malkhozov (2016) document the limited pass through of negative policy rates to aggregate bank rates. Brunnermeier & Koby (2016) defines the reversal rate as the rate where expansive monetary policy “reverses” its intended effect and becomes contractionary for lending. However, this rate can in principle be both positive and negative, so it is unrelated to the observed lower bound on deposit rates.

Rognlie (2015) studies the use of negative interest rates as part of optimal monetary policy, without any changes to the monetary system. In the paper he set up a model where he allows for negative interest rates due to money storing costs. He finds that negative interest rates are costly, because they imply an ineffective subsidy to cash. He further finds that negative interest rates are most useful as a tool when cash demands are inelastic, so policies that can constrain cash demand are therefore important complements to negative interest rates.

3 Descriptive statistics (Negative interest rates in practice)

As mentioned above only a few countries have implemented NIRP, with various motivation and results. However, for academics and CBs this raises some questions of interest. For instance, how do consumers react when deposit rates become negative? Do bank runs occur? And if they do, why or why not? And the biggest one, is NIRP expansionary?

To answer these questions, we will use a cross country analysis between Sweden, Denmark, Switzerland, euro area, and Japan. This will give some understanding on how the transmission of NIRP has behaved in the different countries, before focusing mainly on Sweden.

3.1 Other countries

3.1.1 Denmark

Denmark had by 2011 slowly recovered from the financial in 2008. However, the Euro area was moving sluggishly behind due to the sovereign debt crisis, and by the second quarter (same year) European investors started to use the Danish Krona as a safe-haven currency. To defend their peg toward the Euro, the Danish National Bank lowered their policy rates, closely following the policy rates of the European central banks (ECB) and sold considerable amounts of Danish Krona. Following the decrease in policy rates, the certificate of deposit (CD) rates turned negative⁵, which resulted in weakening of the Krona. Furthermore, the Danish Krona experienced more pressure when Switzerland abolished their peg in mid-2014. Unilaterally⁶, this followed by further cuts in the policy rates and the Danish National Bank had to decrease CD rates even further to -0.75%. With great success the negative rates managed to reverse the build-up of foreign exchange rate reserves by the end of 2015, mitigating the appreciatory pressure (International Monetary Fund, 2017).

⁵ Denmark's National bank conducts monetary policy by setting monetary-policy interest rates via the lending and deposit facilities made available to the banks and mortgage banks. This arrangement of policy setting is part of Denmark's Tiering system to smooth transmission of policy rates into the economy.

⁶ Denmark set interest rates closely relating the ECB policy rates, but also conducts decisions unilaterally from the ECB, as a way to protect their peg toward the Euro (Danish National Bank, 2017).

3.1.2 The Euro area

From the financial crisis in 2008, and the sovereign debt crisis which followed, the European area have experienced difficulties improving their economic outlook. Trying to change this, the European Central Bank (ECB) started lowering interest rates and initiated extensive QE programme to fuel the economy.

However, the negative shocks were too deep and the traditional monetary policy tools have been insufficient to reach economic targets (International Monetary Fund, 2017). As a result, the ECB introduced NIRP, by setting policy rates slightly negative in mid-2014. But this was not enough, and further cuts was implemented, and by the end of the first quarter of 2016 interest rates reached negative 0.4%. In addition, the ECB also implemented TLTRO-II⁷, which is an expansionary monetary-policy scheme implemented to incentivise banks to make more loans to businesses and consumers in the euro area.

This resulted in a combination of three monetary policy schemes, QE, NIRP and TILTRO-II, which have helped provide growth in the euro area. As a result, inflation has picked up, and has become stable between the 1-2%, see figure 2 (Tradingeconomics, 2018e). A range which is in line with the ECB monetary policy strategy, however, below their medium target at 2% (European Commission, 2018a).

Figure 2: European Union Inflation Rate



*Note: European union inflation rate over 10 years.
Source: Tradingeconomics.com | Eurostat*

⁷ In normal times CB funds commercial banks with liquidity, which needs to be repaid in one week or three months. However, TLTRO-II allows commercial banks borrow an additional 30% of their outstanding loans to businesses and consumers, with maturity of four years. In turn, this provides the market with stable funding when times are uncertain. (European Central Bank, 2016).

3.1.3 Switzerland

Switzerland's goal when implementing NIRP was to increase inflation⁸ and fight appreciation of the Swiss Franc towards the Euro. When the Euro area announced that they would bring about a QE package, cash started to flow into Switzerland, and appreciatory pressure rose on the Swiss Franc (Swiss National Bank, 2015). To mediate this the Swiss National Bank lowered its interest rates to negative 0.75% at the end of 2014.

From figure 3, we see that it has had a positive effect, bringing up inflation. But It should be noted that inflation is still far below target, which is set to be approximately 2% (Tradingeconomics, 2018a).

Figure 3: Switzerland Inflation Rate



*Note: Shows Switzerland's inflation rate over the past ten years
Source: Tradingeconomics.com | Swiss Federal Statistical office.*

3.1.4 Japan

As in the case for the Swiss Franc, Japanese yen is also used as a “safe haven” currency. In addition, when oil prices fell by the end of 2015, although benefitting oil importers such as Japan, it affected inflation negatively. Other countries were also affected by the oil price shock, which spilled over to financial markets (Park & Ratti, 2008). The unstable financial market caused Japanese stock market to drop and triggered investors to invest in Japanese yen causing it to appreciate. This affected Bank of Japan's (BOJ) credibility to support its inflation target. To alleviate deflationary pressure and reinstate their credibility the BOJ implemented negative rates in the middle of the first quarter of 2016.

⁸ In the mandate for SNB on monetary policy strategy, price stability is important for growth and prosperity. Furthermore, by ensuring stable prices it facilitates an environment where the economy can exploit its production potential. In other words, stable prices are important for the prosperity of the real economy (Swiss National Bank, 2015).

Figure 4: Japan Inflation Rate



Note: Japan inflation rate over the past ten years

Source: Tradingeconomics.com | ministry of internal affairs & communications

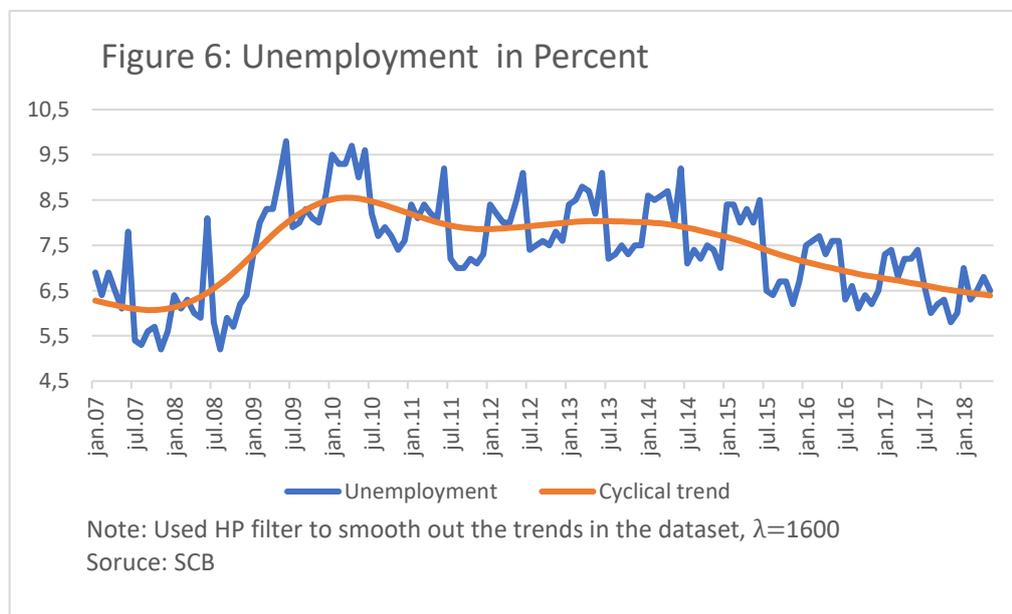
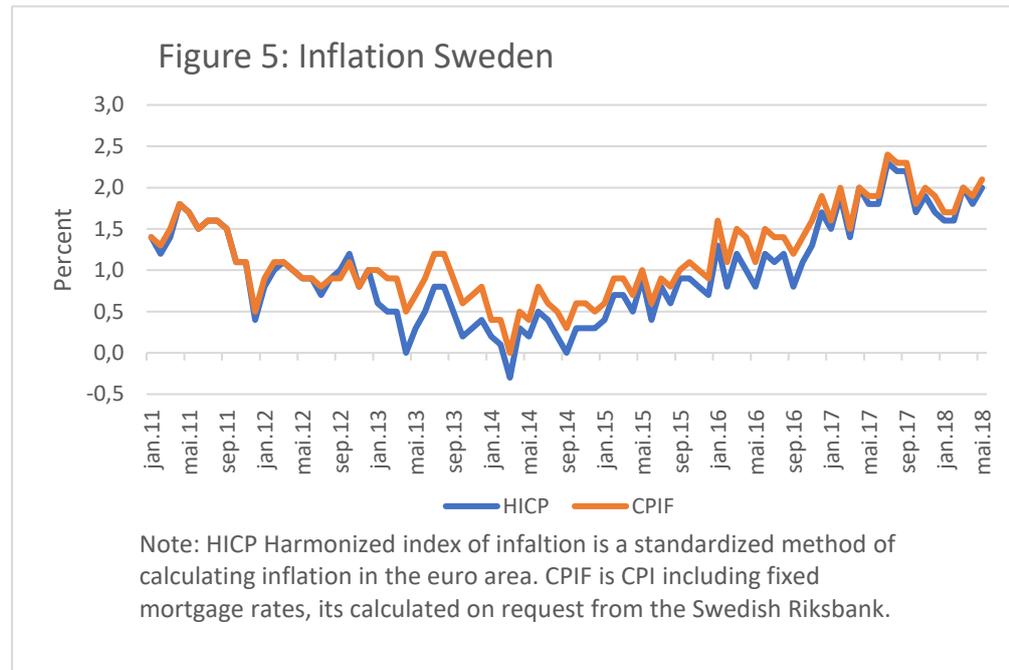
From figure 4 (Tradingeconomics, 2018c), we can see that inflation is moving in the right direction. However, the BOJ has not been able to reinstate their credibility and inflation is slow moving (Nishino, Yamamoto, Kitahara, & Nagahata, 2016). This together with a stronger Yen, and lower lending volumes have muted the effects of NIRP, which is visible by the flatness of Japan's inflation line, compared to other economies implementing NIRP.

3.2 The developments in the Swedish economy

According to the Sveriges Riksbank Act," the objective for monetary policy is to maintain price stability. The Riksbank has defined this as a 2 percent annual increase in the consumer price index with fixed interest rates (CPIF)" (Sveriges Riksbank, 2018b).

In the aftermath of the financial crises of 2008, Sweden experienced low and decreasing inflation. In addition, other major trading partners of Sweden also experienced slow growth, which inevitably affected their demand for imports. Being an industrial heavy economy, lower exports will ultimately affect the Swedish economy in a negative manner (Sveriges Riksbank, 2012). In addition, falling oil prices have also contributed to lower inflation both in Sweden and in the rest of the world (Park & Ratti, 2008). However, low oil-prices can contribute positively to growth in gross domestic product (GDP), since Sweden is an oil-importer (Herrera, 2018; Sveriges Riksbank, 2015). To counteract this, the Swedish Riksbank steadily decreased their repo rate, reaching the ZLB in early

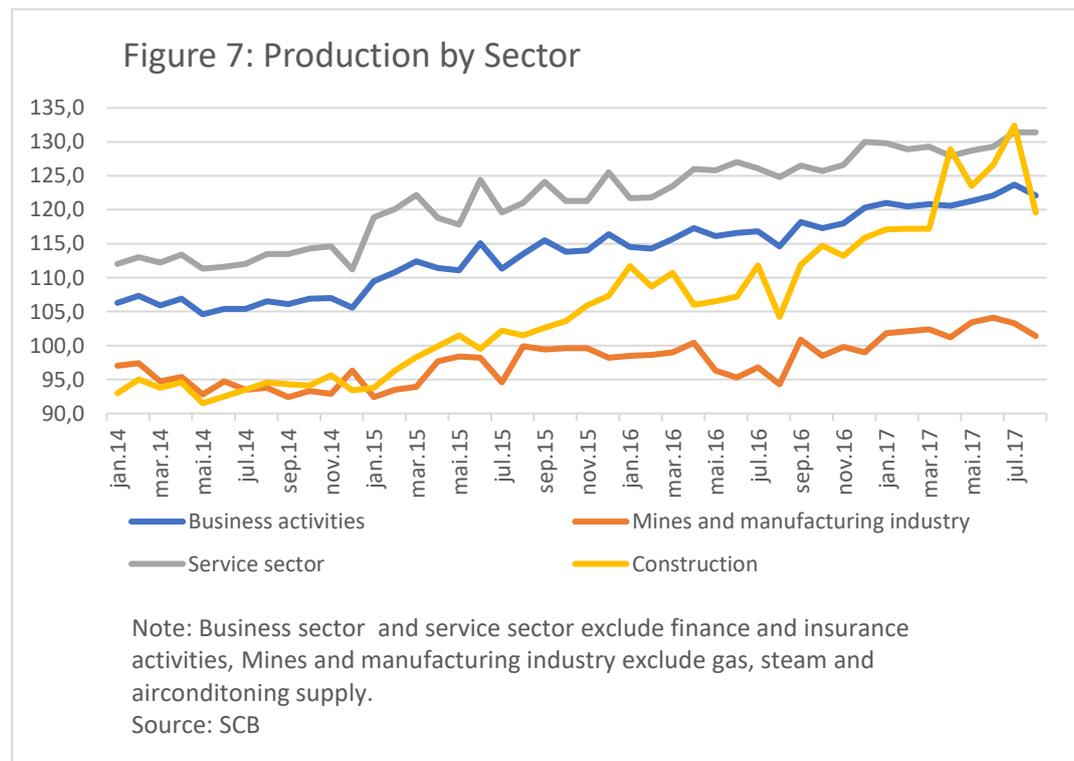
2015. However, traditional monetary policy has proved ineffective, and cutting interest rates had little effect on economic growth (Sveriges Riksbank, 2014, 2015). By mid-2014 Swedish inflation reached its lowest point, shown by Figure 5. This was further transmitted to inflation expectations, which fell abruptly in late 2014 (International Monetary Fund, 2017).



