Houses, we have a problem!

A Bayesian structural VAR analysis on how unconventional monetary policies affect house prices in the Scandinavian countries

LUND UNIVERSITY

David Grahn & Stefania Mammos

Supervisor: Anna Grodecka-Messi

Department of Economics

Master Essay I

Spring 2021

Abstract

This thesis investigated how expansionary unconventional monetary policies affect house prices in the Scandinavian countries, using quarterly data from 1995 to 2020. Unconventional monetary policy, such as quantitative easing and forward guidance, has become widely used by central banks, in order to stimulate the economy when being in a zero lower bound environment. While inflation has remained on a rather modest level, the development on the housing market has been much stronger. A Bayesian structural VAR analysis was used with two different identification methods, Cholesky decomposition and zero and sign restrictions. The instruments used to capture unconventional monetary policies were the central bank balance sheet and shadow rates. The results from a Cholesky decomposition supported the hypothesis of the thesis, i.e., unconventional monetary policy leads to inflated house prices, particularly for Sweden and Denmark. The second identification approach, zero and sign restrictions, generated no significant effect on house prices, following an unconventional monetary policy shock for the Scandinavian countries. Using VARs is very popular among academic researchers, however, the results are highly sensitive to the identification method, which was evident in this thesis.

Keywords: Unconventional monetary policy, House prices, BSVAR, Cholesky decomposition, Zero and sign restrictions.

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1 Introduction

Pictures of people going with wheelbarrows full of money to buy basic groceries in Germany during the 1920s are famous for illustrating the absurdness of hyperinflation. This is what some economists feared when central banks started to use unconventional monetary policies, such as quantitative easing and forward guidance, in order to stimulate the economy. Measured inflation, however, has stayed at a modest level despite vast amounts of money being put into the system. On the other hand, the growth on financial markets, such as the housing market, has on average been much stronger. The large increase in house prices in the low interest rate environment is of utter importance for economists to investigate. Mainly as house price booms affect the financial stability greatly, due to household wealth primarily consisting of residential owning, whilst at the same time being the largest part of household indebtedness. Other concerns evolving from the large increase in house prices, include growing wealth disparities as well as the enhanced importance of inheritance to enter the housing market. This thesis will focus on the question whether it can be concluded that unconventional monetary policy inflates house prices.

The Scandinavian countries have some of the highest household indebtedness in relation to income in the world. In the last quarter of 2020, Denmark had a ratio of 239%, Norway 230% whilst Sweden had 193%. To put perspective on these numbers, the corresponding ratio of household debt to income for the euro area is on average 109% (OECD, 2020). History has shown that high levels of household indebtedness can be very dangerous if a crisis would occur and the effect has been prolonged in those countries with higher household debt, compared to those with lower levels (see for example, Schularick & Taylor, 2012; Jordà et al., 2017). For monetary policy makers, it has become a question of priority. Financial stability must be set against reaching other targets such as price stability, which has been the main objective for most central banks. Tinbergen's rule states that for each policy target, the policy maker needs a unique policy tool (Tinbergen, 1952). In reality, central banks only have one unique tool, the interest rate. This limits the power of the central bank, which in small open economies like the Scandinavian countries, is already limited due to today's large global economic dependency between countries.

The wealth distortion and the importance of socio-economic background emerging from a boom in financial assets, is more of an ideological discussion and not the main topic of interest in this thesis. However, it is worth mentioning that a large increase in house prices leads to stronger requirements of a larger down payment, which makes it harder to enter the housing market. The housing market is in many ways different from other financial markets

since dwellings could be regarded as a consumer good and not only a financial asset. The market is also very closely connected to the interest rate which ought to make it sensitive to changes in monetary policy.

The extremely low interest rates have led to largely beneficial mortgages, which can be argued to increase house prices. This thesis investigates whether it is possible to conclude that an unconventional monetary policy shock, measured by innovations in the central bank balance sheet or a decrease in the shadow rate capturing the effect of unconventional monetary policies, lead to higher house prices. Multiple researchers find positive effects on macroeconomic variables from unconventional monetary policy, however, the persistence and magnitude of the effects differ drastically between papers. Fabo et al. (2020) finds that the results from quantitative easing (QE) depends on who conducts the research. A central bank researcher is more likely to overestimate the effects compared to an academic researcher. According to the study, researchers who reports larger effects from QE, increase their opportunity of obtaining a higher position at the central bank.

A Bayesian structural vector autoregression (BSVAR) is used in this thesis, following other researchers investigating the macroeconomic effects from a monetary policy shock. Two different identification methods are used, Cholesky decomposition as well as zero and sign restrictions. The ordering of the Cholesky decomposition is based on characteristics of the variables, i.e., if they are fast or slow-moving in the response of a monetary policy shock. Output and consumer prices are assumed to be slow-moving, which is in line with macroeconomic theory regarding nominal rigidity (Romer, 2019). The decision on whether to order house prices before or after the policy variable, is not straightforward since house prices can be seen as both a consumer good and a financial asset. Rosenberg (2019) argues it moves in a similar speed as consumer prices, following this reasoning, house prices are put before the policy variable. The exchange rate is put after the policy variable, as the only fast-moving variable in the vector. The identification scheme for the zero and sign restrictions is based on both previous literature and macroeconomic theory. It is assumed, on impact, that an unconventional monetary policy shock will increase consumer prices, have no contemporaneous effect on real GDP and lead to a depreciation of the exchange rate. Since house prices is the main variable, it is left unrestricted, thus, the key question of this thesis is left "agnostically" open, which means that the data controls the outcome (Uhlig, 2005).

The thesis will start by investigating and presenting information regarding unconventional monetary policies, that have become more frequently used by central banks in the zero lower bound environment. Thereafter, focus will shift onto the housing market and its development in the Scandinavian countries, their similarities and differences in monetary policy as well as

evidence from earlier studies. The methodology used in the thesis is presented later, along with the data used. Results from the impulse response functions will be presented in figures and reviewed. The thesis ends with a section for conclusions containing a summary and final thoughts.

2 Unconventional monetary policy

2.1 Negative interest rates

For a long time, negative interest rates were regarded as an impossibility with reference to the zero lower bound theory. The theory considers a liquidity trap where the central bank no longer can be efficient when the nominal interest rate is set at, or close to zero (Romer, 2019). For example, Rudebuch (2009) argued through a Taylor rule estimation that the federal funds target rate should have been much lower (-5%) during the financial crisis, if the zero lower bound could have been breached. On the other hand Milton Friedman (2000), did not agree with the view that monetary policy would become inefficient with a policy rate at the zero lower bound. He argued that the central bank could continue providing money to the economy by purchasing long-term government securities and doing so until the economy gets running. Utilizing a negative nominal interest rate has become increasingly common in today's economies. Primarily to stimulate the low inflation environment, which came as a response following years of recovery and strong economic growth after the financial crisis in 2008 (Rossi, 2021).

Despite negative interest rates becoming more frequently used by the world's central banks, the belief of a of lower bound constraint for nominal interest rates still exists, which is why the policy rates are only zero or slightly negative. To be able to stimulate and regulate the amount of money in the economy, central banks (at the zero lower bound) have been forced to use other methods, i.e., unconventional monetary policies. Unconventional monetary policy mainly refers to quantitative easing and forward guidance, however, as argued by Rossi (2021), these methods have been used in conventional times and have become more normalized in recent years. It could very well be the case that they will be as present outside zero lower bound conditions.

2.2 Quantitative easing

In order to stimulate the economy and control the money supply, when being at the zero lower bound, central banks need to look for other tools than lowering the policy rate. One method that has become more widely used during the last few years, is quantitative easing. The definition of quantitative easing has changed somewhat over the years. Originally it referred to, when at a liquidity trap, central banks buying government zero-interest-rate short-term government debt, but now the purchase of any asset with a positive interest rate can be called quantitative easing. By purchasing these assets, central banks hope to decrease the long-term interest rate and thereby increase incentives for investments (Romer, 2019). When

announcements of large-scale asset purchases are made, Fratzscher et al. (2012) claims that market actors increase in confidence. On the other hand, it could be argued that the low interest rate environment increases uncertainty, especially when going on for a longer time period, and discourages investments due to the fear for a larger increase of interest rates in the future (Neely, 2010).

Critics to quantitative easing often refers to it as money printing and questions the effectiveness of the tool. Kaminska and Zinna (2014) argues that quantitative easing only works with stable inflationary expectations and a reliance of the monetary policy. Other economists, based on traditional views on the relationships between real and nominal variables, were confident that quantitative easing would lead to a harmful level of inflation (Czeczeli, 2016). However, this has not yet shown to be the case, instead central banks have been struggling to increase inflation, despite carrying out large-scale asset purchases. From a more theoretical perspective, inflation could be seen as the price development of everything that can be bought for money. However, inflation is measured only through consumer prices and does not take financial markets (such as the housing market) into account, despite those markets perhaps being the most directly influenced by quantitative easing. To change from the consumer price index, which has been the approach for decades, might on the other hand, lead to uncertainty. Moreover, incorporating financial markets could be problematic due to their volatile characteristics.

2.3 Forward guidance

In line with macroeconomic theory, which has become substantially more forward-looking in the models, central banks try to influence expectations of the future economic outlook. In particular, it involves making statements on future interest rates, with the belief that people will take this into account when making economic decisions. If a statement is made by the central bank on keeping a low policy rate for a certain period of time, the hope is that inflationary expectations will increase and be more accurate, which in turn will boost the real inflation rate, thus, stimulating the economy (Romer, 2019). This is regarded as an unconventional tool that central banks began to use more frequently when confronted with the zero lower bound. However, announcing that the policy rate will remain on a low level must not necessarily lead to increased inflation, it depends on the timing and the interpretation people make of the statement (Campbell et al., 2012). Furthermore, the effectiveness of trying to impact people's economic decision making is disputable. Behavioral economists often argue that people are not as rational, thus, engaging in uninformed decision making. In fact, McKay et al. (2015) finds that the influence of forward guidance is heavily reliant on

the assumption of complete markets. The effect is instead dampened if people fear a sudden decrease in income and have borrowing constraints, leading to precautionary savings instead of consumption. Thereby, inflation will remain on a low level, although announcements on the policy rate being low continues.

This could very well be an explanation as to why the consumer price development has remained on a rather modest level despite central banks' efforts to stimulate the economy. It could be argued that when other markets get inflated, with house prices being of most relevance for this thesis, people want to invest their money in assets rather than consumer goods. The opportunity of receiving a higher payoff and utility by investing a larger part of their income, could be an argument for a delayed effect on inflation. Precautionary savings mentioned above, could serve as another potential explanation to the rigidity of consumer prices. Due to large increase in house prices, people will need to hold more money since they have taken on a large debt in relation to their income.

2.4 Measurements on unconventional monetary policy

Quantifying the effect of unconventional monetary policy using one measurement has proven to be difficult for many researchers. Papers frequently employ two instruments: the central bank balance sheet and the shadow rate. Innovations in the central bank balance sheet is meant to measure quantitative easing. When central banks expand their portfolio, the amount of money circulating in the economy increases and the goal is to decrease the long-term interest rate. Although it has become more relevant to look at the magnitude of quantitative easing, the balance sheet fails to capture some important aspects, such as the effect on interest rates (Rossi, 2021).

