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Monetary Policy Surprises, House Prices and Household Credit in Norway

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Abstract

In this master thesis we analyze the effects of monetary policy shocks on economic and financial variables in Norway, where we focus in particular on the responses of house prices and household credit. Our main approach involves combining the traditional structural VAR analysis with high frequency identification of policy shocks. We identify monetary policy shocks using changes in forward rate agreements over a 30-minute window surrounding policy announcements by Norges Bank, which we use as external instruments in the SVAR. The usual recursive identification of the model is rejected based on an analysis of the impulse responses and the issue of simultaneity. We find that a contractionary monetary policy shock has a large and negative impact on house prices in Norway, while the response of credit is modest and positive. We also find evidence supporting that monetary policy operates through a credit channel.

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1.0 INTRODUCTION

In the time leading up to the recent financial crisis, advances in both theory and empirical work in the study of monetary economics had led both academic economists and policymakers to argue that there was now a well-defined “science of monetary policy”. There was a general consensus in central banks about most elements of monetary policy strategy, and monetary policy was perceived as being highly successful in OECD countries, with not only low inflation, but also low variability of inflation (Mishkin 2011). However, in the years after the crisis, many policy-makers have disagreed about the cause of the crisis and the role of central banks, especially when it comes to promoting stable housing- and financial-markets. According to the Swedish professor of economics Lars E.O. Svensson, the crisis was not caused by monetary policy and was mostly due to background macro conditions, distorted incentives in financial markets, regulatory and supervisory failures. Taylor (2007) on the other hand believes that an overly expansionary monetary policy played an important role. Low money market rates made housing finance less costly and more attractive, which motivated house price overvaluation that created financial imbalances in the housing and credit- markets. In the aftermath of the global financial crisis and the current low interest rate environment, it has become important to properly assess the relationship between monetary policy and asset prices (Alessi and Kerssenfischer 2016). The crisis has also placed the issues of credit and financial stability back at the center of academic research, which is where they were when the field of macroeconomics began (Taylor 2015).

In this thesis we wish to quantify the effect of a monetary policy shock on macroeconomic variables, asset prices and financial variables in Norway. Our chosen topic is motivated by the increased focus on the role of financial variables and asset prices in the business cycle and the monetary policy transmission mechanism. We will focus in particular on the responses of house prices and household credit. Although the events of the recent financial crisis have led to more empirical research on the topic, the research done on Norwegian data is still limited. There is also a lack of consensus in the literature regarding both the size and the direction of the response of credit to a monetary policy surprise, which is a strong motivational factor as to why we wish to study the dynamics of credit. The topic is of high relevance in Norway today, with a rising concern that financial imbalances may be building up and an uncertain outlook for the Norwegian economy.

Following the decline in oil prices since the summer of 2014, the key policy rate has been reduced. Persistently low interest rates may lead to financial system vulnerabilities and the rapid rise in house prices and growing debt burdens indicate that households are becoming more vulnerable (Norges Bank 2017c). Even though debt growth has slowed somewhat in recent years, household debt continues to grow faster than household disposable income. Owing to high house price inflation, household borrowing may increase further (Norges Bank 2016). As a result, there has been growing concern that the rapid rise in prices and associated increase in debt in the household sector could pose a risk of financial imbalances building up (Danske Bank 2017). The housing and credit markets are showing similar developments as before the recent financial crisis and policymakers are experiencing high pressure regarding the conduct of monetary policy.

The empirical research on the monetary policy transmission mechanism and its effect on economic variables using vector autoregressive (VAR) models is extensive. However, most studies use short-run, long-run and/or sign restrictions in order to identify monetary policy shocks. To answer our question of interest we use a new measure of monetary policy surprises. Following the work of Gertler and Karadi (2015), our approach involves combining the traditional VAR analysis with high frequency identification (HFI) of policy surprises. We identify monetary policy shocks using changes in forward rate agreements over a 30-minute window surrounding policy announcements by Norges Bank, which we use as external instruments in the structural VAR. The use of external instruments in a VAR is based on the methodology developed by Stock and Watson (2012) and Mertens and Ravn (2013). This is to our knowledge the first study that uses this method to analyze the effects of monetary policy shocks using Norwegian data. Our approach has some advantages with respect to previous studies in Norway. The HFI approach allows us to analyze the dynamic response of both financial and economic variables simultaneously. This is important because financial variables are widely believed to be a crucial determinant of the transmission of monetary policy (Cesa-Bianchi, Thwaites and Viccondoa 2016).