To counter this, by the beginning of 2015 the Swedish Riksbank set policy rates below zero to negative 0.1%, hence for the first time breaking the ZLB. The central bank after continued this to lower the repo rate, and by February 2016 the repo rate reached -0.5%, see figure 10. In addition, bond purchasing programs were initiated to buy back 40% of outstanding government bonds by the end of 2016 (International Monetary Fund, 2017) to intensify its commitment to reach target inflation rates.

Looking at figure 5, we can see a turning point in the inflation line by the end of the first quarter, 2015. This shows some indication that inflation has reacted positively to the negative interest rates and QE programme initiated by the central bank. Today, inflation is at target with CPIF⁹ slightly above at 2.1% and HICP¹⁰ at 2%. However, the central banks projections do expect this to be lower at 1.8% in one year (Sveriges Riksbank, 2018c).

The Swedish labour market also experienced increase in unemployment after 2008, but as can be seen in figure 6, unemployment has since 2010 had a falling trend, particularly after 2014.

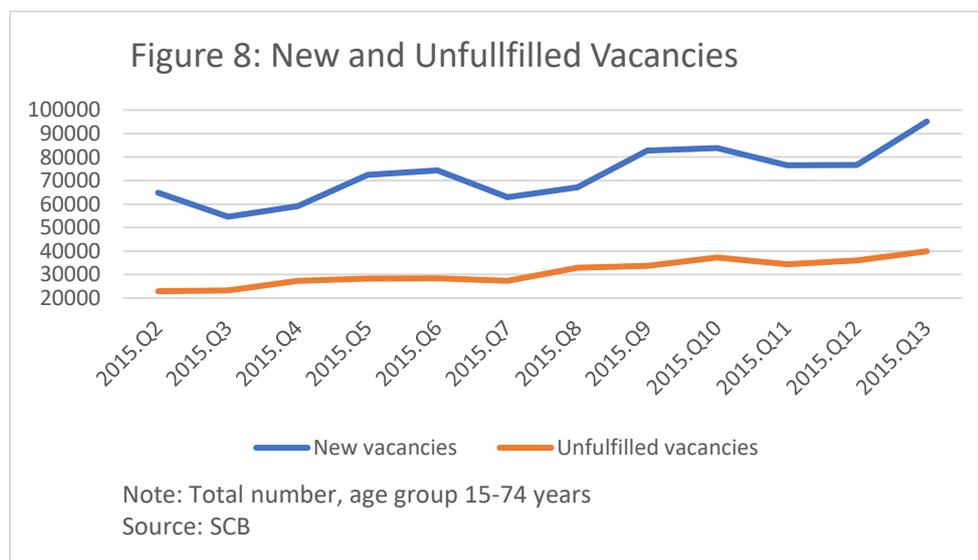


⁹ Consumer price index with fixed mortgage rates

¹⁰ Harmonized index of inflation

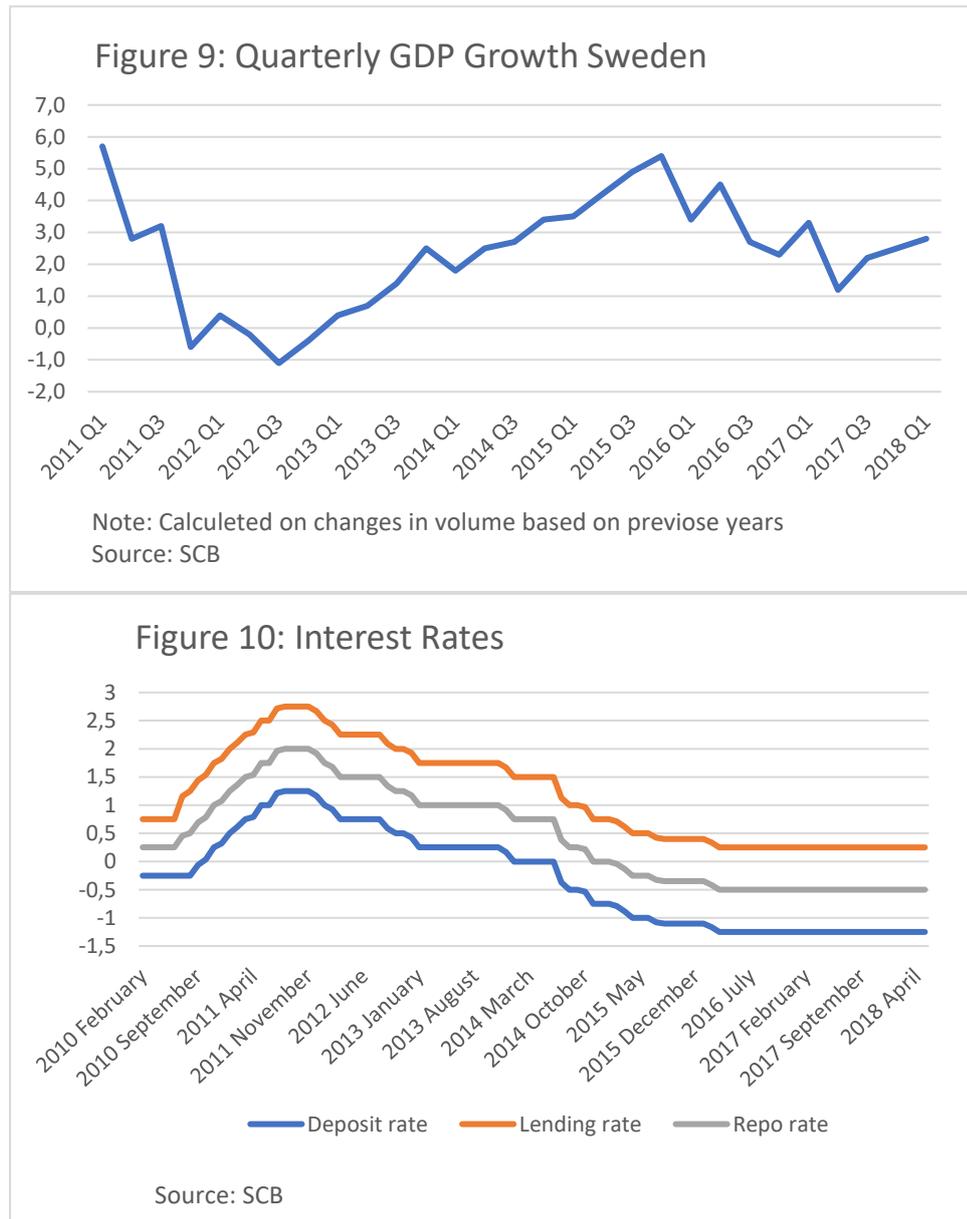
From figure 7, We can see that business activities and the service sector has experienced steady growth from the beginning of 2015, where there is a slight upward kink. Especially construction has experienced a sharp upturn when new capital became cheaper. The exception is the mining and manufacturing industry, where growth has been slow. The reason is that this sector is dependent on exports which has been slow moving due to the stagnant growth internationally causing demand for exports to reside. This is signified by the rather flat line in figure 7 (Sveriges Riksbank, 2017). On the other hand, negative rates support investment opportunities in the production sector, which also create new jobs.

The increase in production in the other sectors have helped contribute to new job openings, see figure 8. Thus, demand for labour is high which contributes to lower unemployment in the future. Unfulfilled vacancies and new job openings are both growing at a constant rate. This can indicate some matching problems between applicants and employers (Sveriges Riksbank, 2018d). The decrease in unemployment is expected to continue going forward, which will contribute to more consumption and taxes (Beijron & Broman, 2018) .



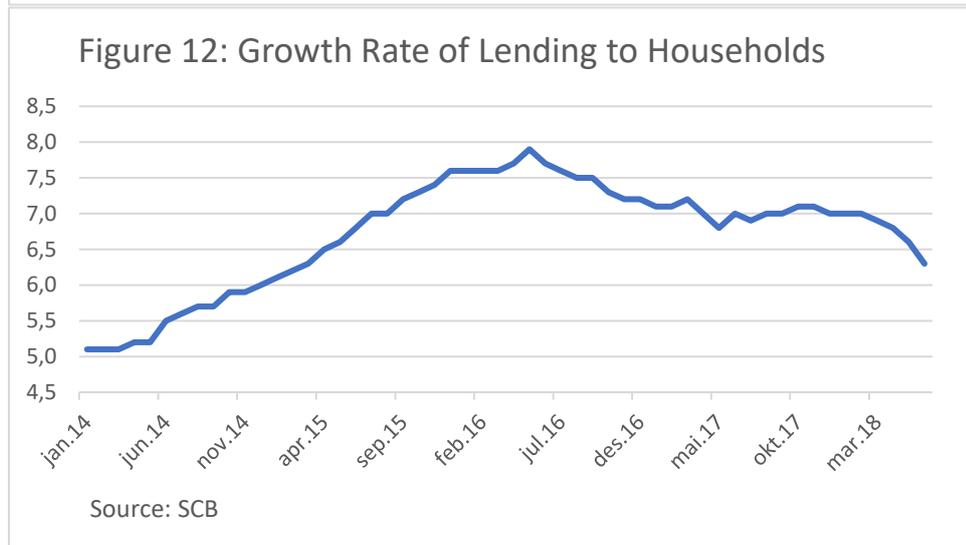
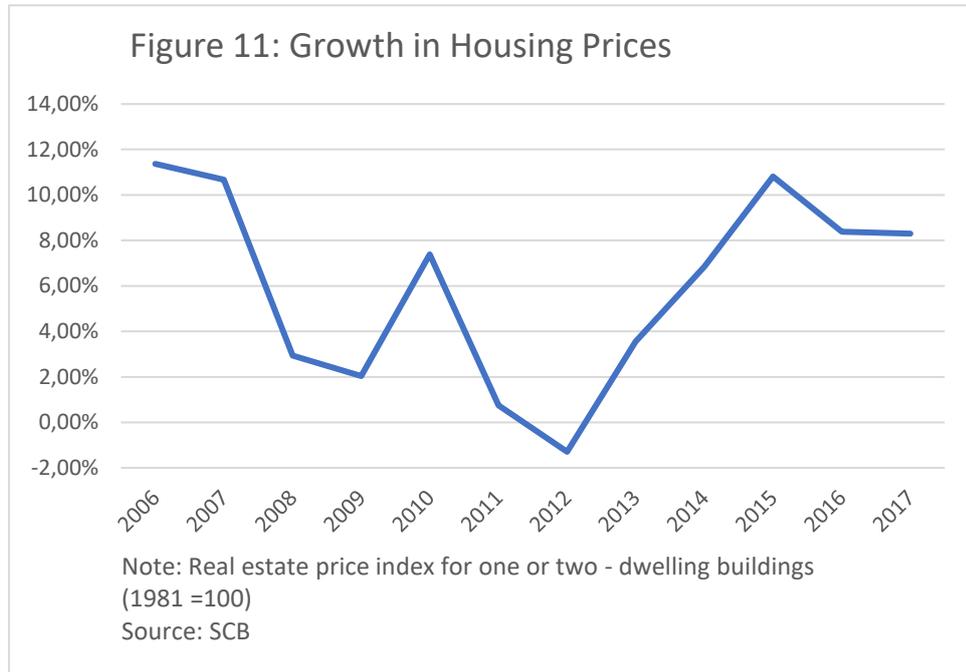
Looking at figure 9, we see that GDP growth in Sweden has increased from 2012 Q3. At the same time monetary policy has continued to be expansionary, see figure 10. In addition, immigration has steadily increased in the same period which also contributes to GDP growth in form of increased public spending (Ekberg, 2011). Low interest rates have also supported growth in the housing

market, see figure 11, which have led to growth in the construction industry. The effects of immigration and increase in housing construction have contributed to GDP growth, where it reached its peak at 5.4 % in Q4 2015 where growth was double the historic average of 2,67% (Tradingeconomics, 2018d). The issue of simultaneity is apparent, and it is hard to pinpoint the exact economic driver. Moreover, when interest rates turned negative, the growth rate pivots and decreases to 2.8% in 2018 Q1.