Shadow rates are supposed to measure the nominal interest rate that would continue without a zero lower bound. It is not the rate that the central bank would impose, instead it is an estimate calculated through the structure with a zero lower bound (Rossi, 2021). The shadow rate tracks monetary policy through announcements of policy rate changes, balance sheet expansions (contractions) and forward guidance. During times of conventional monetary policy, the shadow rate equals the short-term interest rate, on the other hand, when unconventional monetary policy is conducted, the shadow rate is a function of factors which drive the government bond yield curve and its short-rate expectations component (De Rezende & Ristiniemi, 2018).

3 Housing market and monetary policy in the Scandinavian countries

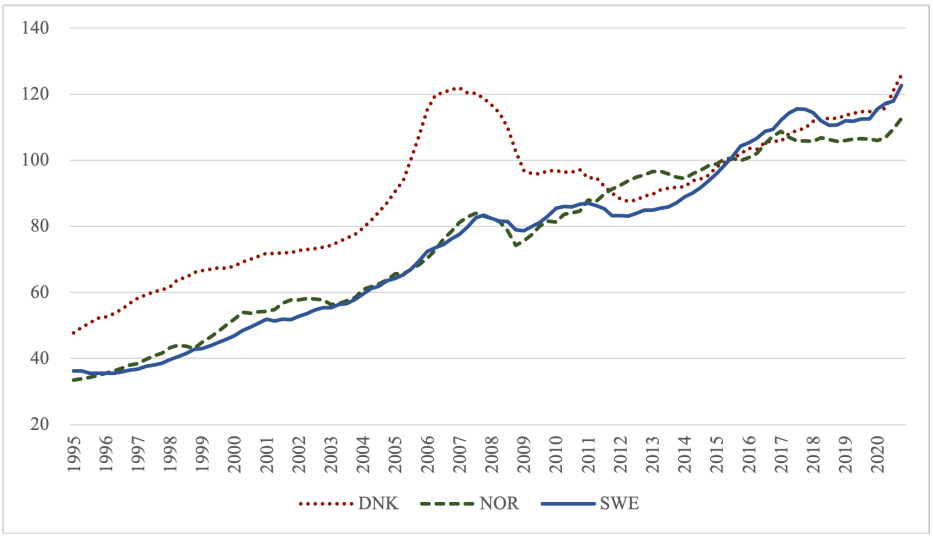
3.1 Housing market

House price fluctuations are highly dependent on monetary policies, which has been demonstrated throughout history, e.g., the subprime mortgage crisis in the U.S. starting in 2007 and the housing bubble in Sweden in the 1990s. Monetary policies are certainly not the only cause for these crises. However, they illustrate a common denominator: lost control of financial stability, which is considered to be a high priority for a central bank.

In the Scandinavian countries, the housing market plays an important role in the dynamics of business cycles. Before the financial crisis in 2008, the progress of house prices was rather similar; an upswing in housing prices was a feature in the three countries. This can be explained by geographical reasons, as well as them sharing some similar attributes in the housing loan system. For example, the loan-to-value ratio is quite similar at around 65-85% for the Scandinavian countries (Finansinspektionen, 2019; Finanstilsynet, 2019; Danmarks Nationalbank, 2019). The loan-to-value ratio is what financial institutions and other lenders use to assess the lending risk before approving a mortgage. The global crisis in 2008, however, was a breaking point for the development as it was followed by a fall of house prices in varying sizes. Denmark experienced the largest fall in house prices, the reason being that the downturn on the housing market started 1-2 years before the international crisis hit in 2008. The crisis was more of an amplifier of the housing market fluctuations (Bødker & Skaarup, 2009). However, prices have recovered and are now at a higher level than its peak before the crisis in Denmark (see Figure 1).

House prices in Sweden and Norway have grown exceptionally, with only a few, modest declines. The boom that had begun in the middle of the 1990s in Sweden, led to prices more than doubling from 1995 to 2007-2008, and in Norway the house prices had a three-folded increase during the same period (Englund, 2011). The house prices in both countries, following the 2008 crisis, decreased moderately, and then continued in the same path. In addition, Sweden and Norway have even more similarities in the mortgage market compared to Denmark. The housing loans are provided by commercial banks in Sweden and Norway, whereas in Denmark they are given by mortgage credit institutions which in turn are funded by themselves by issuing covered bonds. These differences in the structure of the mortgage market can affect how the housing prices fluctuate (Rosenberg, 2019).

Figure 1: Real house price indices in the Scandinavian countries



Source: OECD

Along with the growing house prices, the household indebtedness in Sweden has grown sharply, with a more than doubled increase in real terms from 1995-2020, to a level of 193% of net disposable income (OECD, 2020). Dermani et al. (2016) studied whether Swedish house prices are overvalued and if the price development is feasible in the long run. The house prices, at least up until 2015, do not exhibit the characteristic of being apparently overvalued. On the other hand, if households' low costs in relation to their income were to increase, the current high valuation of housing would not be sustainable. Therefore, if this price growth is ignored, problems may arise in the foreseeable future. Moreover, the authors found that in Denmark, the actual house prices were higher than the estimated ones, which could potentially be explained by country-specific variations in credit supply or institutional differences. However, the rise in house prices for Denmark and Norway, is explained to a greater extent if one takes increased household indebtedness into account (Dermani et al., 2016).

Sweden has seen an increase in financial net wealth and disposable income, along with low levels of housing investments. These factors, along with substantial population growth and low real interest rates in recent years, has contributed to the acute increase in house prices during the period 1995-2015 (Dermani et al., 2016). However, the increase could perhaps be explained by common macroeconomic variables, since the house prices did not show signs of being overvalued. The slow development of the supply of housing has been a similar problem in Denmark and can also be an explanation for the rapid increase in house prices, after the financial crisis 2008 (Rosenberg, 2019). The problem with non-matching demand and supply

has been an increasing issue especially in the capitals of the Scandinavian countries, where the population growth has been stronger, leading to increased house prices (Torstensen & Roszbach, 2019). Further, Torstensen and Roszbach points out the impact oil price fluctuations has on the housing market in Norway. When oil prices fell in 2015 and 2016, house prices in the regions most dependent on the oil industry fell sharply.

3.2 Monetary policy

The three countries have somewhat different monetary policy systems. The Swedish central bank (the Riksbank) is an authority under the Parliament (the Riksdag) with the task of controlling the price stability in the economy, with a 2% inflation target. In addition to this, the Riksbank also has the objective of keeping the aggregate demand and employment rate on a steady level whilst at the same time keeping track of the financial stability. The Riksbank changed from a fixed exchange rate regime to a floating one in November 1992, as a consequence of the financial crisis which started in 1990, and this system has not been altered since. Furthermore, the Riksbank is an independent authority from the Riksdag, i.e., the decisions are solely made by the Executive Board. However, the governor of the Riksbank, Stefan Ingves, has admitted a large dependence on the monetary policy conducted by the European Central Bank (ECB) (Svenska Dagbladet, 2017).

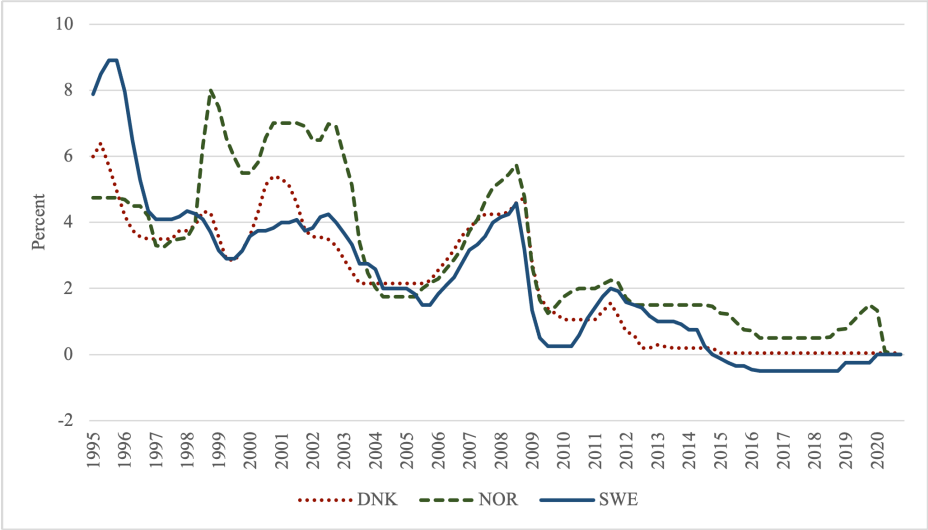
The Danish central bank (Danmarks Nationalbank) is almost entirely dependent on the decisions made by the ECB with their fixed exchange rate regime. Danmarks Nationalbank has since the introduction of the Euro in 1999 been a part of the the European Exchange Rate Mechanism, ERM 2. The Danish krone is pegged at a band from 7.29 to 7.63 kroner per euro. The fixed exchange rate regime clearly limits Denmark's influence of monetary policy, but the objectives are stated in a similar fashion as the Swedish Riksbank. Norway, on the other hand, has a flexible exchange rate regime with the same inflation target as Sweden and once again, other similar objectives, although stated slightly different. The Norwegian central bank (Norges Bank), similar to the Swedish Riskbank and Danmarks Nationalbank, has a considerable degree of autonomy. However, Norway differs from both Sweden and Denmark in not being a member of the European Union and by their access to oil.

In Sweden, the purchase of government bonds, as an expansionary monetary policy tool, was announced in 2015 (Riksbanken, 2021). In Norway and Denmark, however, the unconventional monetary policy has not been official. Still, the balance sheet policies affect housing prices, which was something studied by for example Rahal (2016). Rahal found strong evidence of unconventional monetary policy shocks having an effect on house prices, residential supply and mortgage markets when studying different countries of varying sizes, including

Norway and Sweden.

The quarterly policy rates for each country, from 1995 to 2020, are illustrated in Figure 2. The Scandinavian policy rates follow each other closely and the correlation seems to increase over time. In Sweden, the large-scale asset purchases, along with a negative policy rate, was at first thought of as a temporary solution to the low inflation, but it remained for a longer time period than anticipated since inflation did not respond as much as expected. When looking at the policy rate for Denmark, it follows the ECB interest rate closely due to their exchange rate regime. The ECB started, as the Swedish Riksbank, with quantitative easing in 2015 and opted a negative interest rate in 2014. The policy rate in Norway is, at the moment of writing this thesis (2021-05-24) zero, which is the lowest level ever opted by Norges Bank. Furthermore, Norway has been stimulating the economy through fiscal policy in a larger extent (OECD, 2016).