We begin our analysis with an evaluation of different policy indicators and instruments, where we consider a number of interest rate swaps and forward rate agreements. Our findings suggest that the one-year rate is the preferred policy

indicator and that the two-year rate leads to a weak instrument problem. We therefore use the one-year rate as our policy indicator, which is instrumented by the change in the current three-month NIBOR rate (NOK3MD). Further, we use two models to quantify the effects of a monetary policy shock. The first model we use is a simple VAR which illustrates how the external instrument approach works, as well as how it compares to the Cholesky identification scheme. The simple VAR includes the one-year interest rate swap (instrumented by NOK3MD), unemployment, inflation and the exchange rate. Despite a small price puzzle, we find that in a VAR with both economic variables and asset prices, our external instrument approach produces a more convincing set of responses to a monetary shock than does a standard Cholesky identification scheme. We therefore employ only the external instrument approach in our main analysis. Our main model allows us to answer the question of interest and includes the one-year interest rate swap, inflation, exchange rate, TED spread, house prices and household credit. The results from the main model suggest that the effect of a contractionary monetary policy shock on house prices in Norway is large, where a one percentage point increase in the yearly interest rate leads to a 4 percent decline in house prices after 1.5 years. The variance decomposition shows that the relevance of the interest rate in explaining the variation in house prices is 40 percent after two years and that the interest rate shock has a larger impact on the variation in house prices than on any other variable in the main model. This finding is consistent with previous empirical findings on the effects of monetary policy shocks on house prices in Norway. We find a modest and positive response of credit in the short run, where a one percentage point increase in the interest rate leads to a one percent increase in real household credit. We argue that the shock leads to an increase in both nominal debt and the price level, which makes the effect on real household credit positive in the short run. The reasoning behind this is that it takes some time for households to adjust their credit levels. Although our results strongly suggest that the effect on real household credit is positive, we find it difficult to draw a conclusion regarding the forces driving the response. We also find that a one percentage point increase in the interest rate leads to an increase of approximately 0.25 percentage points in the Norwegian TED spread. This result confirms one important result put forth by Gertler and Karadi (2015), that monetary policy operates through a credit channel.

The thesis proceeds in the following way. In chapter 2 we give an overview of the relevant literature regarding our chosen topic. The data used in our high frequency identification method and structural VAR models is presented in chapter 3. In chapter 4 we present our methodology, where we describe the VAR framework and how we make use of changes in forward rate agreements as external instruments. The results are presented in chapter 5, where we begin with a discussion regarding our choice of policy indicator and instrument, followed by the results from our simple VAR and main model.

2.0 LITERATURE REVIEW

In this chapter we will give an overview of the relevant literature regarding our topic. We begin with presenting different views and empirical findings of the transmission mechanism of monetary policy, which we proceed to review in relation to the variables that are included in our analysis.

2.1 The Transmission Mechanism of Monetary Policy

An understanding of the transmission mechanism of monetary policy is imperative in order to implement an efficient monetary policy strategy. The literature consists of many different views regarding the monetary transmission mechanism. These views differ in the emphasis they place on money, credit, interest rates, exchange rates, asset prices or the role of commercial banks and other financial institutions (Taylor 1995).