In addition, growth in housing prices also subdued around the time of implementation of NIRP. This indicates that housing prices in Sweden had a contributing effect on GDP growth before this. However, the slowdown in housing prices is probably not caused by NIRP but is due to the implementation of minimum amortization payments on mortgages and that mortgages rates stopped

declining around this point (International Monetary Fund, 2017; Sveriges Riksbank, 2018c). This have further translated into less lending, which decreased by 1.1% in May 2016 to 6.8% in May 2018, see figure 12.

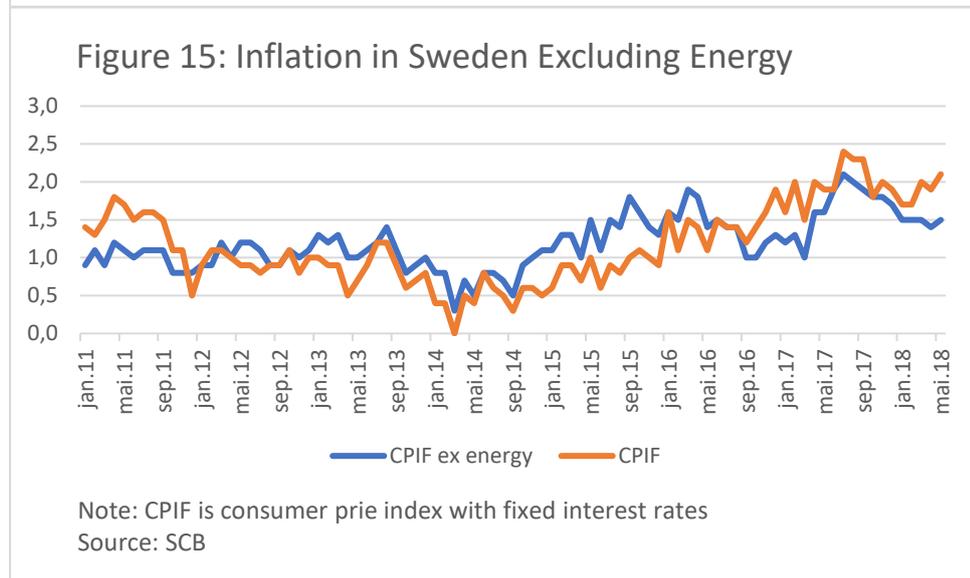
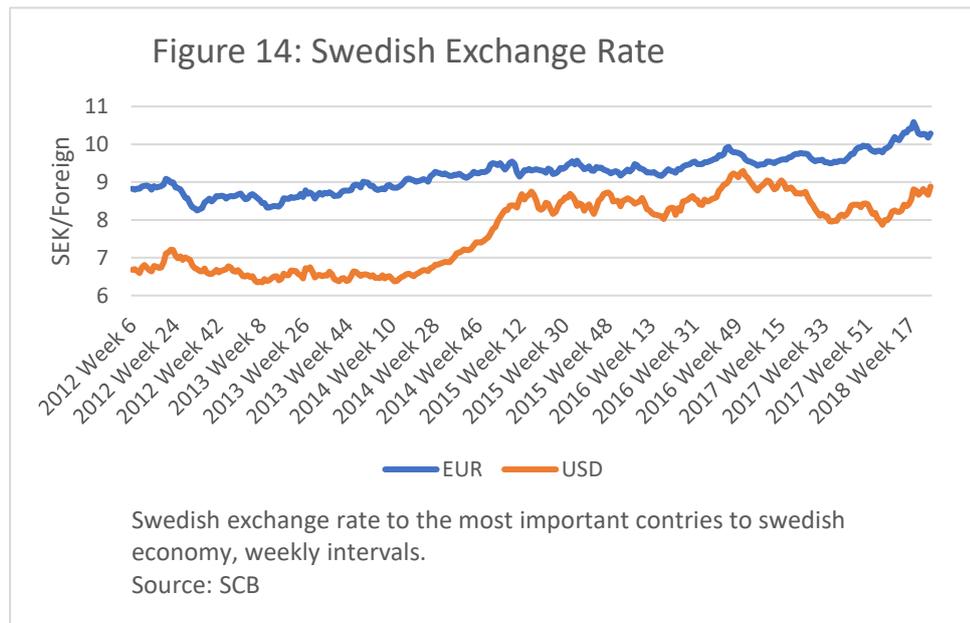


The reason for this development is probably due to the macroprudential policy implemented by the government to mitigate some of the lending volumes. On the other hand, it could also be because of uncertainty due to NIRP. However, growth is still considered high at just above 6%, although much lower than what it was prior to the financial crisis at over 10% growth per year (Sveriges Riksbank, 2018c).

3.2.1 Effects of international developments on the Swedish economy

The outlook for the world economy is less uncertain and global trade is starting to pick up (Sveriges Riksbank, 2018c). This will further contribute to more demand for Swedish goods which in turn increases exports. From figure 13, we see that exports and imports have steadily increased since Q1 2014. In addition, figure 14 shows that the Swedish krona have depreciated against EUR and especially towards USD, which helps support competitiveness of exported goods. Moreover, economic growth abroad is starting to pick up, where United states and the euro area are both close to normal resource utilization (International Monetary Fund, 2017). GDP growth in the United States was 3% and in the Euro Area 2,5% in Q4 2017. In recent times however, this trend has turned, where GDP growth has dropped to 2.2% in US and 2.4% in the Euro Area. However, GDP growth is expected to remain stable and hover around 2-3% (European Commission, 2018a; Federal Reserve, 2018)





In addition, oil prices have also increased slowly since the beginning of 2016, before gaining some momentum by mid-2017. This increase has affected inflation both for Sweden (see figure 15) and their biggest trading partners US and EU. In the US, inflation has risen to 2.8% (Tradingeconomics, 2018g) in May 2018, where 0.6% of this is caused by energy prices (Tradingeconomics, 2018f). Comparably, euro area has not experienced as much increase in inflation with 1.9% (Tradingeconomics, 2018b) where 0.8% of this is due to energy prices (Tradingeconomics, 2018f). By excluding energy prices in EU and US we see that growth is still weak (more so for EU) which is expected to contribute less pressure to inflation in Sweden trough trade (Sveriges Riksbank, 2018c).

4 SVAR methodology

4.1 Motivation

Vector autoregressive (VAR) models have become widely used in empirical macroeconomics over the past decades, after Christopher Sims (1980) provided this new framework to make casual inference in macroeconomic data. Christiano, Eichenbaum & Evans (1998), Stock & Watson (2001), Llaudes (2007), Bjørnland (2008), Gertler & Karadi (2015) and many more uses either recursive VAR or Structural VAR (SVAR) to examine and to present the impacts of monetary policy shocks to the economy, since they offer a convenient method to do this. Moreover, VARs is a convenient method for estimating the first and second order moment properties of the data (Christiano et al., 1998).

In consideration, we believe that using an SVAR approach to examine the effect of NIRP on the Swedish economy will give informative results. Particularly, this method is often used to examine the effect of monetary policy shocks by academics. Based on this, we believe the SVAR can infer how transmission mechanism of monetary policy differ between negative and positive interest rates.

Next, we will begin by characterizing the basic VAR model, and examine the identification problems related to this. For our model we propose two identifications methods. First the Cholesky identification, which is a common choice by academics when identifying monetary policy shocks. Secondly, we will describe an identification method developed by Stock & Watson (2012) and Mertens & Ravn (2013) called proxy SVAR, where we will use an external instrument to identify the monetary policy shocks.

4.2 SVAR

The main source for the explanation of the VAR and SVAR are from Bjørnland & Thorsrud (2015), Killian & Lutkepohl (2017), Stock & Watson (2001), Lutkepohl & Kratzig (2004), Bagliano & Favero (1999) and Christiano et. al (1998).

The general SVAR system can be written as a combination of several autoregressive equations:

$$\Psi y_t = A_1 y_{t-1} + \dots + A_p y_{t-p} + \epsilon_t \quad (1)$$

This is the structural representation of the VAR model. Often, the exact representation of the structural model is unknown, but one can assume some relationship based on theory and prior beliefs (Bjørnland & Thorsrud, 2015). In equation (1), y_t is a $(k \times 1)$ vector of the dependent variables in the equation system, A_p is a $(k \times k)$ coefficient matrix of the p th lag of the dependent variables y_{t-p} . The remaining part of the y_t vector, is ϵ_t which captures the structural shocks of the system. The structural shocks are a $(k \times 1)$ vector and is assumed to be independent. Lastly, the matrix Ψ is a $(k \times k)$ restriction matrix that allows for contemporaneous relationships between the dependent variables.

From equation (1) we see that the variables in the y_t vector is explained by its own lags, including the current values of the other dependent variables with their respective lags and structural shocks. In the structural model, all variables are endogenous and is decided in the model. All dependent variable in the y_t vector is dependent on other dependent variables and on all structural shocks ϵ_t simultaneously. Hence, it is not possible to estimate the SVAR model directly with conventional estimation techniques, such as ordinary least squares (OLS).

Left multiplying both sides by Ψ^{-1} , equation (1) can be written as:

$$y_t = \Lambda_1 y_{t-1} + \dots + \Lambda_p y_{t-p} + e_t \quad (2)$$

Where:

$$\Lambda_1 = \Psi^{-1} A_1, \quad \Lambda_p = \Psi^{-1} A_p \quad \text{and} \quad e_t = \Psi^{-1} \epsilon_t$$

By iterating backwards infinitely many times, equation (2) can be written as:

$$y_t = \sum_{j=0}^{\infty} \Phi_j e_{t-j} \quad (3)^{11}$$

¹¹ The mathematical explanation for how one goes from equation 2 to 3 is straight forward and tedious. It is thoroughly explained in many books on the subject. For instance Kilian & Lütkepohl (2017) and Bjørnland & Thorsrud (2015) does this very well.

Which now is a reduced form moving average process, where Φ is a function of Λ . The reduced form errors, e_t , are linear combinations of the structural errors, ϵ_t with covariance matrix:

$$E[e_t, e_t'] = \Psi^{-1}E[\epsilon_t \epsilon_t'](\Psi^{-1})' = \Psi^{-1}\Omega(\Psi^{-1})' = \Sigma_e \quad (4)$$

Here, Ω is the covariance of the structural errors, and Σ_e is the covariance matrix of the reduced form errors. The variance-covariance matrix Σ_e contains all covariance's in the upper and the lower triangle and all variance of e_t on the diagonal. By design, the variance-covariance matrix indicates that a structural shock in one dependent variable will affect the other dependent variables simultaneously.

$$\Sigma_e = \begin{bmatrix} \sigma_1 & \sigma_{12} & \cdots & \sigma_{1k} \\ \sigma_{21} & \sigma_2 & & \sigma_{2k} \\ \vdots & & \ddots & \vdots \\ \sigma_{k1} & \sigma_{k2} & \cdots & \sigma_k \end{bmatrix}$$

All the parameters of the reduced form model, i.e., equation (2) can be estimated using conventional estimation techniques such as OLS, equation by equation. This means that one can run a series of regressions to estimate the coefficients in the Λ matrices, and then compute the covariance matrix Σ_e . However, without any restrictions, the variance-covariance matrix will likely not be a diagonal matrix, with zeros off the diagonal. Hence, the reduced form errors are likely correlated.

4.3 Cholesky Identification

As mentioned above, equation (2) can be estimated using OLS. Hence, the coefficients in $\Lambda_0, \Lambda_1, \dots, \Lambda_p$ can be estimated, as can the components of the variance-covariance matrix. However, it is impossible to identify the SVAR system given the information from the estimation of the reduced form VAR system due to an under-identification of parameters in the SVAR system. Sims (1980) suggested the original solution to the identification problem of the structural parameters from the reduced form model. Sims assumed a recursive structure for how the structural shocks affected the variables in the VAR system, and thereby achieve identification.

As mentioned before the reduced form errors are likely correlated, since Σ_e is likely not a diagonal matrix. Hence, a shock in one variable is likely to be accompanied by a shock in another variable. If one is to do structural analysis, the shocks must be made uncorrelated. The most simple and popular way to do this is by using the Cholesky decomposition, after French military officer and mathematician Andre-Louis Cholesky. The Cholesky decomposition is very well known and is a result that is much used in matrix algebra. It states that every positive definite symmetric matrix can be written as the product $\Sigma_e = PP'$ where P is the Cholesky decomposition of Σ_e . P will in this case be a lower triangular matrix with positive diagonal elements and zeros above the diagonal, while P' is its conjugate transpose.