Figure 2: Policy rates in the Scandinavian countries



Sources: Danmarks Nationalbank, Norges Bank and the Swedish Riksbank

3.3 Previous literature on monetary policy

History tells us that changes on the housing market can have a great impact on financial stability. Unconventional monetary policy's effect on the housing market has been studied more frequently following the financial crisis in 2008. However, the effect from monetary policies on different housing variables was studied prior to the crisis. Lastrapes and Potts (2005) for example, studied the effects of a money supply shock on price and quantity of durable goods and housing in the US, under the assumption that money neutrality holds

in the long-run. The result was that a money supply shock has an effect on the market for both durable goods and housing. Moreover, it explains at least some of the variation of the expenditures on these markets. McCarthy and Peach (2002) investigated whether the rebuilding of the housing financial system, which has been in progress for the past 25 years, has affected the behaviour of the housing market. One result was that, under more deregulated mortgage financial systems, quantitative financial constraints have a smaller impact on house prices and residential investments. However, it was stated that even though the housing sector is sensitive to changes in monetary policy, the timing of response to the housing sector is more in line with the rest of the economy, due to the mortgage market becoming a part of the capital market.

Gambacorta et al. (2014) and Schenkelberg and Watzka (2013) studied the effects of unconventional monetary policy at the zero lower bound on macroeconomic variables, using a VAR and a SVAR approach respectively. Gambacorta et al. (2014), concluded that a balance sheet shock only increases consumer prices and other economic activity temporarily. Further, the effects on output were similar to the effects during conventional monetary policy. However, the impact on consumer prices were not as significant or persistent compared to those of conventional monetary policy. The findings of Schenkelberg and Watzka (2013) was that output and consumer prices increased significantly from quantitative easing, but similar to what Gambacorta et al. (2014) found, the real effects were only temporary.

Bjørnland and Jacobsen (2010) and Rahal (2016) studied the impact of monetary policy on house prices in Scandinavia and other countries. Bjørnland and Jacobsen (2010) analyzed the monetary policy transmission mechanism of house prices in Norway, Sweden and the U.K. One of their findings was that house prices reacts swiftly and significantly, in the case of a monetary policy shock. In addition, an unforeseen change in the interest rate affects house prices instantaneously. Further, the authors stated that the variation of timing and magnitude in the response, could be due to differences in monetary policies. Rahal (2016) investigated how the housing market reacts to unconventional monetary policy shocks, where Sweden and Norway were two of the eight OECD countries studied in the paper. Rahal found a persistent and positive response in house prices, reaching its maximum between the first and second year after the shock, and the results being somewhat similar across different lag lengths. According to the study, the evidence of a more substantial response in the U.S. and the U.K., was linked to the countries having a more evolved mortgage market structure.

Rosenberg (2019) studied the effects of both conventional and unconventional monetary policies in the Scandinavian countries, covering a period of almost 30 years. The central bank balance sheet and the policy rate were used as proxies for unconventional and conventional

monetary policy respectively. The paper used a Bayesian structural VAR (BSVAR) with zero and sign restrictions as the identification method. Rosenberg concluded that expansionary shocks to both the balance sheet and the policy rate increased house prices in the Scandinavian countries, however, with considerably varying effects between the countries. The response of house prices to a balance sheet shock was found to be more persistent than a policy rate shock, which was explained by the author to be an effect of a large debt to income ratio in these countries. Rosenberg stated that if this is the case, households are more sensitive to mortgage rates changes, since a balance sheet shock results in a prolonged decline in mortgage rates, which in turn makes the rise in house prices more persistent.

This thesis has many similarities with the paper by Rosenberg (2019) but differs in some important aspects. Firstly, Rosenberg distinguish between conventional and unconventional monetary policy, which is not the angle of this thesis where a shadow rate is used, which captures both types of monetary policies. Secondly, Rosenberg assumes a lagged impact on the main variable, while the approach in the thesis is "agnostic", i.e., house prices are left unrestricted. Thirdly, in addition to zero and sign restriction, this thesis utilizes a Cholesky decomposition as one of the two identification methods. Lastly, different variables are collected in the vector of endogenous variables to investigate the impact of a monetary policy shock on house prices.

4 Methodology

4.1 Bayesian structural vector autoregression (BSVAR)

When using regression analysis, variables are often referred to as dependent or independent. However, in the area of economics and particularly macroeconomics, it rarely, if ever, exists such a thing as an independent variable. To acknowledge and to be able to draw conclusions on causalities when examining macroeconomic disturbances, researchers frequently lean towards the work of Sims (1980), who promoted the use of vector autoregressions (VARs) and in particular the use of structural VARs (SVARs).

In a SVAR, the endogenous variables are collected in a vector y_t and investigated over time with varying lag lengths. In contrast to conventional VAR, it allows for contemporaneous effects for the variables and puts structure on the shocks. This is more in line with macroeconomic theory, where the variables move more or less simultaneously, and the innovations are often connected. The model can be expressed as follows:

$$Ay_t = k + B_1 y_{t-1} + B_2 y_{t-2} + ... + B_p y_{t-p} + S\epsilon_t \quad (1)$$

where k is a vector of constants, $y_{t-1}, y_{t-2}, ..., y_{t-p}$ are vectors of the lagged endogenous variables of order 1 through p, with corresponding coefficient matrices $B_1, B_2, ..., B_p$. A matrix A is put before the vector y_t and contains information on possible contemporaneous effects. Adding S before the error term ϵ_t (assumed to be white noise) creates a linear combination of the shocks and imposes structure while, at the same time, creates more possibilities of accurate conclusions to be made. The necessary assumptions in a SVAR, are fewer compared to DSGE-models where the shock is endogenously incorporated in the model, whereas a SVAR creates exogenous disturbances to variables (Di Casola, 2021).

Although SVARs allows for more interpretations, the assumption needed for conventional estimation techniques (e.g., Ordinary least squares) are problematic and can lead to larger uncertainty than necessary. A Bayesian estimation approach, however, increases the economic validity and precision in the estimated parameters (Sims & Zha, 1998). The Jeffreys prior used in this thesis, is a Bayesian estimation technique introduced by Harold Jeffrey in 1939 (Jeffrey, 1998). This is further the default prior used in the MATLAB toolbox created by Canova and Ferroni (2020). The use of a BSVAR model in this thesis is further motivated by the work of Rosenberg (2019) who looks at a similar topic and makes use of this model.

When evaluating the BSVAR, impulse response functions (IRFs) are created by first putting

(1) into a reduced form by premultiplying the expression with A^{-1}:

$$y_t = K + C_1 y_{t-1} + C_2 y_{t-2} + ... + C_p y_{t-p} + u_t \quad (2)$$

letting $K = A^{-1}k$, $C_i = A^{-1}B_i$ and $A^{-1}S\epsilon_t = u_t$. Since ϵ_t is assumed to be white noise, we now have that expected value $E[u_t] = 0$ and variance covariance matrix,

$$\Sigma_u = \begin{bmatrix} \sigma_{11} & \dots & \sigma_{1k} \\ \vdots & \ddots & \vdots \\ \sigma_{k1} & \dots & \sigma_{kk} \end{bmatrix}$$

where $Var[u_{it}] = \sigma_{ii}$ and $Cov[u_{it}, u_{jt}] = \sigma_{ij}$, allowing for covariation between the u_{it}.

Now, the issue is to uniquely present Σ_u which consist of $k(k+1)/2$ estimated elements, with A and S each having k^2 parameters to be estimated. In conclusion, this means that $k^2 + k(k-1)/2$ restrictions must be placed on A and S. There exist numerous identification schemes solving this issue, enabling economic analysis to be made. Along with the Cholesky decomposition, which has been the benchmark identification method after first being introduced by Sims (1980), this thesis uses a combination of zero and sign restrictions. Two lags are used for all countries following the values gathered from the AIC, BIC, HQC.[1]

4.2 Data

All variables have a quarterly frequency, covering the first quarter of 1995 until the last quarter of 2020 for the majority of variables, with the exception of shadow rates (1996 Q1 - 2020 Q3 for Sweden, 1999 Q1 - 2020 Q3 for Denmark (ECB)). The included variables are: house price index (HPI), harmonized index of consumer prices (HICP), central bank balance sheet, shadow rate, exchange rate and gross domestic product (GDP)[2] (See Appendix A for information on data sources as well as additional information on the variables). Visual presentation on the development for each variable can be found in Appendix B.

The seasonally adjusted real house price indices (HPI) are meant to measure the overall price development of residential housing in relation to the overall price change in the country. House prices will serve as the main variable of interest when examining the monetary policy shock.

[1] AIC, BIC and HQC measure information received for different models and in this case the tests consider different numbers of lags. A robustness test was performed by using different lag lengths. For the Cholesky decomposition, results were robust. However, when looking at the zero and sign restrictions the results are somewhat more sensitive to lags of higher order.

[2] The variables, except for the shadow rates and the exchange rates, have been transformed using natural logarithms in line with other studies.

The central bank balance sheet, total assets, is used to measure unconventional monetary policy, following the example of Rosenberg (2019) and Rahal (2016). Norges Bank include the investments for the government petroleum fund (currently known as the Government Pension Fund - Global), but since this is a separate investment, thereby not capturing monetary policy, the data is deducted from the total assets. Except for the central bank balance sheet, the thesis utilizes another measurement for unconventional monetary policies, namely a shadow rate. The shadow rates used in this paper are created by De Rezende and Ristiniemi (2018), however, Sweden was the only Scandinavian country included in the data set. As a proxy for Denmark, the shadow rates for the ECB are used since their exchange rate regime makes them closely connected.

The Harmonized index of consumer prices (HICP) measures the aggregate consumer price level over time and is used by the ECB in their inflation target. The HICP is constructed to be comparable between countries and is thereby a natural choice for this thesis. When studying monetary policy shocks, including an inflation measurement is not difficult to motivate. The real GDP used in this thesis, is meant to measure output and is usually included in the studies of monetary policy shocks.

Exchange rates are not typically included when investigating monetary policy shocks. However, it is more relevant to examine the relationship between monetary policy and exchange rate through a VAR analysis in small open economies (see for example, Bjørnland & Halvorsen, 2014; Scholl & Uhlig, 2008). In addition, the differences between the Scandinavian exchange rates regimes further motivates the variable's inclusion.

4.3 Cholesky decomposition

Cholesky decomposition has served as the benchmark identification method for the VAR approach following the work of Sims (1980). There exists some variation to this method but the main strategy is to choose an ordering of the variables in a triangular matrix (Ramey, 2016). The ordering in this paper is following the approach of "slow-moving" versus "fast-moving" variables from a monetary policy shock discussed in Uhlig (2017), where slow variables often refer to output and prices. The sticky prices conform to New Keynesian models, which allows for rigid movements after a shock (Romer, 2019). This motivates the ordering in this thesis where GDP is put first followed by HICP. The placement of house prices is somewhat more difficult since it could be argued to be fast-moving through its financial characteristics. However, Rosenberg (2019) argues that the housing market differ from other financial markets and move in a similar pace as consumer prices, which motivates its placement in the Cholesky ordering. The only fast-moving variable is the exchange rate which reacts instantaneously to

economic news and is thereby put after the monetary policy variable (central bank balance sheet or shadow rate in this case).