A significant number of industrialized and middle-income countries have adopted inflation targeting as their framework for making monetary policy. As the name suggests, in an inflation-targeting regime the central bank is responsible for achieving a publicly announced objective for the inflation rate, typically at a medium-term horizon of one to three years (Bernanke and Woodford 2007). However, a number of commentators have suggested that central banks should reconsider the desirability of inflation targeting in the light of the global financial crisis (Woodford 2012). While it is premature to suggest that inflation is no longer an issue of great concern, it is quite conceivable that the next battles facing central bankers will lie on a different front. One development that has already concentrated the minds of policymakers is an apparent increase in financial instability, of which one important dimension is increased volatility of asset prices (Bernanke and

Gertler 2000). Cecchetti et al. (2000) argue that leaning against movements in asset prices improves overall macroeconomic performance. This view has gathered increased support and attention after the crisis and has led to calls for monetary policy to react to movements in credit and asset prices “over and beyond” what is dictated by the medium-term outlook for inflation and real activity (Woodford 2012). However, leaning against the wind by setting a tighter monetary policy than suggested by the central bank policy rule might be costly in terms of lower inflation and lower output (Svensson 2014).

The conventional models of monetary policy transmission treat financial markets as frictionless, meaning that for a given maturity, the interest rate on a private security equals the corresponding government bond rate, up to a first order (Gertler and Karadi 2015). Bernanke and Gertler (1995) argue that it is difficult to explain the magnitude, timing and composition of the economy’s response to monetary policy shocks solely in terms of conventional interest-rate effects. Further they state that the mechanisms known as the credit channel help to fill in the gaps in the traditional story. The basic premise of the credit channel theory is the recognition of imperfections in credit markets (Hendricks and Kempa 2011). In particular, with credit market frictions operative, the private annual borrowing rate exceeds the rate on a similar maturity government bond, adjusted for risk. This wedge between the private borrowing rates and government bond rates is called the external finance premium and arises because of agency costs associated with information asymmetries and the inability of lenders to monitor borrowers costlessly (Walsh 2010). With a credit channel present, a monetary tightening not only raises government bond rates but also the external finance premium, which amplifies the overall effect of the policy action on private borrowing rates. The external finance premium increases because the tightening of monetary policy leads to a tightening of financial constraints due to agency costs. Theories of the credit channel differ with respect to the precise way the central bank interest rate influences credit constraints. A common prediction, however, is that the credit channel magnifies the impact of the interest rate adjustment on private borrowing rates via the impact on credit spreads (Gertler and Karadi 2015).

Despite fifty years of empirical research, there is still a lot of uncertainty around the effects of monetary policy. Not just the magnitude and the significance, but even

the sign of the responses of prices and output is controversial (Miranda-Agrippino and Ricco 2016). There is little hope that economists can evaluate alternative theories of monetary policy transmission, or obtain quantitative estimates of the impact of monetary policy changes on various sectors of the economy, if there exist no reasonable objective means of determining the direction and size of changes in policy stance (Bernanke and Mihov 1995). A reason for the lack of consensus in empirical research is that it is econometrically very difficult to disentangle time series on financial variables such as interest rates and exchange rates into the parts that are due to monetary policy measures and the parts that merely reflect endogenous responses of financial markets to unobserved economic disturbances. Alternative empirical methodologies therefore tend to give different estimates of the role and effects of monetary policy (Gerlach and Smets 1995).

A number of researchers have found the need to identify new measures of monetary policy shocks in order to estimate the real effect of a shock. Romer and Romer (2004) argue that the accuracy of estimates of the effects of monetary policy depends on the validity of the measure of monetary policy that is used. The use of an inappropriate measure may obscure a relationship between monetary policy and other economic variables that actually exists, or create the appearance of a relationship where there is no causal link. Further they argue that the conventional measures of monetary policy have some obvious flaws, such as the likelihood of endogenous and anticipatory movements. This is the reason why they derive a new measure of monetary policy shocks that is free from some key deficiencies of previous measures. The narrative approach of Romer and Romer (1989) is the seminal reference in this literature, which involves using information from outside the VAR to construct exogenous components of specific shocks directly. Their specific approach will be explained in further detail in the methodology chapter.