Using this, equation (3) can be written as:

$$y_t = \sum_{j=0}^{\infty} \Phi_j PP^{-1} e_{t-j} \quad (5)$$

$$y_t = \sum_{j=0}^{\infty} \Theta_j V_{t-j} \quad (6)$$

Where $\Theta_j = \Phi_j P$ and $V_{t-j} = P^{-1} e_{t-j}$ so that:

$$E[V_t V_t'] = P^{-1} E[e_t e_t'] (P^{-1})' = P^{-1} (PP') (P^{-1})' = I \text{ (Unit variance)} \quad (7)$$

Hence, given that P is a lower triangular matrix, the components of V_t will be uncorrelated, although the components of e_t might not be.

The next point to consider is the ordering of the dependent variables. In the case of the reduced form VAR model, this is not of importance, however it plays a very important role for the Cholesky identified VAR. In conjunction, the ordering of the variables decides which variables are contemporaneously affected by the shocks of the other variables. To identify the ordering, economic theory is normally used.

Writing out equation (6):

$$\begin{bmatrix} y_{1,t} \\ y_{2,t} \\ \vdots \\ y_{k,t} \end{bmatrix} = \begin{bmatrix} \theta_{0,11} & 0 & \cdots & 0 \\ \theta_{0,21} & \theta_{0,22} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ \theta_{0,k1} & \theta_{0,k2} & \cdots & \theta_{0,kk} \end{bmatrix} \begin{bmatrix} v_{1,t} \\ v_{2,t} \\ \vdots \\ v_{k,t} \end{bmatrix} + \Theta_1 v_{t-1} + \Theta_2 v_{t-2} + \cdots \quad (8)$$

Or since $\Phi_0 = I$ and $\Theta_0 = P$,

$$\begin{bmatrix} y_{1,t} \\ y_{2,t} \\ \vdots \\ y_{k,t} \end{bmatrix} = \begin{bmatrix} p_{11} & 0 & \cdots & 0 \\ p_{21} & p_{22} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ p_{k1} & p_{k2} & \cdots & p_{kk} \end{bmatrix} \begin{bmatrix} v_{1,t} \\ v_{2,t} \\ \vdots \\ v_{k,t} \end{bmatrix} + \Phi_1 P v_{t-1} + \Phi_2 P v_{t-2} + \cdots \quad (9)$$

We see that the Cholesky decomposition implies that the second shock v_2 does not affect the first variable contemporaneously, while both shocks can affect the second variable contemporaneously. However, after one period, no restrictions are in place and both shocks are then free to affect both variables.

In the case of k variables in the system, the Cholesky decomposition restricts the least necessary number of parameters, $(k^2 - k)/2$, in matrix Λ to enable identification of the remaining parameters. According to Ramey (2016), the Cholesky VAR is the most common approach to evaluate monetary policy shocks. Ramey (2016, pp. 9) writes on Cholesky decomposition to evaluate monetary policy shocks:

“The most commonly used identification method in macroeconomics imposes alternative sets of recursive zero restrictions on the contemporaneous coefficients. This method was introduced by Sims (1980), and is also known as “triangularization.””

4.4 Proxy SVAR

The proxy VAR method was developed by Stock & Watson (2012) and Mertens & Ravn (2013) in independent work. This model utilizes external instruments, that is, instruments that are obtained from outside the VAR/SVAR to identify the coefficients in the model. Stock & Watson (2012) incorporated shocks from over 200 external variables to examine the channels of the 2008 to 2009 recession, while Mertens & Ravn (2013) concentrated on instrumenting tax shocks in the SVAR model with a narratively identified shock series. In a paper on macroeconomic shocks, Ramey (2016) refers to this as “a promising new approach for incorporating external series for identification”.

The instrument one use in external identification has to fulfil the two essential conditions of instrumental variables:

$$\text{Relevance condition: } E[\eta_t \varepsilon_{j,t}] \neq 0 \quad (10)$$

$$\text{Exogeneity condition: } E[\eta_t \varepsilon_{i,t}] = 0 \quad (11) \quad \text{for } i \neq j$$

Here η_t is an external series and, the instrument used to identify the parameters in the Φ matrix. In this case $\varepsilon_{j,t}$ is the structural shock and will be instrumented on eta. The relevance condition states that the instrument η_t must be contemporaneously correlated with the structural shock $\varepsilon_{j,t}$. The exogeneity condition on the other hand implies that there is no contemporaneous correlation between η_t and any other of the structural shocks than $\varepsilon_{j,t}$, ie. correlation between η_t and $\varepsilon_{i,t}$.

Merten & Ravn (2013) outline two steps to estimate the proxy SVAR model:

(1) Estimation of the reduced form VAR version of the SVAR model to obtain the residuals e_t .

(2) Regressing the reduced form error terms $e_{i,t}$ on $e_{j,t}$, using η_t as an instrument.

$$e_{j,t} = \varphi_0 + \varphi_1 \eta_t + v_{j,t} \quad (12)$$

$$e_{i,t} = \beta_0 + \beta_{i,t} \hat{e}_{j,t} + v_{i,t} \quad (13)$$

Equation (12) denotes the first stage and equation (13) the second stage of the instrumental variable regression. Here, $e_{j,t}$ are the fitted values of equation (12), where $\beta_{i,t}$ represents its estimates and $v_{i,t}$ are the error terms in the second stage.

In our model we will use Stockholm interbank offered rate (STIBOR) as the external instrument, i.e. $\varepsilon_{j,t}$. Constructed on Swedish monetary policy announcements.

4.5 High Frequency identification

High frequency identification (HFI) is an approach where one identifies monetary policy shocks through changes in high frequency financial market variables.

Krueger & Kuttner (1996) find that the Fed funds future market anticipates the

month-to-month changes in the Fed funds rate quite well. They write that all relevant information is priced in the future rate, which implies that the future rate incorporates the economies expectation regarding the Fed funds rate.

Kuttner (2001) examines the response of US treasury bills and bonds to changes in the Fed funds rate. The adjustment in the money market rate that takes place immediately after a change in the target rate identifies the reaction towards the unexpected part of monetary policy, that is, the monetary policy shock. Kuttner writes that not all financial market variables react equally to monetary policy shocks. He finds that 3-month and 6-months bill rates are sensitive to changes in the target rate, while say a 30-year bonds are unresponsive as they are set in a long-dated forward-looking manner.

The method used by Kuttner (2001) to identify monetary policy shocks using the Fed funds future rate have been applied to different economies using different interbank rates. Gregoriou et al. (2009) uses LIBOR¹² future contract with a maturity of three months to identify monetary policy shocks in the case of the United Kingdom. Bjørnland (2008) uses the NIBOR¹³ with a maturity of three months to gauge the effect of monetary policy shocks on changes in the Norwegian weighted exchange rate. Here, three different NIBOR series are used, the 1-week NIBOR, the 3-month NIBOR and the 6-month NIBOR.

Tafjord (2015) examines the NIBOR further, and describes the different components of this rate. He states that the NIBOR is composed of the expectations about the key policy rate in dependence of the remaining days to the next key policy rate decision, plus a premium. Hence, the rest of the change in the NIBOR is due to random noise.

While Tafjord writes this about the NIBOR, we believe that the same can be said about the Stockholm interbank offered rate (STIBOR). We will further assume this.

The STIBOR can hence be written:

$$STIBOR_d = \alpha_d + E[R_d | i] + u_d \quad (14)$$

¹² London interbank offered rate

¹³ Norwegian interbank offered rate

Where subscript d , denote the day. α is here the premium, and $E[R_d | i]$ is the expectation about the key policy rate in dependence of the remaining days, i , to the next key policy rate decision from the Swedish Riksbank. The last term, u_d is here the random noise term.

The STIBOR hence reflect what the market believes about the future policy rate, and when the Bank of Sweden announces a new rate, any changes in the STIBOR is due to changes that were not expected by the market. Hence, by looking at the changes of the STIBOR from the day before a key policy rate announcement to the end of the day of the announcement, one can extract the interest rate shock.

The policy rate announcements of the Bank of Sweden normally come at 9 AM, while the STIBOR is set later the same day. Hence, the STIBOR at the day of the announcement reflect the central Bank's monetary policy decision. We identify the daily monetary policy shock Ω_d^{HFI} by the following equation:

$$\Omega_d^{HFI} = \delta_d(STIBOR_d - STIBOR_{d-1}) \quad (15)$$

Here δ_d is a dummy variable, which takes the value 1 if a key policy rate decision is published by the Bank of Sweden on that day (d). One assumption is that no other shocks influence the STIBOR during the day of the policy rate decision. The larger the time span between the two measurements, the larger the risk that other shocks than the monetary policy shock can have an influence on the identification. On the other hand, using a too short time window, poses the risk that one misses the effective adjustment of the STIBOR to the new policy rate.

The highest frequency of macroeconomic data are months as the frequency is restricted by variables such as the industrial production index, which we use as a substitute for the quarterly available GDP. The monetary policy shock is daily and the conversion of this to monthly data is not a completely straightforward process. The impact of the monetary policy shock to the other variables in the model depends on the days that are left in the month. Shocks in the start of the month will have longer time to affect the other macroeconomic variables, while shocks late in the month will have less time. Hence, taking a simple average of the shocks across the month will bias the weights put on the monetary shocks. Romer & Romer (2004), Barakchian & Crove (2013) and Gertler & Karadi (2015) solves this by accumulation for each day, all monetary policy shocks that occurred in the past 31 days and take the average for every month afterward.

To convert the daily shocks into monthly data we use the following equation as proposed by Kapfhammer (2017). This equation takes into consideration that not all months have 31 days, and is built on the foundations proposed by Romer & Romer (2004), Barakchian & Crowe (2013) and Gertler & Karadi (2015).

$$\begin{aligned} \eta_t^{HFI} = & \sum_{d_m=1}^{D_m} \delta_{d_m} \left((STIBOR_{d_m} - STIBOR_{(d-1)_m}) \left(1 - \frac{d_m - 1}{D_m} \right) \right) \\ & + \sum_{d_{m-1}=1}^{D_{m-1}} \delta_{d_{m-1}} \left((STIBOR_{d_{m-1}} \right. \\ & \left. - STIBOR_{(d-1)_{(m-1)}}) \left(\frac{d_{(m-1)} - 1}{D_{(m-1)}} \right) \right) \end{aligned} \quad (16)$$

Here, the monthly monetary shock η_t^{HFI} can be decomposed into two components. Firstly, the cumulated shocks from the first day of the month of the announcement d_m to the last day D_m are weighted with the remaining days of the month after the shock occurred. The second component is the cumulated shocks from the first day of the previous month before the announcement $d_{(m-1)}$ to the last day of the previous month $D_{(m-1)}$, weighted with the days prior to the announcement of the past month after the day of the shock.

4.6 Critique of methodology

While the Cholesky decomposition ensures the shocks are orthogonal, another question is whether this assumption makes sense in terms of economic theory. In fact, macroeconomic theory suggests that there is a lag (quarterly or monthly depending on the frequency of the data) in the implementation of monetary policy, depending on the variable (Svensson, 2000). Hence, such restriction is reasonable from a theoretical point of view, and with only one such restriction, we can recover the structural model based on the reduced form representation of the model.

The Cholesky identification is simple to implement and does not require a strong theoretical construct, it is also widely used in SVAR analysis. However, at the same time, this poses a risk that the magnitude of monetary policy shocks could be over-or under estimated. Barakchian & Crowe (2013) writes about the failure

of conventional identification schemes, referring particularly to the Cholesky identification. They write “These schemes generate unrealistic impulse response functions for output, and to a lesser extent prices” when measuring the effect of US monetary policy shocks on the wider economy.

Furthermore, the orthogonality restriction to identify shocks comes under criticism due to issue of comingling shocks when dealing with SVAR of low dimensions. Therefore, the identified shock will be comprised by the “true” shock and other underlying shocks, which will hamper the reliability of the SVAR estimates (Gottschalk, 2001).

Another issue is the assumption that one can find unexpected shocks to the economy when the central bank announces its new policy rates. Gottschalk (2001) writes:

“The SVAR approach to analysing the monetary transaction mechanism is often criticised on the grounds that it supposedly suggests that central banks operate as ‘Random number generators’. Since hardly any monetary policy authority wishes to randomize its decisions, any error is likely to be quickly reversed”.

Further, the question is whether monetary policy shocks are large enough to matter.

Bernanke & Mihov (1996, pp.34) writes on monetary policy shocks that:

“Policy shocks can be generated from two realistic sources: (a) imperfect information on the part of the central bank about the current economy, and (b) changes in the relative weights put by the central bank on moderating fluctuations in output and inflation”

Hence, assuming monetary policy announcements by the bank of Sweden will generate “huge” shocks might not be correct. This implies that finding a relevant external instrument might prove difficult.

Lastly, we would like to point out that most econometric methods come under scrutiny, but are the best models developed to date to estimate the variables of interest. Or as Gottschalk (2001, pp.39) puts it:

“Nevertheless, even though this suggests characterizing this methodology as useful but not particular reliable, this puts the SVAR models into good company, because a similar judgement is likely to hold for most econometric models”.