The Cholesky decomposition is widely used by macroeconomic researchers, due to its simplicity and clear interpretation. On the other hand, Uhlig (2017) presents a couple of limitations with the "slow-fast" approach from both a theoretical and empirical sense. The author argues that although prices very well could be sticky, when looking at a VAR however, there will exist one-step-ahead prediction errors which indicates that at least some prices react contemporaneously. Furthermore, when investigating a contractionary monetary policy shock, Uhlig finds that CPI increases which is in defiance to macroeconomic theory.

This price puzzle emerging from a Cholesky decomposition is not an unusual problem. The approach to come about this problem vary between researchers, some try to theoretically motivate the results, some include a commodity price index (which seems to work rather well) or they look for other identification schemes (Uhlig, 2017; Giordani, 2001). Giordani (2001), further finds a possible explanation where the price puzzle is explained by a small misspecification in the model. He argues for using the output gap instead of output to solve the puzzle, this would further be more in line with macroeconomic models. Uhlig (2017) however states: "If you are worried by the "price puzzle" and the like, do not rely on the Cholesky decomposition. Use it if you are willing to "live or die" by its implications". Instead, Uhlig advocates for using sign restrictions which by construction gets rid of any price puzzle.

4.4 Zero and sign restrictions

In the structural VAR model, problems regarding the parametric identification can arise and imposing sign restrictions could, in some cases, solve this issue. The papers using a combination of zero and sign restrictions are recent, compared to the other methods which are commonly used when studying monetary policy, and for this reason there exists no consensus on the exact approach. Uhlig (2005) pioneered in the use of sign restrictions on the impulse responses of prices, as a method for estimating the effects of monetary policy shocks. Since the response on output was the key question, no restrictions were imposed on the response of real GDP. Moreover, Uhlig used a minimalist approach where the sign restrictions were only imposed for a short period after the shock. Peersman (2011) and Gambacorta et al. (2014), imposed the zero and sign restrictions to be binding on impact. It was stated in both papers that such mix of restriction reduces the number of models allowed, thus enhancing the identification.

As the Cholesky decomposition, the zero and sign approach has limitations which need to be addressed. One issue present for the identification method is the multiple shock problem, where the restrictions fail to exclusively identify a single shock from the set of restrictions imposed (Fry & Pagan, 2011). For example, a fiscal policy shock may have identical signs on impact as a monetary policy shock. Another drawback to the approach is that zero and sign restrictions compute models which are only set-identified, i.e., there is no guarantee for unique impulse responses, as opposed to the Cholesky decomposition (Moon et al., 2011). These two problems complicate the interpretation of the results and make them questionable due to their non-unique representation.

The sign restrictions imposed in papers using a VAR approach vary, Peersman (2011) and Rahal (2016) for example, restrict the contemporaneous effect on output and consumer prices to be zero following a balance sheet shock. The motivation for the restriction is in line with traditional macroeconomic theory, i.e., nominal shocks only have a lagged influence on real GDP and consumer prices (Peersman, 2011). However, Peersman does not include the house prices in the model and studies the impact of both conventional and unconventional monetary policy. Rahal (2016) includes house prices and analyzes the effects on unconventional monetary policy only, which is more similar to the approach in this thesis. The central bank balance sheet has been used as a proxy for unconventional monetary policy in, for example, Peersman (2011) and Gambacorta et al. (2014). The change in this variable, according to Gambacorta et al. (2014), reflects the extensive lending to banks, which is done in order to reduce the risk spread in the money markets. Since an expansionary unconventional monetary policy shock is identified as an innovation to the central bank balance sheet, a positive sign on this variable is usually imposed.

Studies using a VAR approach differ a lot on the sign restriction used on the exchange rate. Authors that aim to study the effects on monetary policy on the exchange rate, generally leave their identification "agnostic" about the response of the exchange rate (see for example, Fisher & Huh, 2016; Scholl & Uhlig, 2008). Scholl and Uhlig (2008) studied monetary policy and exchange rates in open economies and found evidence of a price puzzle on the exchange rate. A price puzzle arises when the results do not coincide with conventional wisdom regarding macroeconomic theory, whereas favorable results are aligned with what is considered conventional. Further, they found it sensible to impose a larger set of sign restrictions since this removes the price puzzles and delayed liquidity puzzles, i.e., when nominal interest rate and money supply do not have the expected negative relationship in the case of a monetary policy shock.

It is clear by the discussion above that there are several ways of imposing sign restrictions,

which all rest on several different theoretical foundations. In this thesis, the zero and sign restrictions imposed are binding on impact only. The house price variable is left unrestricted since this is the main question of analysis, in order to not skew the results (Uhlig, 2005; Vargas-Silva, 2008). The central bank balance sheet is the variable that is going to be shocked for all countries, which is why it will be restricted to have a positive sign. For Sweden and Denmark, another impulse response function and identification scheme is used, restricting the shadow rate to be negative since this corresponds to an expansionary monetary policy shock. The contemporaneous effect from the shocks is restricted to be zero for output. Consumer prices are often restricted to have a zero simultaneous effect as the real GDP, however, in this thesis consumer prices have a positive sign restriction on impact. Peersman (2011) admits that a zero restriction is rather conservative but also motivates it by the monthly frequency in the variables. Since this thesis is based on quarterly data, a zero restriction would imply an all too inefficient monetary policy. Furthermore, putting a sign restriction on inflation avoids the price puzzle by construction as well as putting more structure onto the identification.

The exchange rate is restricted to depreciate on impact. An expansionary monetary policy shock is assumed to cause a depreciation of the exchange rate, which is in line with macroeconomic theory, i.e., when interest rates decreases, it discourage foreign capital to enter the country which, ceteris paribus, would lead to a depreciation of the exchange rate. Scholl and Uhlig (2008), as mentioned above, found evidence of an exchange rate puzzle when studying monetary policy and exchange rate in open economies. By restricting the variable to have a positive sign, this price puzzle (as with the consumer prices) will be avoided. Due to the fixed exchange rate regime in Denmark, the effect of a monetary policy shock could be argued to rather reflect a decision made from the ECB especially when looking at the shadow rate, but also the central bank balance sheet. To exemplify, if the ECB decides to lower the interest rate, Danmarks nationalbank would need to match this expansionary policy because of their exchange rate program. Hence for exchange rate, the shock also demonstrates the impact on the EUR/USD.

In summary the identification scheme looks as follows:

Table 1: Identification of expansionary monetary policy shocks.

	HPI	GDP	HICP	ER	CBB	SR
Balance sheet shock	UR	0	>0	>0	>0	
Shadow rate shock	UR	0	>0	>0		<0

Note: UR indicates that the variable is unrestricted, 0 a zero contemporaneous effect, >0 a positive sign restriction and <0 a negative sign restriction. When blank, the variable is not included in the BSVAR. The abbreviations that might need clarifications: ER is the exchange rate, CBB is the central bank balance sheet and SR stand for the shadow rate.

5 Results

The results will be focused on the impulse responses from the monetary policy shocks where the response of house prices are of main interest. Initially, results from the zero and sign restrictions are presented for the different countries, followed by the Cholesky decomposition. The impulse responses are presented in figures with a median response and a corresponding 68% credible set. Moreover, the impulse responses are illustrated for a horizon of 20 quarters, however, the first number of quarters are of main interest. These results are obtained by using the MATLAB toolbox created by Canova and Ferroni (2020), along with the accompanying guide (Canova & Ferroni, 2020).

5.1 Zero and sign restrictions

5.1.1 Sweden

Figure 3 shows the impulse responses in Sweden following a balance sheet shock while using zero and sign restrictions. The response of the main variable on impact is negative, but not significantly according to the credible set. In the fifth quarter the median response becomes positive, however, only increasing to a modest level and staying there persistently for the entire horizon with a large credible set. Overall, the reaction of house prices to a negative interest rate shock seems to be muted. GDP was restricted to be zero on impact, after the balance sheet shock the median response decreases moderately to a negative level, and in the fifth quarter it becomes positive and stays persistently at a low, but positive level, for the remaining time period. The credible set on the impulse response of GDP is, similar to the one for house prices, large and including the value zero for the entire horizon. Consumer prices were restricted to have a positive sign on impact. Following the balance sheet shock, the median response of consumer prices stays persistently at the initial positive level with the credible being positive until the tenth quarter. The exchange rate was restricted to be positive (depreciate) on impact. Following the balance sheet shock, the median response slowly returns to the zero value. However, the credible interval stays at a significant positive value until the eight quarter.

In Figure 4, the impulse responses from a shadow rate shock are plotted for Sweden, using zero and sign restrictions. The house prices index responds almost identical as in the case for the balance sheet shock, but the response on impact is at a more negative level. Around the seventh quarter the median response becomes positive but is still close to zero. When a shock to the interest rate occurs, the impact is expected to be much greater on the housing variable since it is assumed to be more interest rate sensitive, however, this does not seem to

be the case, using this identification scheme. GDP responds negatively for the first quarters and the median response becomes positive only after five quarters and has somewhat of a hump shape. However, the corresponding credible set includes zero for the whole period, indicating no effect on output. The response of consumer prices following the shadow rate shock is almost identical to the impulse response during a balance sheet shock. The response of the exchange rate is similar for both shocks, the impact is slightly greater and prolonged following a decrease in the shadow rate, but not at a remarkable level.

The lack of response for both shocks on house prices could indicate that there exist other factors that inflates house prices more directly, compared to an expansionary monetary policy shock. Despite being a housing market characterized by high indebtedness, it does not seem to be sensitive to interest rate changes, the mismatch of supply and demand could have a more prominent impact on house prices rather than the low interest rate environment (Rosenberg, 2019). Although the median response indicates a positive impact in the long run following, the large credible sets does not allow for a conclusion of a positive impact on house prices. The unexpected and vague results could originate from the limitations regarding partial identification, mentioned in section 4.4. It is possible that the identification scheme used, is not uniquely representing an unconventional expansionary monetary policy shock. The imposed signs could serve as a scheme for other types of shocks, such as expansionary fiscal policy.

Figure 3: Impulse responses to central bank balance sheet shock in Sweden (zero and sign restrictions).