2.2 The Macroeconomy

The central banks of most industrialized countries use interest rates to stabilize economic activity and inflation. To do this well, they need to know how changes in their policy instruments affect the economy (Cesa-Bianchi, Thwaites and Vicondoa 2016). The effect of monetary policy on the economy is one of the most studied empirical questions in all of macroeconomics (Ramey 2016). Most economists would agree that, at least in the short run, monetary policy can significantly

influence the course of the real economy (Bernanke and Gertler 1995). Monetary policy cannot be expected to directly contribute to raising long-term economic growth, though it can foster sustainable growth by maintaining an environment of price stability (Papademos 2003). From empirical analyses, in particular VAR models, and from theoretical work, there has emerged a relatively clear picture of the effects on the U. S. economy from changes in the Federal Reserve's monetary policy. It is often taken as a stylized fact that after an unexpected drop in the short-term interest rate, output, inflation, and productivity go up. The responses are "hump-shaped" and the maximum effects are recorded after about 1.5 to 2 years. The theoretical open economy models presented by Svensson (2000) and McCallum (2001) imply effects of monetary policy shocks that are in agreement with those reported for the U. S. However, they suggest that the effects are likely to occur somewhat faster in an open economy due to foreign influence and the importance of the exchange rate (Jacobson et al. 2002).

2.2.1 Inflation

The primary task of monetary policy is to ensure price stability, in the sense of low and stable inflation. In Norway, inflation targeting has helped to anchor inflation expectations, enabling monetary policy to stabilize output and employment. However, inflation will often deviate from the target in response to shocks and the trade-offs they entail (Norges Bank 2017b). A standard theoretical prediction is that a contractionary monetary policy shock will lead to lower inflation. However, empirical studies of open economies typically do not confirm theory. In particular, open economy VAR models often yield price puzzles such that a contractionary monetary policy shock leads to an increase of the price level (Jacobson et al. 2002). According to Sims (1992), this puzzle is likely to reflect that policy authorities might know that inflationary pressure is about to arrive and therefore increase the interest rate to dampen the effects of these pressures. Then prices would rise after the monetary contraction (though by less than they would have without the contraction) and output would fall because of the standard effects of nominal demand contraction on real output. The falling currency value in the wake of the interest rate rise is consistent with this story. The impact of a monetary policy shock on inflation may also have a lagged effect by first affecting inflation expectations which, in turn, have a lagged effect on inflation via wage and price setting behavior. However, Bjørnland and Jacobsen (2010) find that the price puzzle is curbed by

including a few asset price series in a structural VAR. Further reductions are found when they allow for simultaneous responses using our structural decomposition instead of the Cholesky decomposition

2.2.2. Unemployment

It is generally accepted that policymakers, as well as financial markets, pay especially close attention to labor market indicators during periods of economic uncertainty. The reason, in short, is that changes in labor market activity are thought to be useful predictors for changes in real gross domestic product, the broadest measure of economic activity (Gavin and Kliesen 2002). When a central bank embarks on an expansionary monetary policy, it typically does so to stimulate the domestic economy and reduce unemployment (Engler 2011). When economic activity is high, more production happens overall, and more people are needed to produce the higher amount of goods and services. When economic activity is low, firms reduce their workforce and unemployment rises. In that sense, unemployment is countercyclical (IMF 2012). A widely-spread belief among economists is that monetary policy has relatively short-lived effects on real variables such as unemployment (Alexius and Holmlund 2007). Ravn and Simonelli (2007) estimate a twelve-dimensional VAR on U.S. data and find that unemployment responds with a large elasticity to a monetary policy shock in addition to displaying hump-shaped dynamics. Unemployment reaches a peak increase of around 2.5 percent 6 quarters after the rise in interest rates. Using a structural VAR model on Swedish data, Alexius and Holmlund (2007) find that a contractionary monetary policy shock of one percentage point results in 0.25 percentage points higher unemployment after 9 quarters. They find that shocks to monetary policy explain between 22 and 35 percent of the fluctuations in unemployment and that the effects of the shock remain after 10 years. Their results suggest that monetary policy has a high and persistent effect on unemployment in Sweden and that the effects of monetary policy shocks may be more persistent in countries with more highly regulated labor markets.