5 Data

For our empirical SVAR model for Sweden we have used four dependent variables: The repo rate (R), consumer price index (CPI), real effective exchange rate (REER), and industrial production (IP). Due to the relatively short period of NIRP in Sweden, we have chosen to use monthly data, as a way get more observations. CPI and REER comes in monthly intervals, but since GDP only comes quarterly, we have chosen to use IP as a proxy for this. For our high frequency approach, we use the STIBOR as the instrument to estimate the shocks. This data comes in daily intervals but will be formatted to fit monthly data as described above.

The dataset is retrieved from July 1994 up until May 2018, which is some time after the introduction of inflation targeting in 1993, but Sweden did not apply it before 1995. July 1994 is also the start date of the shortest variable, so to create a dataset that have equal amount of observations for all variables, we use this as our first observation.

The CPI and the repo rate are retrieved from the Swedish Riksbank which get their data mainly from Statistics Sweden (Statistiska Sentralbyråen). Furthermore, IP and REER was retrieved from The Federal Reserve Bank of St. Louis Research Division (FRED), since Statistics Sweden only have IP from 2010 and use KIX¹⁴ instead of REER.

Regarding the dependent variables in the model, we use Consumption Price Index with fixed interest rate (CPIF)¹⁵. This variable is however, affected by energy prices, and by removing this we remove some of the noise that comes together with volatility in energy prices¹⁶. Furthermore, the CPIF with energy prices has been the formal target variable for Swedish monetary reports, and in September 2017 it became the target variable for inflation (Sveriges Riksbank, 2018a). The reason is that the central bank wanted to remove the volatile effect the repo rate

¹⁴ A weighted average of the currencies of the most important trading partners of Sweden.

¹⁵ In the CPIF, the effects of changes in interest rates on households housing loans is excluded from the price changes (Statistics Sweden, 2017).

¹⁶ The CPIF comes both with and excluding energy prices from Sveriges Riksbank, and we use the one excluding energy prices.

has on mortgage prices. When lowering the repo rate, CPI move in the wrong direction causing mortgages rates to fall, which decreases the CPI in the short run.

Based on this, we believe that using CPIF ex energy prices is a stable and confident variable to use in our model. The IP index is seasonally adjusted and contain total production of Sweden. By being seasonally adjusted it removes some spurious behaviour and hence, we believe it is better suited for the SVAR.

The last variable, REER, measures the trade capabilities of a country. In other words, it measures how competitive a country's exports is on the international market. The REER gives more economic interpretation than using the nominal effective exchange rate (NEER). The NEER is a trade weighted currency index, which only measures the overall performance of a country's currency¹⁷. The difference between these two is that REER is adjusted for price inflation or labour cost inflation, thus accounting for the real effects of trade. To put it in perspective, if a country's REER increase, its trade competitiveness worsens, meaning that its exports become more expensive and imports become cheaper. The opposite happens when the REER declines. Thus Declining REER is positive for the trade balance of a country's because it enhances the competitiveness of their exports (European Commission, 2018b; Investopedia, 2018). In addition, the REER is also a popular tool used by the World Bank, Eurostat, the Bank of International Settlement (BIS) and many more when conducting economic analysis.

¹⁷ In Sweden this index is called krona index or KIX

6 The model

To be able to create an unbiased SVAR model it is imperative that the data used in the model are stationary so that neither the first nor the second order moments are dependent on time. However, most data are dependent on time, and need to be modified to become stationary. This is easily done by differencing the data by taking the change from one period to the next. In some extreme cases even a second difference is needed to fully remove the time trend, but this makes economic analysis complicated (Haldrup, 1998).

However, there is also debate regarding loss of information in the IRFs when using differenced data. This debate also concludes that VAR's in levels¹⁸ gives more robust results than implementing restrictions (Gospodinov, Herrera, & Pesavento, 2013). Furthermore, there is also little debate on the necessity behind pre-tests for unit-root. The reason is that reduced form VAR's become stationary when their eigenvalues are less than one (Bjørnland & Thorsrud, 2015; Kilian & Lütkepohl, 2017).

Given this research we will implement levelled data that are not differenced for our analysis as proposed by Gospodinov et al. (2013), we will further examine this in the robustness test¹⁹. Furthermore, when using non-stationary data, it is important that the data is cointegrated. We tested the dataset for cointegration conducting an Engle-Granger cointegration test²⁰. In all accounts the test failed to accept the null of no cointegration²¹. The result is satisfying as not cointegrated variables will induce spurious results when regressing these types of variables (Bjørnland & Thorsrud, 2015).

Even though, our variables are not stationary independently, combination of the variables are cointegrated which cancel out the common trend making the combination stationary. In addition, our model has eigenvalue less than one, upholding the rule of estimating a stationary model (Bjørnland & Thorsrud, 2015; Kilian & Lütkepohl, 2017).

¹⁸ Only calibration of the variables is taking logs, no differencing has taken place.

¹⁹ We did conduct the necessary test for non-stationary data which can be viewed in appendix 1

²⁰ The Engle-Granger test is an OLS regression run on the data matrix used in the reduced form VAR. Furthermore, it tests if the residuals in the OLS is stationary. If true there is cointegration, false the opposite.

²¹ P-value = 0,001 for both tests

Moreover, we also remove structural breaks by removing the financial crisis by trimming the data from January 2009. This is important since structural breaks could potentially lead to misleading estimations in the SVAR (Bjørnland & Thorsrud, 2015). In addition, our data of interest also contains a structural break when it changes from policy rates above ZLB and policy rates below ZLB. In conjunction we also separate the data between the two regimes, ending up with two models with two SVAR approaches²², a total of four models. Two for Cholesky approach and two for the proxy SVAR approach.

As mentioned above, the contemporaneous relationship between the variables depends on their ordering in the Cholesky identification. Hence, the ordering of the variables is crucial to get a sound economic representation. For our model we use the following order; Industrial production (IP), Consumer Price Index (CPI), Repo rate (R), and Real Effective Exchange Rate (REER). Moreover, there is debate in other literature whether IP should be before CPI or vice versa. Gertler & Karadi (2015) present their model, using IP before CPI, so the decision to have IP first, falls on the beliefs of which variable would logically affect the other contemporaneously. However, as we only are interested in the monetary policy shock, the ordering of these variables is not of interest if they are ordered above R. For our model we choose to put IP first and CPI second.

Furthermore, if R were to be ordered before these variables, it will fail to identify the right monetary policy shock. The reason is that CPI and IP will now react contemporaneously to monetary policy shocks, which is contradictory to the behaviour of monetary policy in SVAR literature.

R will not have a contemporaneous effect on either IP or CPI but will contemporaneously affect the REER. The reason is that the REER is closely related to NEER, which will contemporaneously react to fluctuations in the policy rate, and not the other way around. This is logical since inflation rarely react contemporaneously to economic variations but moves endogenously to economic changes. In this regard, inflation could be assumed fixed at the time of policy announcements. Implying, that NEER is the only variable to react to changes in policy rates (Bjørnland & Thorsrud, 2015; Kilian & Lütkepohl, 2017).

²² The first model is from January 2009 to January 2015, post financial crisis with positive policy rate regime and the second from February 2015 to May 2018, post financial crisis with negative policy rates.

Furthermore, Sweden has floating exchange rate regime, meaning that the central bank will not set policy rates to support the exchange rates. Rather, fluctuations in the Swedish Krona rate is a bi-product of changes in the policy rates and other market rates.

When choosing optimal lag length most researchers utilize either Akaike or Bayesian information criteria, AIC or BIC for short. For our tests both AIC and BIC propose one lag for both models. However, in choosing too few lags we might omit valuable information while choosing too many might lead to estimation error (Bjørnland & Thorsrud, 2015). In addition, Kilian & Lütkepohl (2017) write that economists are rarely interested in the lag order. They are interested in impulse responses, forecasts and related statistics that can be written as a smooth function of VARs parameters, and they also propose to choose the lag order ad hoc.

Kilian & Lütkepohl (2017) proposes using 12 lags when working with monthly data, to remove seasonality. Furthermore, Strongin (1995) and Bernanke & Gertler (1995) also uses 12 lags when working with monthly data. Based on this, we started out using 12 lags. However, this led to spurious impulse responses due to the variables being underfitted in the SVAR. This is probably because we work with a relatively small sample²³. By reducing the number of lags, we ended up with a model that matches IRFs in other literature. For our model we choose two lags for positive policy rates and one lag for negative policy rates.

Based on this, we ended up with the empirical SVAR model when policy rates are positive with $t = 2$;

$$A \begin{bmatrix} IP_t \\ CPI_t \\ R_t \\ REER_t \end{bmatrix} = A_0 + A_1 \begin{bmatrix} IP_{t-1} \\ CPI_{t-1} \\ R_{t-1} \\ REER_{t-1} \end{bmatrix} + A_2 \begin{bmatrix} IP_{t-2} \\ CPI_{t-2} \\ R_{t-2} \\ REER_{t-2} \end{bmatrix} + B \begin{bmatrix} \varepsilon_t^{IP} \\ \varepsilon_t^{CPI} \\ \varepsilon_t^R \\ \varepsilon_t^{REER} \end{bmatrix} \quad (17)$$

And when policy rates are negative $t = 1$;

$$A \begin{bmatrix} IP_t \\ CPI_t \\ R_t \\ REER_t \end{bmatrix} = A_0 + A_1 \begin{bmatrix} IP_{t-1} \\ CPI_{t-1} \\ R_{t-1} \\ REER_{t-1} \end{bmatrix} + B \begin{bmatrix} \varepsilon_t^{IP} \\ \varepsilon_t^{CPI} \\ \varepsilon_t^R \\ \varepsilon_t^{REER} \end{bmatrix} \quad (18)$$

²³ 74 data points for the positive model and 40 for the negative model.

For the high frequency instrument (HFI) approach, we have used the daily STIBOR to identify the monetary policy shocks using the announcement of policy reports to identify this instrument. In this approach we will estimate three different SVARs, on the two different regimes using daily data from 1-week STIBOR (HFI1W), three-month STIBOR (HFI3M), and six-month STIBOR (HFI6M). Before fitting the instrument, we need to reduce the VAR, in the equations above. From the reduced-form VAR we obtain the residuals ε_t^{IP} , ε_t^{CPI} , ε_t^R and ε_t^{REER} , where ε_t^R will be instrumented by the STIBOR η_t^{HFI1W} , η_t^{HFI3M} and η_t^{HFI6M} . By the IV - regression we obtain the matrix B, where the bold printed variables are the estimations from the IV.

$$B = \begin{bmatrix} 1 & 0 & \boldsymbol{\beta}_{13} & 0 \\ \boldsymbol{\beta}_{21} & 1 & \boldsymbol{\beta}_{23} & 0 \\ \boldsymbol{\beta}_{31} & \boldsymbol{\beta}_{32} & \mathbf{1} & 0 \\ \boldsymbol{\beta}_{41} & \boldsymbol{\beta}_{42} & \boldsymbol{\beta}_{43} & 1 \end{bmatrix}$$

As before the setup in matrix B is designed so that β_{12} , β_{14} , β_{24} and β_{34} are still zeroes. Where the bold printed variables are the estimated instruments i.e. column 3.

7 Results

For the empirical part we will simulate a one percent expansionary monetary policy shock using SVAR. Furthermore, we evaluate the behaviour of the IRFs between expansionary monetary policy when policy rates are positive vs when policy rates are negative. Thus, for both the Cholesky and Proxy VAR approach there will be two models for comparison.

7.1 Cholesky VAR

In this section we present the Cholesky VAR, which will stand as a benchmark to our Proxy VAR approach. The Cholesky VAR uses no instruments and is identified by an upper triangular matrix as described in section 4. Furthermore, we will create two models, one simulating IRFs when policy rates are positive and one when policy rates are negative. The two models will be evaluated on differences in their impulse response functions. In addition, we will assess the cumulative effect of IP to measure the gain or loss when conducting monetary policy.

Figure 16 and 17 show the effect of a one percent expansionary monetary policy shock on IP, CPI and REER. Both figures show that the Cholesky decomposition functions in the manner described above. Here monetary policy shock is only contemporaneous to real effective exchange rate, while industrial production and CPI reacts one period after.

Following the expansionary monetary policy shock in figure 16, we see that both IP and CPI display puzzles by decreasing in the early periods, before increasing. The puzzles are small and short lived and lasts for about two to three months for both IP and CPI.

After ten months IP reaches its peak of about 1.5%. and lasts for about three years after its peak. Cumulative, this consists of about 28% gain in production following an expansionary monetary policy shock. The CPI shocks are shorter lived than IP. Here CPI reaches its peak after six months of only 0.15% before dying out three months later. However, small shocks in CPI is not uncommon, where Christiano et al. (1998) finds that monetary policy shocks have small effect on inflation.