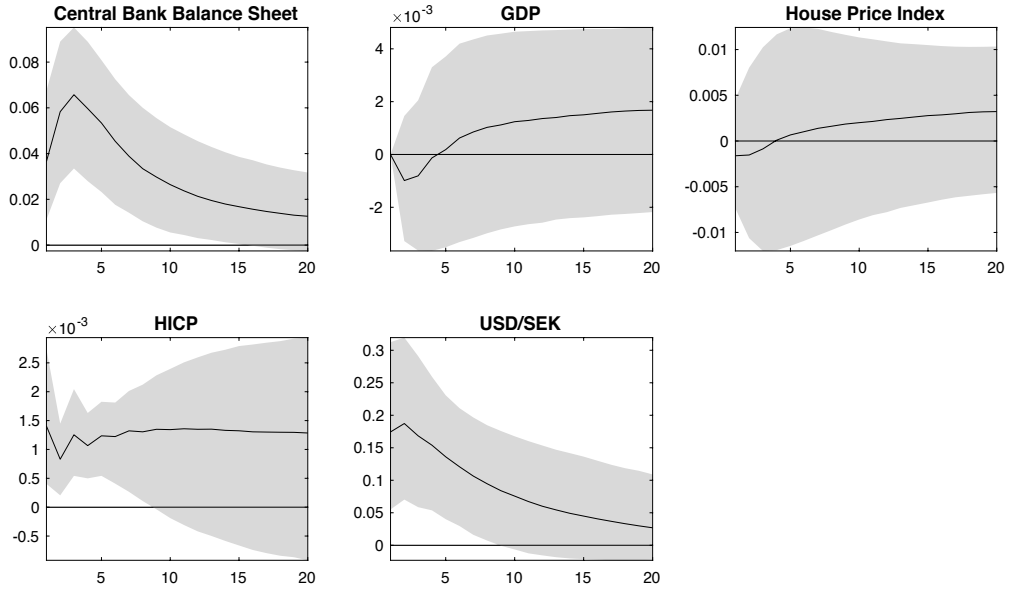
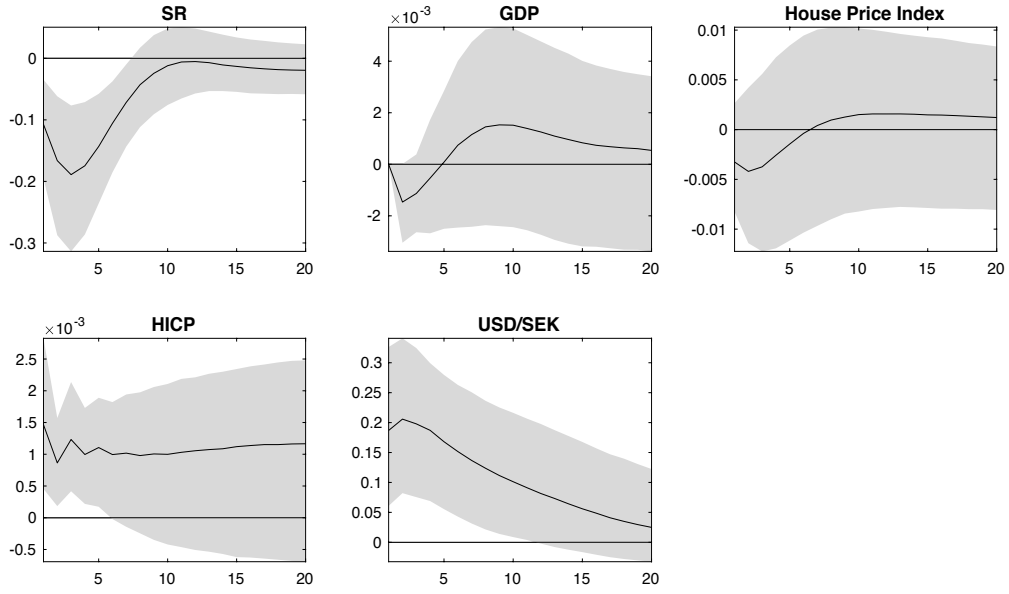


Figure 4: Impulse responses to a shadow rate shock in Sweden (zero and sign restrictions).



5.1.2 Denmark

In Figure 5, the impulse response of a balance sheet shock in Denmark is plotted, using zero and sign restrictions as the identification scheme. The response of house prices on impact is negative, but still close to zero. After a temporary drop in house prices, the median response becomes positive at the seventh quarter where it stays for the remaining time period. However, the response seems to be muted, similar to the corresponding Swedish case. GDP is restricted to be zero on impact, the pattern of the median response is almost identical to the one for house prices, but in this case the fluctuations are much smaller. Consumer prices was restricted to be positive on impact, after the balance sheet shock the median response stays persistently at the initial value. The credible interval is large for the entire period, but it does not include the zero value until the thirteenth quarter. The exchange rate was restricted to be positive (depreciate) on impact when there is a balance sheet shock. The median impulse response of the exchange rate after the shock returns to zero at the end of the horizon analyzed.

In Figure 6, the impulse responses from a shadow rate shock is plotted. House prices responds similar to the case of a balance sheet shock, with a negative median response on impact. However, it becomes positive only after the tenth quarter which is a delayed response, compared to the balance sheet shock. As discussed for the Swedish case, the muted impact on house prices was unexpected, but could have a similar explanation for Denmark, i.e., housing supply has lagged behind compared to demand and population growth (Rosenberg, 2019). Furthermore, the limitations of the identification method discussed in the results for Sweden, also apply in the Danish case.

After the first quarter, the median impulse response on output returns a small, negative value for a short period and then becomes positive with a peak in the fifth quarter where it stays persistently. The credible interval for the impulse response on output is large and includes the zero value until the fifteenth quarter. The median response of consumer prices is rather persistent at the initial positive value but with a tendency of returning to zero. The median response of the exchange rate returns to zero slowly, implying that the effect on the exchange rate following a shock on the shadow rate disappears when looking at the whole time period of analysis.

Figure 5: Impulse responses to central bank balance sheet shock in Denmark (zero and sign restrictions).

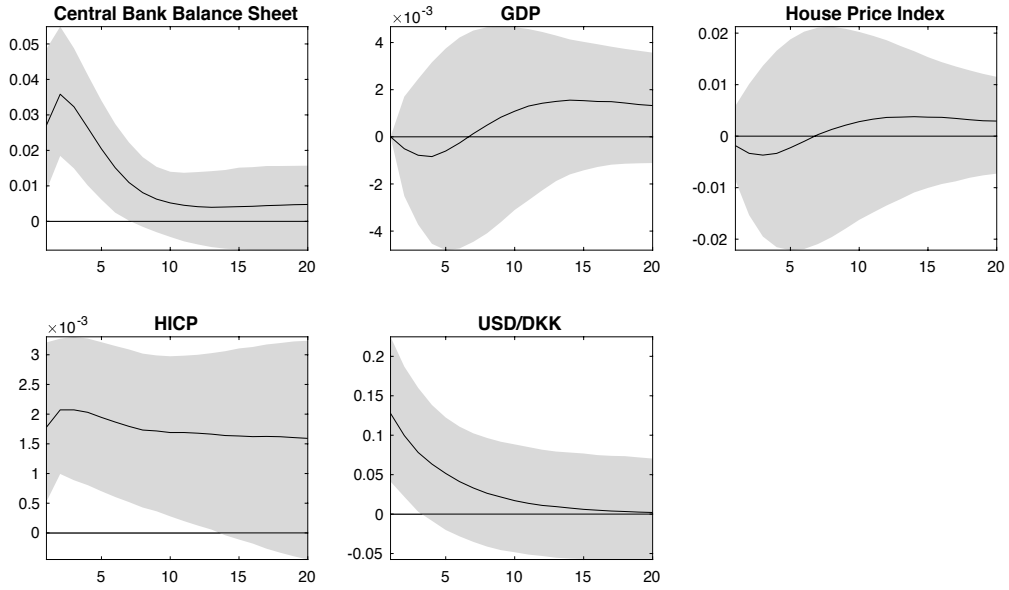
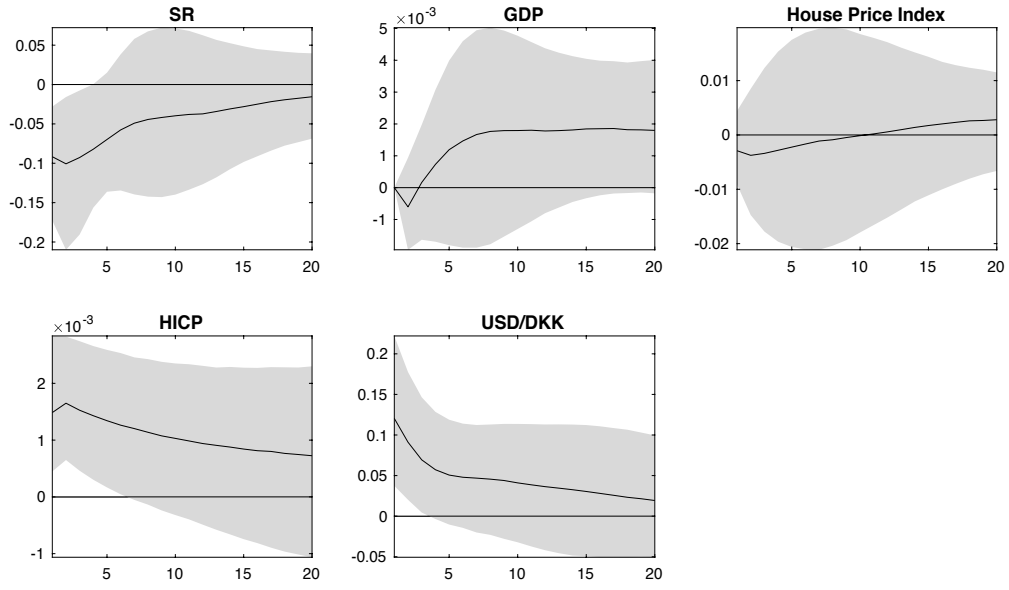


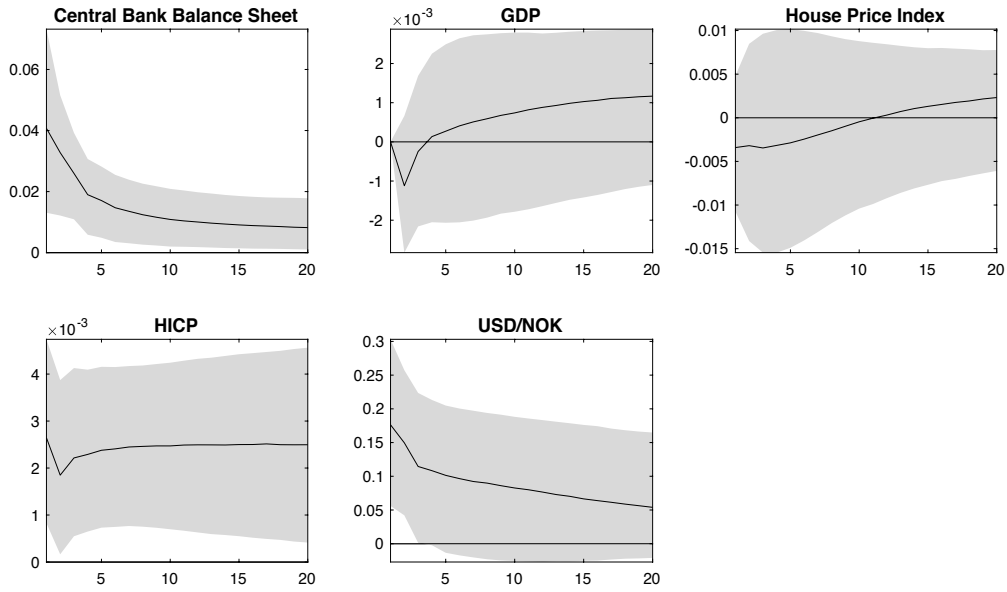
Figure 6: Impulse responses to a shadow rate shock in Denmark (zero and sign restrictions).



5.1.3 Norway

Figure 7 illustrates the different impulse responses of a balance sheet shock in Norway. House prices responds to the balance sheet shock with a negative value on impact. It is, on the other hand, not significant, since the credible interval is large and includes the zero. The median response becomes positive after the twelfth quarter, but still with a modest increase. This can be due to similar reasons to why the response was muted in the other Scandinavian countries when using zero and sign restrictions. The median impulse response for output drops after the first quarter, however, at around the fourth quarter the median response becomes positive and for the remaining horizon it increases slowly. The credible interval is large and includes the zero the entire time period. Consumer prices drops after the positive impact but recovers to the initial value persistently for the time period analyzed. The exchange rate decreases moderately after the first quarter, with the median impulse response slowly returning to zero.

Figure 7: Impulse responses to central bank balance sheet shock in Norway (zero and sign restrictions).



5.2 Cholesky decomposition

5.2.1 Sweden

Figure 8 illustrates the IRFs of the monetary policy shock captured by an increase of one standard deviation to the central bank balance sheet. The expansionary monetary policy shock is followed by a significant increase in house prices, which peaks around the fifth quarter. The median response indicates somewhat of a hump shape; the response of house prices seems to increase again after ten quarters, but the credible set does not exclude zero after the fifth quarter.

The shape and impact on GDP is quite similar to the one of house prices, but with a slightly less convincing and delayed positive response. The reaction of inflation (HICP) is slower with a peak at the tenth quarter, with a significant and persistent, positive median response for the remaining horizon. The exchange rate responds significantly positive on impact (depreciates) and stays positive for the remaining quarters analyzed. Hence, no price puzzle is emerging either for consumer prices or for exchange rates.

When instead examining the IRFs from a decrease in the shadow rate demonstrated in Figure 9, house prices increase significantly for the complete investigated time period. The peak is at the tenth quarter and of greater magnitude compared to the response following a balance sheet shock. The response of GDP drops to a negligibly negative level after the first quarter, then increases and stays positive, peaking at the tenth quarter. Consumer prices responds with a non-significant negative drop in the median response, however, in the seventh quarter the median response becomes positive and increases steadily for the entire horizon. It could be argued that a price puzzle is present at the beginning for the consumer prices if focusing on the median response, however, since the credible set indicates no significant decrease it is not relevant to call it a price puzzle. The exchange rate responds positively (depreciates) on impact following a negative shock to the shadow rate. Moreover, at a similar magnitude as the balance sheet shock, but not as persistent since the median response returns towards zero.

The ordering is altered as a test for robustness, where house prices are put after the monetary policy variable, implying that it is a fast-moving variable rather than a slow-moving variable. For Sweden, the house prices respond slightly negatively on impact from a shadow rate shock and the credible interval does not include the zero value. However, after the third quarter, the median impulse response becomes positive and follows the same pattern as the original ordering. The different results illustrate the sensitivity of Cholesky decomposition, one limitation with this identification method. The results from a balance sheet shock when

altering the order of variables is robust for Sweden.

Rosenberg (2019) found that house prices reacted more to a balance sheet shock, compared to a shock on the policy rate. This was explained by the balance sheet shock pushing down the mortgage rate in the long run, which due to the high level of indebtedness in Sweden, made households more sensitive. The findings of this thesis, however, were that house prices reacted more to changes in the shadow rate, which measures both unconventional and conventional monetary policy. In addition, the shadow rate captures the effect of unconventional monetary policy, as opposed to the balance sheet which only measures the quantity. The significant positive response is in line with the hypothesis of inflated house prices resulting from expansionary unconventional monetary policy.

Figure 8: Impulse responses to central bank balance sheet shock in Sweden (Cholesky).

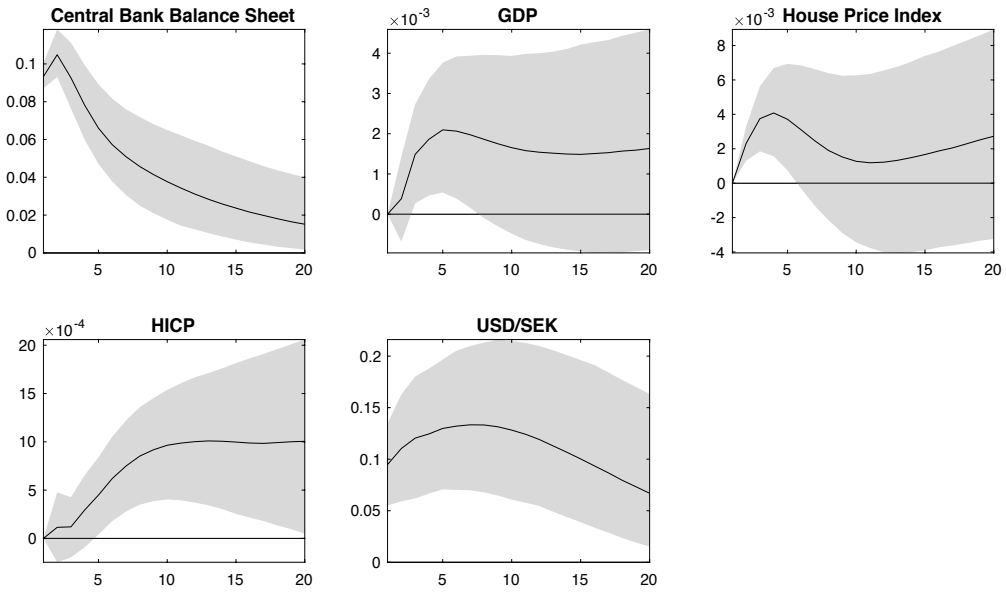
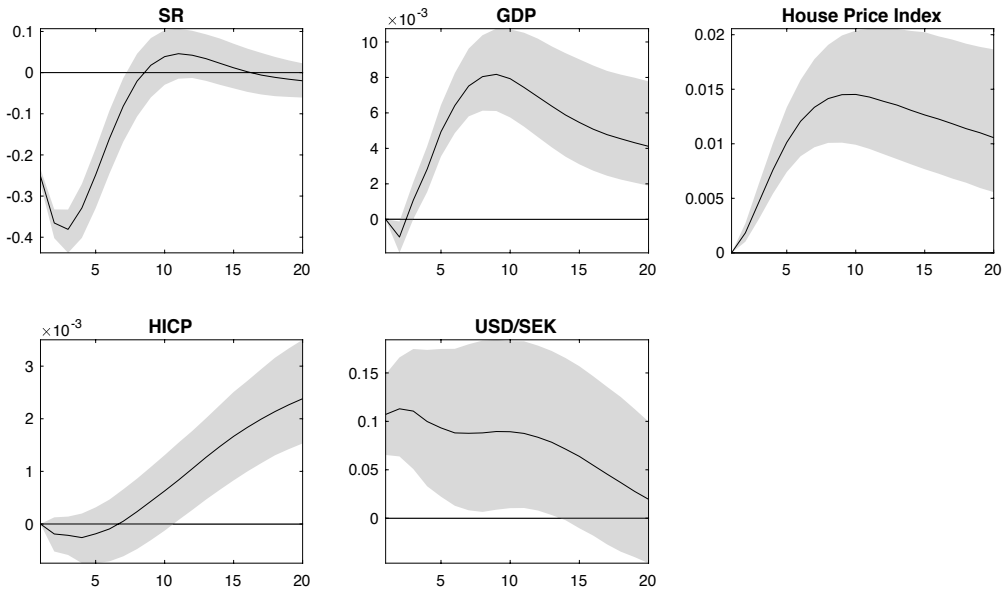


Figure 9: Impulse responses to a shadow rate shock in Sweden (Cholesky).



5.2.2 Denmark

The impulse responses from a balance sheet shock, presented in Figure 10, illustrates a somewhat delayed, but positive impact on house prices in Denmark. It becomes significantly positive after a couple of quarters and peaks around the tenth quarter. The median response is positive for all quarters but shows signs of returning to zero. The response for GDP differs from the corresponding impact in Sweden, following a balance sheet shock. The median response is negative for the first quarters but turns positive after a couple of years, but the impact is small and could be argued to have no effect due to the large credible set. The impact on inflation is positive if focusing on the median response, where it increases after the impact and reaches its highest level at the end of the time horizon. The exchange rate depreciates from the shock but moves persistently into negative territory after a few quarters.

When instead looking at Figure 11, which demonstrates the impulse responses from a shock to the shadow rate, house prices responds faster and with smaller credible sets. The impact peaks at 10 quarters and stays positive.[3] The result coincides with the response of Swedish

[3]When making the same robustness test of ordering as for Sweden for Denmark, the results from a balance sheet shock is robust. The impact on the house prices from a shadow rate shock is significantly, but only slightly, negative as in the Swedish case, thereafter behaving as when the original ordering was used.

house prices from a decrease in the shadow rate. This is also the case for the response of GDP, i.e., a significantly positive impact after a couple of quarters. The response of consumer prices seems to be muted but indicates an increase after the tenth quarter. The exchange rate initially responds with a modest positive impact and the median response enters the negative territory quickly and stays there at a persistent level.

Figure 10: Impulse responses to central bank balance sheet shock in Denmark (Cholesky).