For the last variable, the REER react on impact by -2.1% a real depreciation. This improves the terms of trade for Sweden, allowing for cheaper exports on the

world market. However, imports will become more expensive for Sweden. More expensive imports lead to higher inflation which will raise the REER. The depreciation lasts for one year before it appreciates, which deteriorates the terms of trade. The appreciation lasts for three years before the shocks dies out completely.

The shape of the impulse responses of expansionary monetary policy are consistent with what Neuenkirch & Nöckel (2018) find when evaluating expansionary monetary policy. Furthermore, the IRFs exhibit hump-shaped responses which is consistent with literature (Gottschalk, 2001; Kilian & Lütkepohl, 2017). The overall dynamics of the IRFs exhibit expansionary properties, when policy rates are positive.

In figure 17 we show the impulse responses when policy rates are negative. We can observe that IP impulse response function decreases by 4.5% when it reaches its trough after 2 months. In addition, the IRFs remain contractive for the whole duration before dying out. Cumulatively, the economy experiences a loss of -35% in IP following an expansionary monetary policy shock when policy rates are negative. The IRF for the CPI depicts a short run gain of 0.25% for two months before contracting to -0.1%. From this point it never recovers and continues to contract until the shock dies out. Overall, the effect is contractionary for CPI. Lastly, we have the REER which appreciates on impact of about -6%, however, the appreciation lasts for only a couple of months before it depreciates around 3%, before dying out a year later. The REER under NIRP exhibit depreciatory behaviour larger than what REER exhibit under positive policy rates.

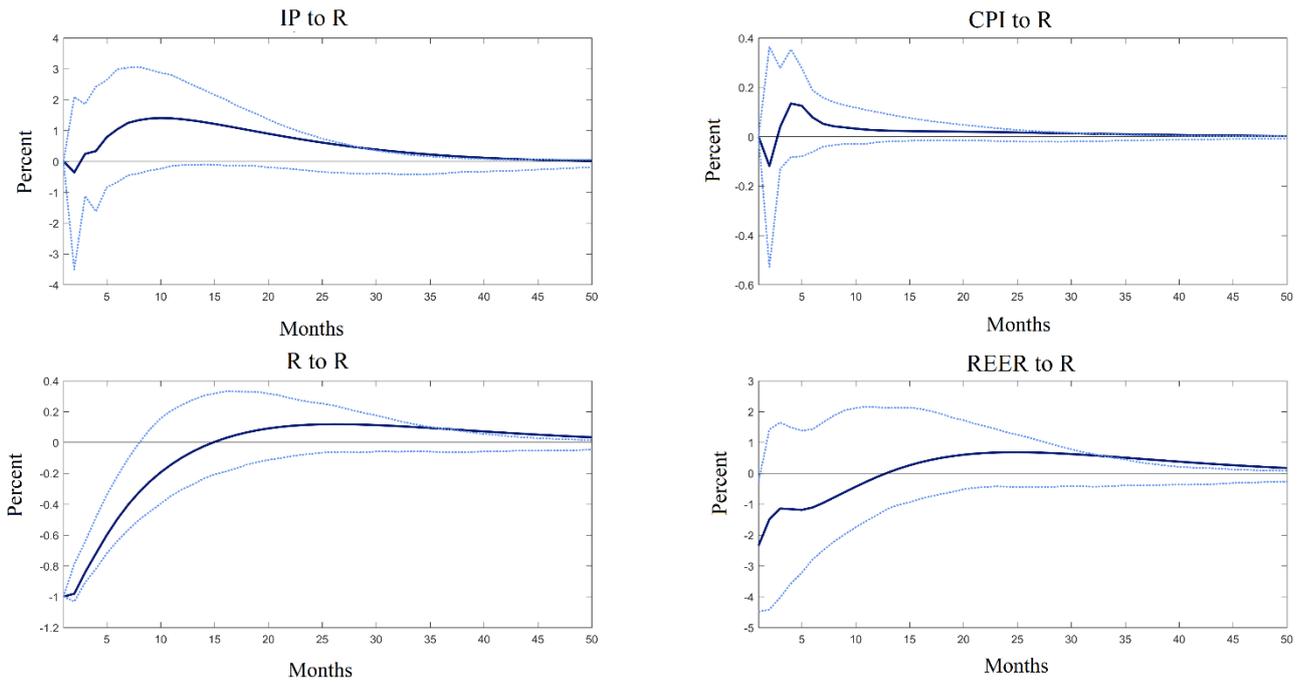
This variable is the only one that exhibit expansionary behaviour, following the expansionary monetary policy. The effect is short-lived and difficult to interpret if the effect exists at all. However, economies adapting to NIRP have experienced depreciating currencies (except Japan), which are sympathetic to this result.

The behaviour of our second model are similar to what Eggertsson et al. (2017) find. Here the authors conclude that negative rates are irrelevant and even contractionary. However, they utilize quarterly data and have GDP instead of industrial production. In addition, they also do not have IRF for real effective exchange rate. In this regard it is difficult to infer if the IRF for REER is behaving in a desirable manner. On the other hand, from section 3 we observe that most

economies that implemented negative rates have experienced depreciation of their currencies. Using this as a benchmark we can establish that the IRF of the REER is estimating functions behaving similarly to what is observed. Hence, monetary policy under NIRP seem to have contractionary behaviour to IP and CPI. On the other hand, REER reacts on impact more expansive than the positive model. However, the longevity of the response is shorter lived under NIRP.

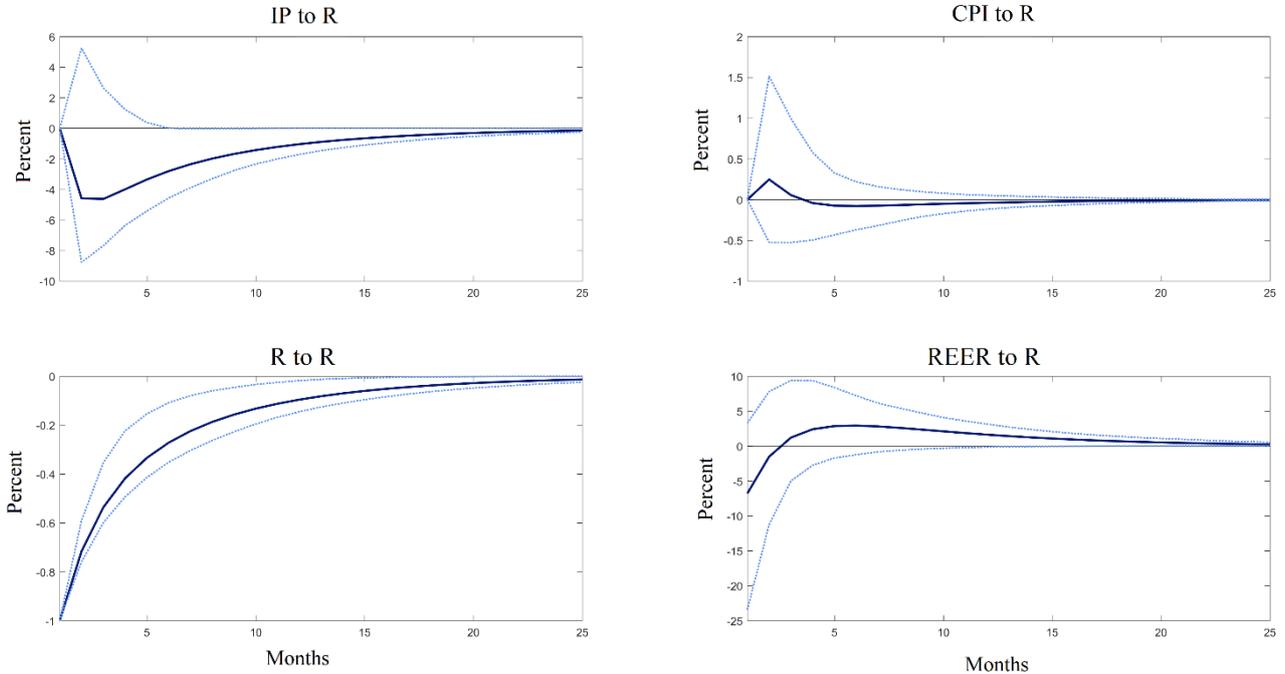
With the evidence collected so far, the Cholesky model exhibit clear distinctions between the two-policy regime. On the one side, expansionary monetary policy when policy rates are positive reacts according to SVAR literature. On the other side, expansionary monetary policy under NIRP reacts contractionary, as described by Eggertsson et al. (2017). We will further on these findings in the robustness test.

Figure 16: Impulse Response Functions when Policy Rates are Positive



Note: The graph represents a one percent expansionary monetary policy shock (R), on industrial production (IP), consumer price index (CPI) and the real effective exchange rate ($REER$). The solid line depicts the estimate, and the blue dotted line represents the 68% confidence bands of the model. In addition, IP , CPI and $REER$ is logged and normalized by multiplying the variables by 100 so the variables correspond to the respective percentage. R have not been logged, and is already presented in percent.

Figure 17: Impulse Response Functions when Policy Rates are Negative



Note: The graph represents a one percent expansionary monetary policy shock (R), on industrial production (IP), consumer price index (CPI) and the real effective exchange rate ($REER$). The solid line depicts the estimate, and the blue dotted line represents the 68% confidence bands of the model. In addition, IP , CPI and $REER$ is logged and normalized by multiplying the variables by 100 so the variables correspond to the respective percentage. R have not been logged, and is already presented in percent.

7.1.1 Robustness test²⁴

As mentioned in section 6, we decided to present the variables in level due to loss of information when using differenced data. By using differenced data, we observed that the behaviour of IRFs lack the hump shaped responses and behaves more erratic than IRFs using levelled variables. In addition, CPI does not depict any puzzles as proposed in other literature. Furthermore, the estimate in R fails to lie within the confidence bands. For the negative model, all IRFs depicts erratic behaviour and lack hump shaped response functions when using differenced data. In addition, all shocks are very short-lived and dies out within a short period. Furthermore, conducting forecast error variance decomposition (FEVD) on differenced data causes none of the shocks in IP, CPI and REER to explain any of the variability in monetary policy. In other words, all the variability in the monetary policy shock is explained by its own shock. This holds for both policy regime. In conjunction, using differenced data reduced the reliability of the estimates from the IRFs. Results from using differenced data are posted in appendix 2.

To evaluate the reliability to the IRFs it is necessary to conduct a forecast error variance decomposition test. By doing so we can ascertain how much of the forecast error variance is regarded by each structural shock (Bjørnland & Thorsrud, 2015; Kilian & Lütkepohl, 2017). Looking at table 1, we observe how much of the variability of monetary policy is explained by the shocks in the other

Table 1: Forecast Error Variance Decomposition for Monetary Policy when Policy Rates are Positive

Percent of h-Step Ahead Forecast Error Variance Explained by:				
Horizon	Industrial Production shock	Consumer Price Index shock	Monetary policy shock	Real effective exchange rate shock
1	0,0372	0,007	0,9415	0,0143
2	0,1058	0,0218	0,8161	0,0563
3	0,1643	0,0321	0,6866	0,1171
10	0,4184	0,031	0,181	0,3697
20	0,4942	0,0288	0,0846	0,3924
50	0,5178	0,0285	0,0701	0,3836

Note: Table shows percentage of variance error explained by a structural change in monetary policy when policy rates are positive. All rows sum to one ignoring rounding errors.

²⁴ This test was conducted for both negative and positive policy rates with equal results.

variables. From horizon one²⁵ we see that shocks in IP, CPI and REER only account for about 6% of the mean square prediction error (MSPE).

As the horizons increase so does the explanatory power in the shocks for IP and REER, however, CPI stagnates as the horizons increase. At horizon fifty the explanatory power of the shocks in IP increases to 51,78%, 2,85% for CPI and 38,36% for REER. Meaning that changes in monetary policy is mostly determined by shocks in IP and REER. However, its interestingly to note that as an economy that conducts inflation targeting almost none of the shocks in inflation explains any of the variability in monetary policy. On the other hand, industrial production is regarded as indicators for economic development (Shapiro, 1989). Meaning that economies experiencing growth will expect inflation to increase, which explains why the shocks in IP explains most of the variability in monetary policy. Furthermore, according to the new Keynesian Philips curve²⁶ inflation is a function of output gap. Hence, by affecting industrial production (proxy for GDP) it will ultimately affect inflation in the long-run.

Shocks in CPI only explains about 2-3% of the variability of monetary policy at any horizon. This indicates a weak relationship that shock to inflation has little effect on the variability monetary policy in Sweden. This relationship is not uncommon, where also uncover that shocks to CPI only accounts for a small amount of variability in monetary policy.

Table 2: Forecast Error Variance Decomposition for Monetary Policy when Policy Rates are Negative

Percent of h-Step Ahead Forecast Error Variance Explained by:					
Horizon	Industrial Production shock	Consumer Price Index shock	Monetary policy shock	Real effective exchange rate shock	
1	0,1258	0,0384	0,8056	0,0302	
2	0,1715	0,044	0,7062	0,0783	
3	0,1822	0,04	0,6475	0,1304	
10	0,1433	0,0335	0,5068	0,3164	
20	0,1352	0,0358	0,4851	0,3439	
50	0,1348	0,036	0,4839	0,3454	

Note: Table shows percentage of variance error explained by a structural change in monetary policy when policy rates are negative. All rows sum to one ingoring rounding errors.

²⁵ Horizon is number periods we allow for structural shocks in the SVAR model, i.e., horizon 1 is the first month of shocks.

²⁶ $\pi_t = \beta E_t(\pi_{t+1}) + \kappa x_t$

Moving over to negative policy regime we observe from table 2 that variation in monetary policy is mostly explained by shocks in REER and accounts for 34.54% in the long run. Furthermore, shocks in CPI still explains little of the variability in monetary policy and accounts for only 3.6% at horizon 50. The figures for IP and CPI resemble what is found in table 1 for the first horizon. However, shocks in IP accounts for only 13.48% of the variability in monetary policy at horizon 50. This indicate a weak relationship between industrial production and monetary policy under NIRP. Hence, a lot of the variability in monetary policy under NIRP goes unexplained.

7.2 Proxy SVAR

As a critique of the Cholesky decomposition regarding the issue of simultaneity we established a proxy SVAR which utilizes an instrument variable (IV) approach using high frequency data. The process was inspired from Mertens & Ravn (2014) where they uses the tax multipliers as a proxy to estimate a tax shock on the US economy. In our case we use the STIBOR where the methodology is described above.

Our expectation was that the instrument would be weak at most, which is similar to Montiel-Olea, Stock & Watson (2016), where other authors find it difficult to find fully relevant instruments. However, in our model all instruments experienced both F-statistics and R-square close to zero²⁷. With so low relevance it is unreasonable to claim that the instruments can be classified as weak. In conjunction, we will present the results in the appendix 3 as the estimates are of low significance.

7.2.1 Robustness test

Overall, both proxy-models contradict traditional impulse response paths uncovered in other literature, which handicap the relevance of our results. In addition, the instruments used is also insignificant which further impede the model credibility We wanted to uncover where the instrument failed. In conjunction, we conducted a correlation test. What we found was that the

²⁷ Positive model: one-week STIBOR F-stat = 0.4199 R²= 0.006, Three-month STIBOR F-stat = 0.2605 R²= 0.0037, six-month STIBOR F-stat = 0.1971 R²= 0.0028.

Negative model: one-week STIBOR F-stat = 0.2209 R² = 0.0059, three-month STIBOR F-stat = 0.0572 R² = 0.0015, six-month STIBOR = 0.0569 R² = 0.0014.

instrument was exogenous, but it was also not dependent on the shocks from the monetary policy, failing the relevance condition. To remedy this behaviour, we tried to include an extra day to ensure that the shock of the monetary policy announcement was captured into our instrument. However, the change was ineffective, and did not yield better results. In addition, we also included the full dataset from 1994 (excluding negative regime) to investigate if lack of shocks in the variables was hampering the relevance condition. Again, the result did not improve.

It is difficult to infer why the STIBOR lack relevance as an instrument for monetary policy, being that both are closely related. One reason could be that the STIBOR market is very efficient and forward looking which contributes to small shocks (Allen, Carletti, & Gale, 2009). In addition, by observing the shocks on announcement we see that most shocks are only on the second or third decimal point and even zero, which implies small shocks.

8 Conclusion

In this thesis we wanted to examine whether monetary transaction mechanisms in Sweden work differently now when negative interest rates are negative, compared to when they were positive. To do this we have both looked descriptively at the developments in the Swedish economy and comparing this to an empirical model to extract the effects of monetary policy shocks.

First looking at the general developments in the Swedish economy, it seems clear that after several problematic years in the aftermath of the financial crisis of 2008, the tide has now turned. Seeing negative developments in variables such as employment, inflation, gross domestic product and several others after 2008, the situation started to stabilize around 2011/2012. In line with general positive developments in the global economy, and in particular the Eurozone, the developments in the Swedish economy started to pick up in the years after 2012. However, unemployment remained high and inflation low to about 2014. In the past years the Swedes have experienced higher growth rates and it seems clear that they now might be leaving behind the effects of the 2008 crisis, and its following recession.

In the second part of the thesis, we developed an SVAR-model, trying to measure the effect of monetary policy shocks. First, we developed one model with data from July 1994 to January 2015, a period when the Swedish key policy rate was above zero. Then we estimated a second model including data from February 2015 to May 2018, a period of rates below zero, using the positive model as a benchmark to compare with the negative model. The positive model showed results in line with previous findings showing expansive effects on IP, CPI and REER.

On the other hand, looking at the negative model, we observe contractionary effects, especially in industrial production following a cumulative loss in production of -35%. However, these results lack some robustness as most of the variability in the monetary policy is explained by itself as proposed by the FEVD in section 7.1.1. In conjunction, our model proposes that other factors than monetary policy are affecting the increase in production as described in figure 7, since only 14.85% of the shocks in IP explain variation in monetary policy.

Based on this, we believe that the positive developments in the Swedish economy over the last years are not due to monetary policy. We ascribe this to other factors, particularly positive developments in export markets, immigration, increasing oil prices, and that important trading partners of Sweden is experiencing economic growth post financial crisis.

Lastly, we do note that the amount of data we have for the negative model is limited, and since the policy rate in Sweden is still negative, we have not yet seen the end of this story. We do believe that the model is not perfect, and we do acknowledge that our findings for the negative model lack robustness. In conjunction, as proposed by the extension, given time more data is made available and a more accurate model can be devised. But, this must be for someone else to examine in a couple of years.

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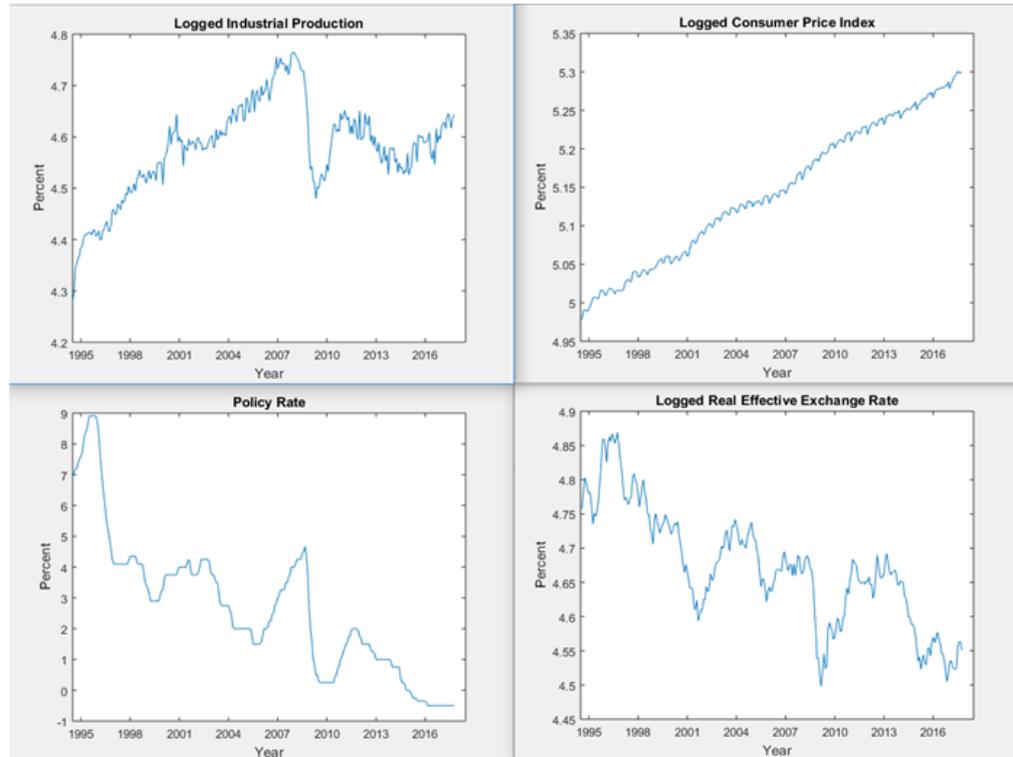
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10 Appendix

Appendix 1: Visual representation of variables and ADF results²⁸

Figure 18: Graph of variables



Note: Graphs show the logged variables of industrial production, consumer price index and real effective exchange rate. Policy rate are already given in its percentage, and is not necessary to take logs.

Table 3: ADF-test results

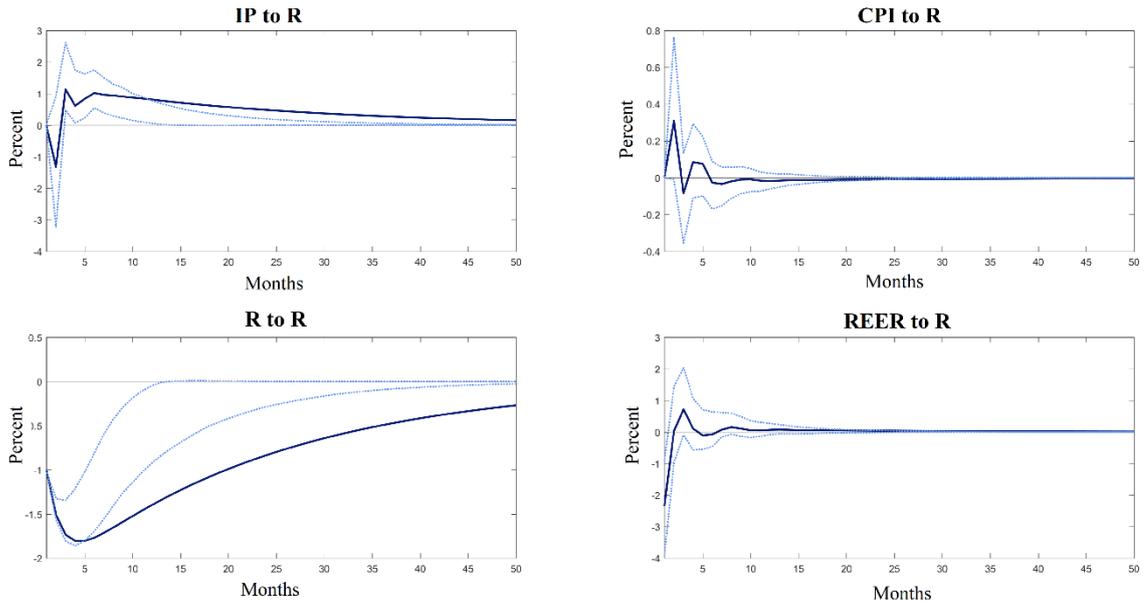
logCPI	logIP	logREER	difflogCPI	difflogIP	RepoRate	difflogREER
false	false	false	true	true	true	true
false	false	false	true	true	true	true
false	false	false	true	true	true	true
false	false	false	true	true	true	true
false	false	false	true	true	true	true
false	false	false	true	true	true	true
false	false	false	true	true	true	true
false	false	false	true	true	true	true
false	false	false	true	true	true	true
false	false	false	true	true	true	true
false	false	false	true	true	true	true
false	false	false	true	true	true	true
false	false	false	true	true	true	true
false	false	false	true	true	true	true
false	false	false	false	true	true	true

Note: table shows the Binary results of the ADF-test at a 95% level. False = not stationary and true = stationary.

²⁸ From figure 18, we can see that the logged data of CPI are clearly not stationary by the distinctive upward trend. Furthermore, industrial production also depicts an upward trend, but has one distinctive structural break from the financial crisis. For the last two this becomes less clear. However, using eyesight alone is not enough to determine stationarity, but a simple ADF-test can arbitrate if the data used is stationary or not. From the test we find that all the variables except the repo rate were not stationary. By differencing once all variables except the repo rate, they become stationary. However, CPI failed at its twelfth lag, but the tests are enough to state that the logged CPI is stationary when differenced.