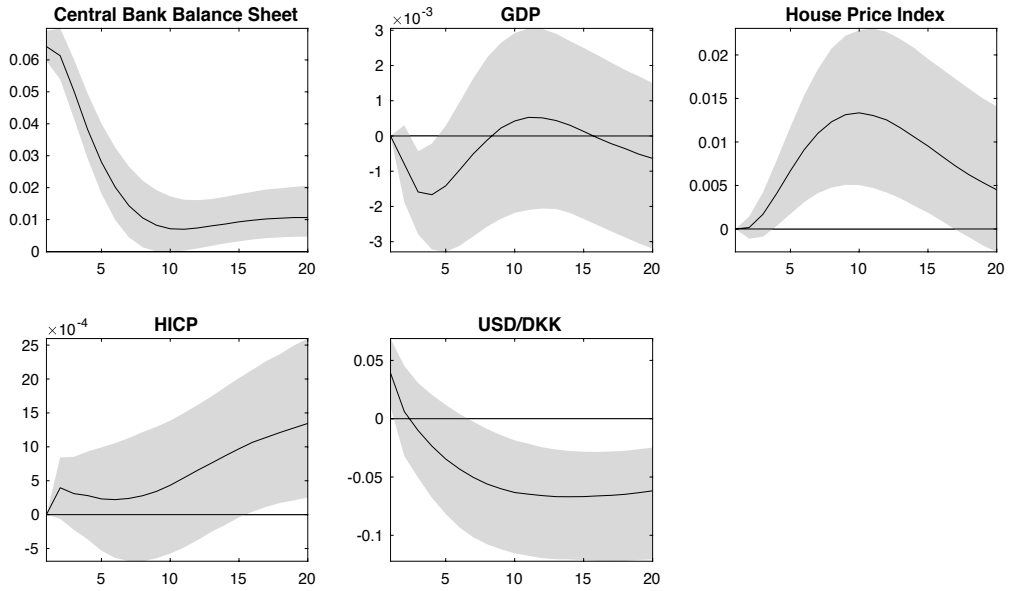
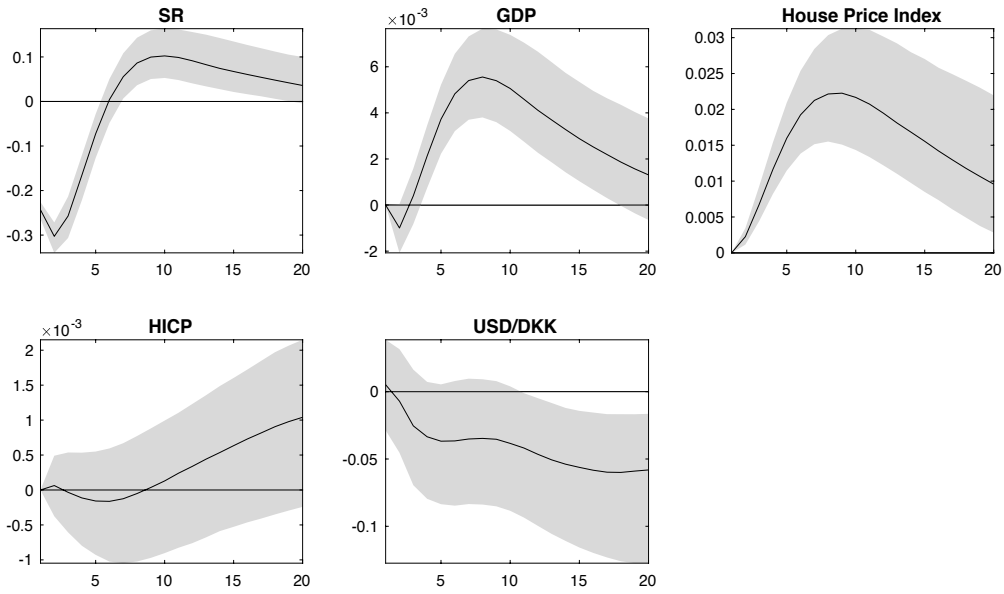


Figure 11: Impulse responses to a shadow rate shock in Denmark (Cholesky).

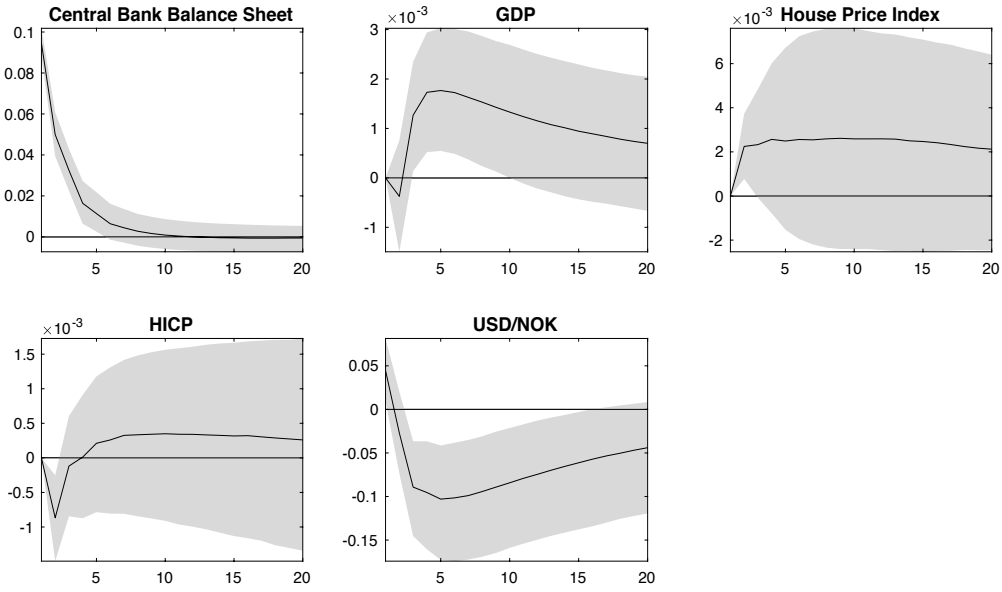


5.2.3 Norway

Figure 12 demonstrates the IRFs from a balance sheet shock in Norway. Initially, the shock has a significant and positive impact on house prices and the median response shows persistence, although, with a large credible set.[4] The median response for output drops moderately to a negative level, thereafter, it increases significantly and peaks in the fifth quarter. Following the balance sheet shock, consumer prices react with a small negative drop, indicating a price puzzle. On the other hand, the median response becomes positive after the fifth quarter, where it stays persistently. The exchange rate responds positively, indicating a depreciation as a result from the shock. Although the impact is positive in the beginning, it quickly turns negative and reaches its lowest level at the fifth quarter, which, as discussed in the Danish case, could be interpreted as a price puzzle.

[4]The original ordering showed a significant positive impact on house prices after the first quarter, the robustness test of altering the ordering removed the significant positive response in Norway.

Figure 12: Impulse responses to central bank balance sheet shock in Norway (Cholesky).



5.3 A cross-country comparison

The similar responses of house prices between the Scandinavian countries, using zero and sign restrictions, were not expected. Despite conducting different monetary policies, with Denmark having a fixed exchange rate regime and Norway acting more through fiscal policy while at the same time not being a part of the European Union, the results indicate an independence from these institutional diversities. On the other hand, it might be the resemblance of household indebtedness in the Scandinavian countries, as well as having a large demand on housing along with low residential investment, that explains the large increase in house prices. When isolating the effect only coming from a monetary policy shock there are no large apparent effect on house prices, according to the zero and sign restrictions approach. As been reflected upon throughout this thesis, there are several factors that influence house prices, and it has proven to be difficult to draw conclusions on causality from only on one of the transmission channels, using zero and sign restrictions as the identification scheme.

House prices had a large positive impact from a shadow rate shock, using the Cholesky decomposition, for Sweden and Denmark. These results coincide with the arguments throughout this thesis, i.e., unconventional monetary policies inflate house prices. A decrease in shadow rates generated larger impacts on house prices compared to the balance sheet shocks. Furthermore, when comparing the results between countries, from a balance sheet shock,

the shape and magnitude of the impulse responses vary considerably. Given that Denmark and Norway do not officially use quantitative easing as a tool, along with the heterogeneity among the Scandinavian countries discussed above, these results were in line with what was anticipated. The identification method used, which is something that has been widely discussed, is of great importance to the result obtained. The results in this thesis illustrates this phenomenon, with vast differences between the impact on house prices from a Cholesky decomposition compared to the zero and sign restrictions.

6 Conclusion

The recent development in house prices in the Scandinavian countries along with increasing household indebtedness, in an all-time low interest rate environment, are alarming sequences of events. If a crisis was to occur, where the economy could be facing a recession, the central bank would respond by lowering the interest rate in order to stimulate the economy. The effectiveness of monetary policy, when being at the zero lower bound, has been widely debated and could become an issue for the Scandinavian countries.

This thesis has examined the impact of unconventional monetary policy shocks on house prices in the Scandinavian countries. A Bayesian structural vector autoregression (BSVAR) was conducted with two different identification methods, Cholesky decomposition and zero and sign restrictions. The ordering of variables in the Cholesky decomposition was motivated by whether they would respond fast or slow, in the case of a shock. The zero and sign restrictions were argued through earlier papers and macroeconomic theory, while leaving the main variable of interest "agnostically" open, following Uhlig (2005). The results from the zero and sign restrictions were almost identical across countries, with a lack of significance and delayed positive median response. However, the impact on house prices using the Cholesky decomposition were similar for all countries, i.e., an unconventional monetary policy shock leads to an increase in house prices, with varying persistence. In particular, the results from a decrease in shadow rates supports the hypothesis of house prices being inflated due to unconventional monetary policy.

The study on the macroeconomic effects from unconventional monetary policy remains relatively unexplored, mostly due to the short period of time it has been conducted outside periods of crises. Moreover, there is no consensus on the exact approach to be used. DSGE-models are used by many central bankers, which incorporates macroeconomic models but at the same time requiring more assumptions to be made. The use of a VAR framework is very popular among academic researchers, however, the results are highly sensitive to the identification method, which is evident in this thesis.

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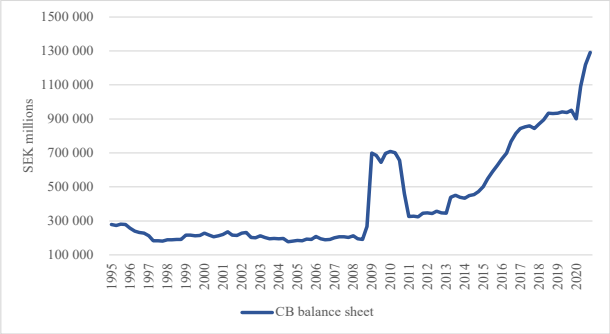
8 Appendix A. Sources of data

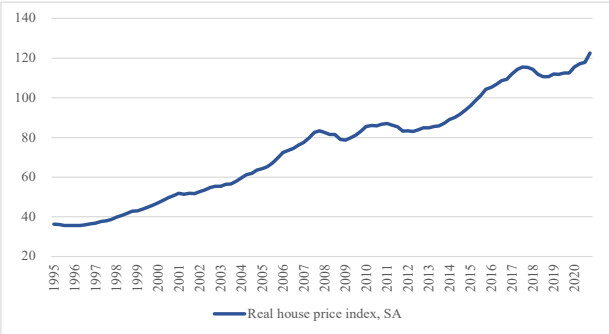
Table 2: Summary of variables, description and data source for all countries.