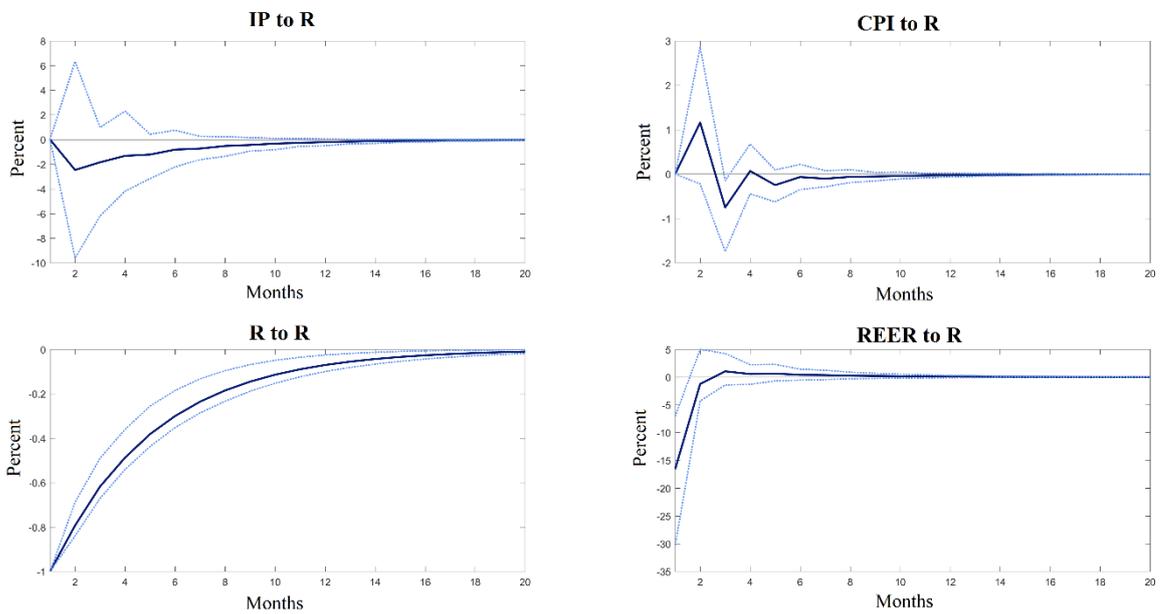
Appendix 2: Robustness test, IRF using Differenced Data

Figure 19: IRFs when Policy Rates are Positive using Differenced Variables (Policy Rate R is not Differenced)



Note: The graph represents a one percent expansionary monetary policy shock (R), on industrial production (IP), consumer price index (CPI) and the real effective exchange rate (REER). The solid line depicts the estimate, and the blue dotted line represents the 68% confidence bands of the model. In addition, IP, CPI and REER is logged and normalized by multiplying the variables by 100 so the variables correspond to the respective percentage. R have not been logged, and is already presented in percent.

Figure 20: IRFs when Policy Rates are Negative using Differenced Variables (Policy Rates R is not Differenced)



Note: The graph represents a one percent expansionary monetary policy shock (R), on industrial production (IP), consumer price index (CPI) and the real effective exchange rate (REER). The solid line depicts the estimate, and the blue dotted line represents the 68% confidence bands of the model. In addition, IP, CPI and REER is logged and normalized by multiplying the variables by 100 so the variables correspond to the respective percentage. R have not been logged, and is already presented in percent.

Table 4: Forecast Error Variance Decomposition for Monetary Policy when Policy Rates are Positive

Horizon	Percent of h-Step Ahead Forecast Error Variance Explained by:			
	Industrial Production shock	Consumer Price Index shock	Monetary policy shock	exchange rate shock
1	0,0234	0,0006	0,972	0,004
2	0,0362	0,004	0,951	0,0088
3	0,0374	0,0047	0,9474	0,0106
10	0,0424	0,0062	0,9367	0,0147
20	0,0434	0,0066	0,9346	0,0154
50	0,0438	0,0067	0,9338	0,0157

Note: Table shows percentage of variance error explained by a structural change in monetary policy when policy rates are positive. All rows sum to one ignoring rounding errors.

Table 5: Forecast Error Variance Decomposition for Monetary Policy when Policy Rates are Negative

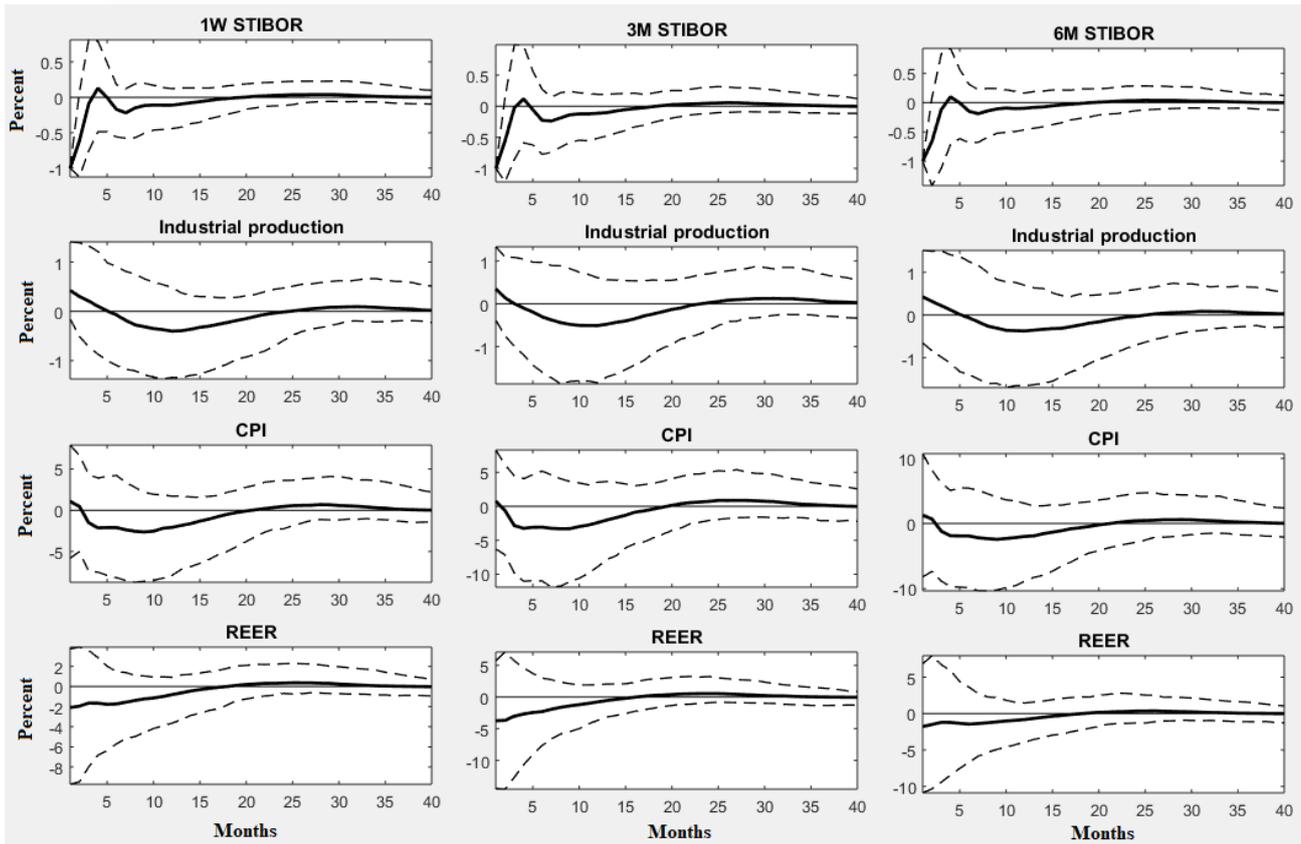
Horizon	Percent of h-Step Ahead Forecast Error Variance Explained by:			
	Industrial Production shock	Consumer Price Index shock	Monetary policy shock	exchange rate shock
1	0,0066	0,0219	0,9705	0,0009
2	0,0068	0,0216	0,971	0,0008
3	0,0068	0,0205	0,9719	0,0008
10	0,007	0,0197	0,9724	0,0008
20	0,0071	0,0197	0,9725	0,0008
50	0,0071	0,0197	0,9725	0,0008

Note: Table shows percentage of variance error explained by a structural change in monetary policy when policy rates are positive. All rows sum to one ignoring rounding errors.

Appendix 3: Results Proxy SVAR

Looking at Figure 21, when policy rates are positive we observe that the IRFs for IP and CPI both contract²⁹ of about -0,2% for IP and -2% for CPI. This behaviour is contradictory to results in other literature and is possibly due to the lack of relevance in our instruments³⁰. The only variable that behaves in the manner expected is the REER, where all IRFs appreciate on impact, and stays below zero before the shocks die out around the twelfth month.

Figure 21: Impulse Response Functions using STIBOR as Instrument when Policy Rates are Positive



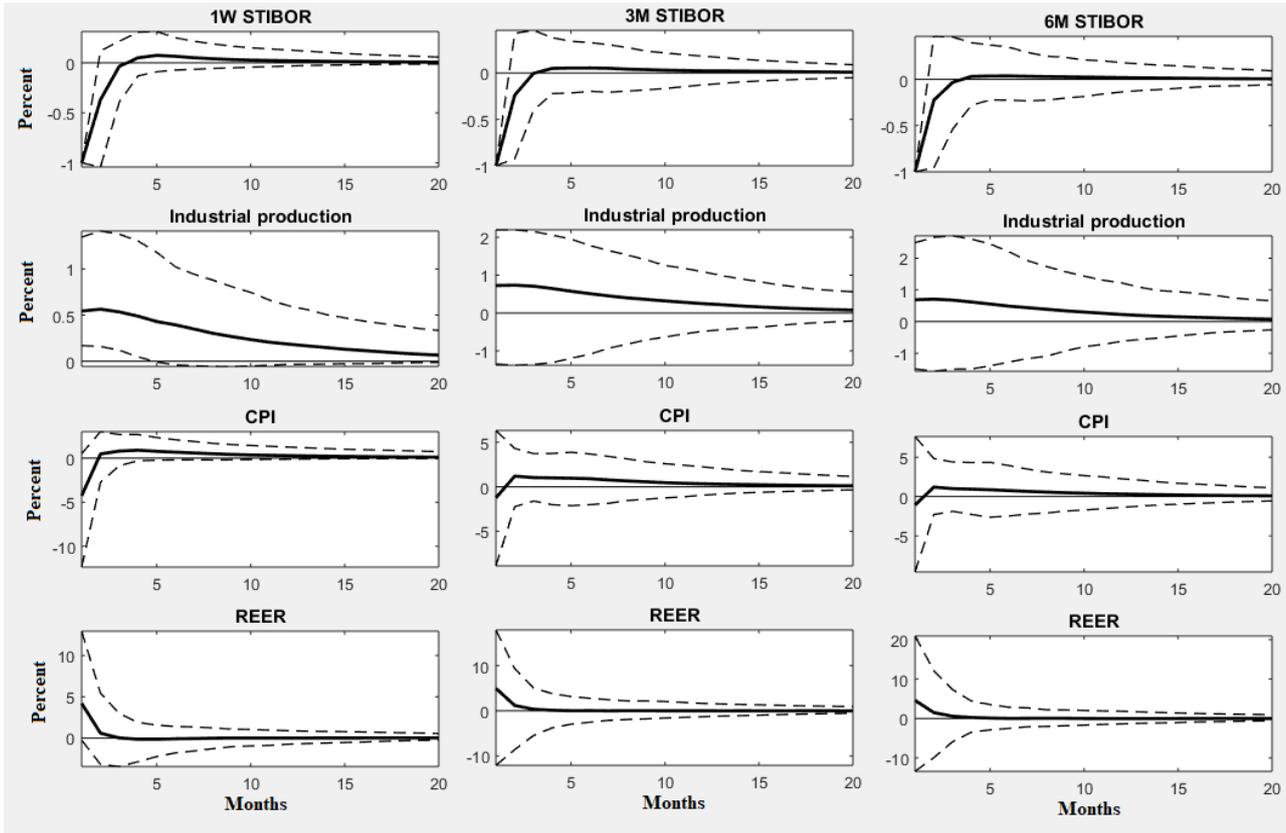
Note: Plots depicts expansionary monetary policy shock of one percent using STIBOR as instrument on industrial production (IP), consumer price index (CPI) and the real effective exchange rate (REER). The solid line depicts the estimate and the dashed line represent the 68% confidence bands of the model. From the left we have one-week STIBOR, in the middle three-month STIBOR, and to the right six-month STIBOR. IP, CPI and REER are in logs have been normalized and multiplied by 100. STIBOR has not been logged and is already in percent.

²⁹ Note that all IRFs react on impact by design, as described in part 5 equation 17 & 18 where matrix B is identified through the instrument, third column. Our interest is only in the trajectory of the impulse responses for CPI and IP when analysing. For REER the contemporaneous behaviour is expected.

³⁰ F-statistics positive instruments: One-week = 0,4199, Three-months = 0.2605 and six-months = 0,197

Looking at Figure 22, we observe that the opposite happens, compared to figure 2.3. Here IP have an expansionary effect of almost 1% for three-months and six-months and 0,5% for one-week STIBOR. This find would be interesting if the instrument were relevant as it opposes what Eggertsson et al. (2017) find in their paper. Furthermore, CPI also behaves expansionary but with very small estimates close to zero, which suggest no reaction at all. In addition, REER depreciates on impact and shocks dies out quickly, also here the shocks are small and insignificant.

Figure 22: Impulse Response Functions using STIBOR as Instrument when Policy Rates are Negative



Note: Plots depicts expansionary monetary policy shock of one percent using STIBOR as instrument on industrial production (IP), consumer price index (CPI) and the real effective exchange rate (REER). The solid line depicts the estimate and the dashed line represent the 68% confidence bands of the model. From the left we have one-week STIBOR, in the middle three-month STIBOR, and to the right six-month STIBOR. IP, CPI and REER are in logs have been normalized and multiplied by 100. STIBOR has not been logged and is already in percent.