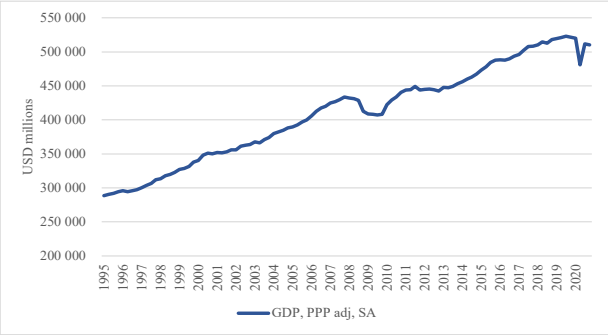
Variable	**Description**	**Data source**
House prices	Real house price index, seasonally adjusted, 2015 reference year.	OECD
Central bank balance sheet	Central bank collection of assets.	Sveriges Riksbank, Norges Bank, Danmarks Nationalbank
Shadow rate	A function derived from the government bond yield, along with its short-rate expectations elements, taking statements on unconventional monetary policy into account.	Rafael B. De Rezende, Annukka Ristiniemi
GDP	Gross domestic product, expenditure approach, ppp adjusted, 2015 reference year, U.S. dollar, millions, seasonally adjusted.	OECD
HICP	Harmonized index of consumer prices, seasonally adjusted, 2015 reference year.	OECD
Exchange rate	National currency expressed in U.S. dollars, USD/SEK, USD/NOK, USD/DKK.	Bloomberg
Household debt	Household debt in relation to net disposable income.	OECD
Policy rate	Short-term interest rate set by the central bank.	Sveriges Riksbank, Norges Bank, Danmarks Nationalbank

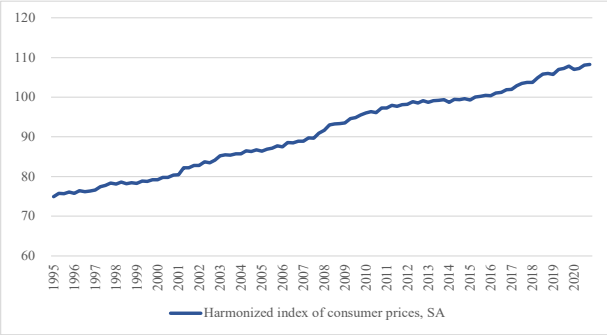
9 Appendix B. Overview of variables

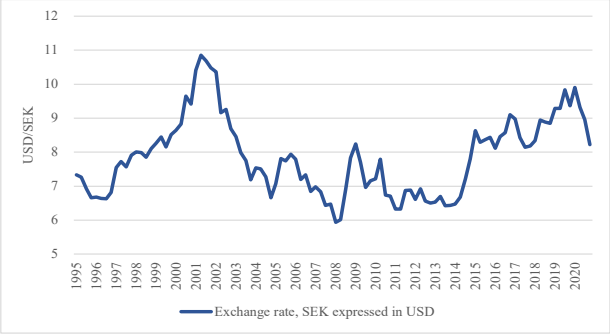
9.1 Sweden

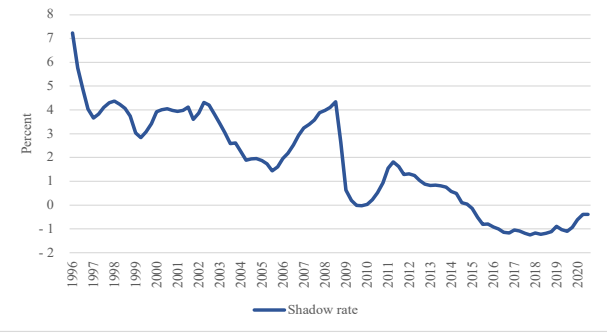




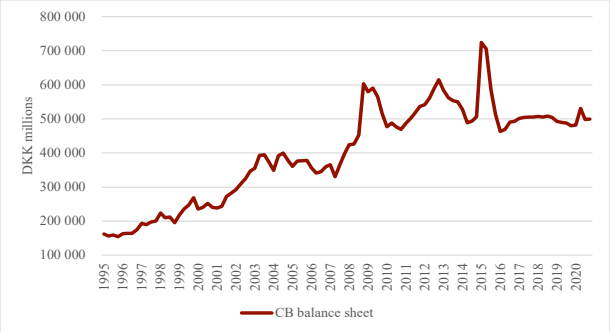


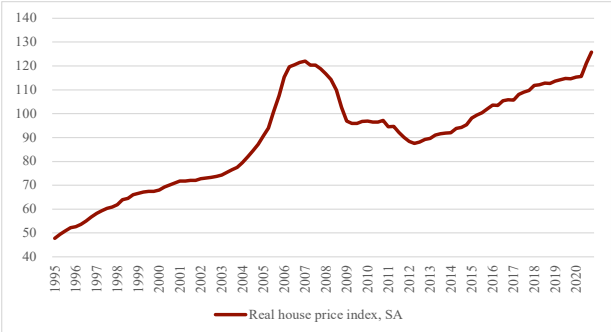


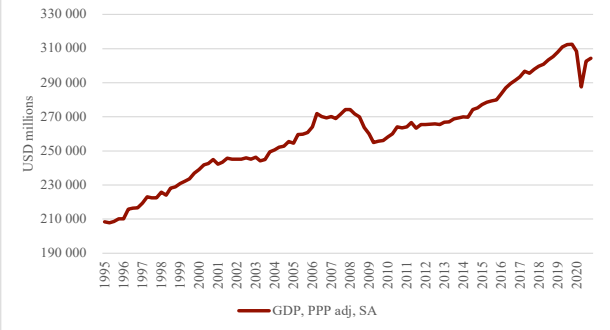


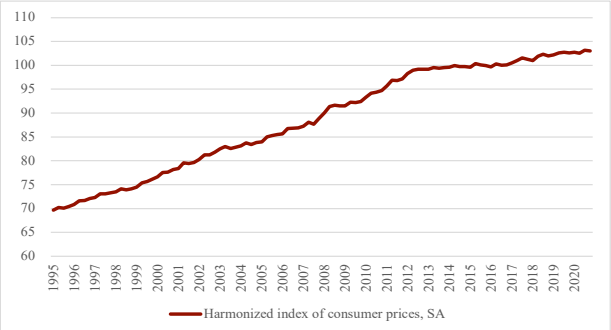


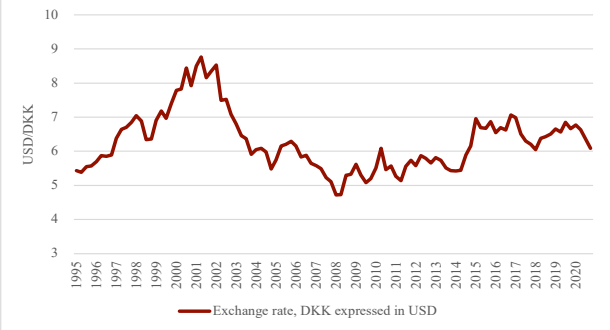
9.2 Denmark

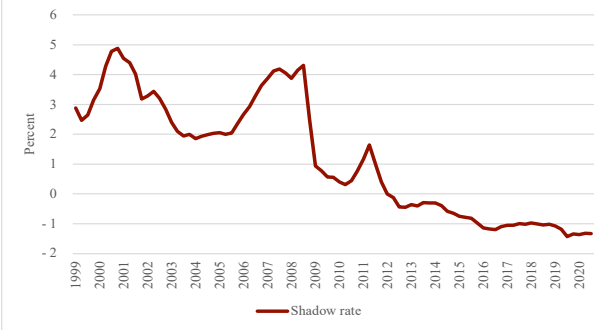

DKK millions
800 000
700 000
600 000
500 000
400 000
300 000
200 000
100 000
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
CB balance sheet


140
130
120
110
100
90
80
70
60
50
40
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Real house price index, SA

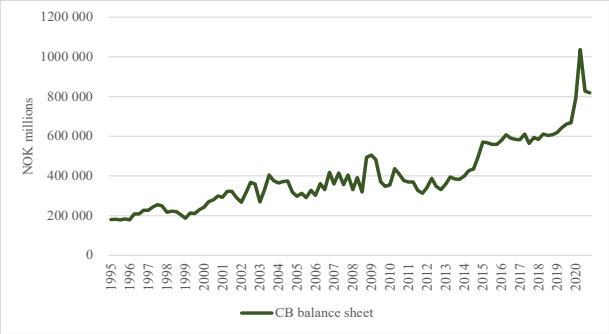

USD millions
330 000
310 000
290 000
270 000
250 000
230 000
210 000
190 000
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
GDP, PPP adj, SA

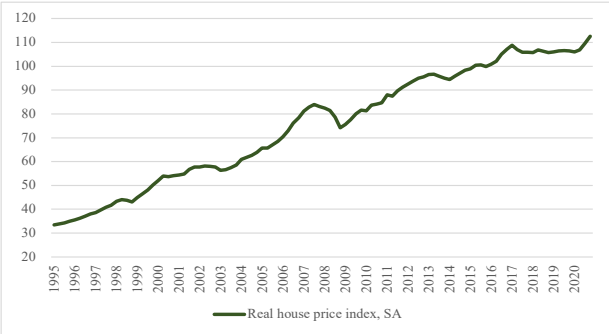

110
105
100
95
90
85
80
75
70
65
60
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Harmonized index of consumer prices, SA

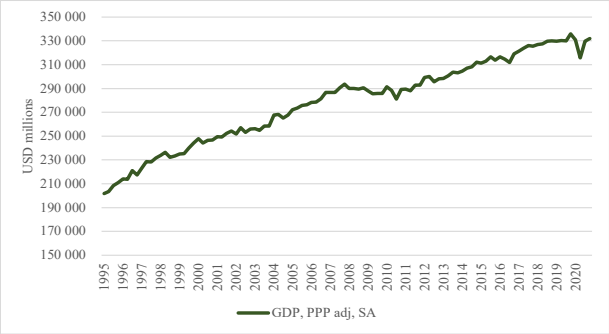

USD/DKK
10
9
8
7
6
5
4
3
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Exchange rate, DKK expressed in USD

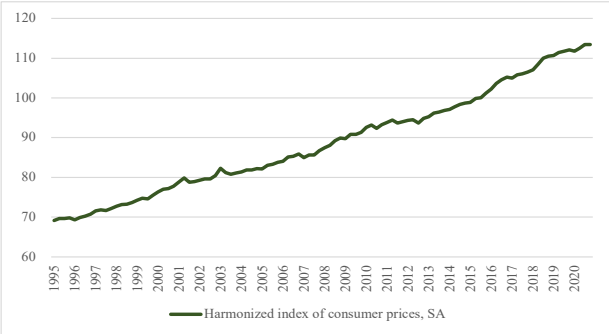

Percent
6
5
4
3
2
1
0
- 1
- 2
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Shadow rate

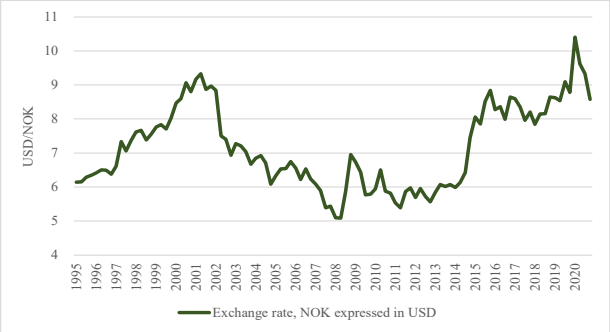
9.3 Norway


1200 000
1000 000
800 000
600 000
400 000
200 000
0
NOK millions
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
CB balance sheet


120
110
100
90
80
70
60
50
40
30
20
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Real house price index, SA


350 000
330 000
310 000
290 000
270 000
250 000
230 000
210 000
190 000
170 000
150 000
USD millions
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
GDP, PPP adj, SA


120
110
100
90
80
70
60
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Harmonized index of consumer prices, SA


11
10
9
8
7
6
5
4
USD/NOK
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Exchange rate, NOK expressed in USD