2.3 Asset Prices

There is a considerable amount of interest in understanding the interactions between asset prices and monetary policy. Much of the transmission of monetary policy comes through the influence of short-term interest rates on other asset prices, as it is the movements in these other asset prices - including longer-term interest rates

and stock prices - that determine private borrowing costs and changes in wealth, which in turn influence real economic activity (Rigobon and Sack 2004). With their timely response to economic shocks, asset prices may be important indicators of the monetary policy stance. Understanding the role of asset prices in the transmission mechanism of monetary policy may therefore be crucial for the implementation of an efficient monetary policy strategy (Bjørnland and Jacobsen 2010). Mainstream macroeconomic theory predicts a rapid response of asset prices to monetary policy shocks. However, conventional VAR models often produce responses that are not in line with economic theory (Alessi and Kersebaumer 2016). It is unclear whether monetary policy has predictable effects on asset prices and, if so, whether these effects occur at the same time horizons for different asset prices, whether they are large relative to the effects of monetary policy on inflation and economic activity and whether they occur faster (Assenmacher-Wesche and Gerlach 2008).

2.3.2 The Exchange Rate

For a small open economy, the exchange rate plays a central role in relation to monetary policy. It is highly significant in the formulation of monetary policy (as an important influence on the overall price level) and, in itself, is also influenced by monetary policy. Hence, monetary policy and exchange rate interactions may be substantial in the sense that each variable reacts to news in the other (Bjørnland 2008). Expansionary monetary policy affects exchange rates by leading to a fall in domestic interest rates, where deposits denominated in domestic currency become less attractive relative to deposits denominated in foreign currency (Mishkin 2001). According to Dornbusch's (1976) well known exchange rate overshooting hypothesis, which is a central building block in international macroeconomics, an increase in the interest rate should cause the nominal exchange rate to appreciate instantaneously, for then to depreciate in line with uncovered interest parity¹ (Bjørnland 2006). However, SVAR studies analyzing the effects of monetary policy on the exchange rate in the past have often found puzzling results. That is, following a contractionary monetary policy shock the exchange rate either depreciates, or, if it appreciates, it does so only gradually and for a prolonged period of up to three

¹ The uncovered interest parity (UIP) is a parity condition stating that the difference in interest rates between two countries is equal to the expected change in exchange rates between the countries' currencies (Investopedia 2017).

years, thereby giving a hump-shaped response that violates uncovered interest parity. In the literature, the first phenomenon has been termed the exchange rate puzzle, whereas the second has been referred to as delayed overshooting or the forward discount puzzle (Bjørnland and Thorsrud 2015). Through a VAR analysis on Norwegian data, Bjørnland (2008) finds evidence of an exchange rate puzzle when using the Cholesky scheme. The puzzle occurs both when the interest rate is ordered last and when the exchange rate is ordered last. However, by imposing a long-run restriction on the real exchange rate and thereby allowing the interest rate and the exchange rate to react simultaneously to news, she finds that a one percentage point increase in the interest rate implies a strong and immediate appreciation of the exchange rate. Thereafter the exchange rate gradually depreciates back to the baseline, as is consistent with the Dornbusch overshooting hypothesis and broadly consistent with uncovered interest parity.

2.3.3 The Housing Market

A house is the largest single asset of most households, and assets whose value is linked to residential real estate represent an important component of the aggregate portfolio of financial intermediaries. The behavior of house prices, therefore, influences not only business cycle dynamics through their effect on aggregate expenditure, but also the performance of the financial system through their effect on the profitability and soundness of financial institutions (Tsatsaronis and Zhu 2004). Given its important role in the economy, the housing market is of central concern to monetary policy makers. To achieve the dual goals of promoting price stability and maximum sustainable employment, it is widely believed that monetary policy makers must understand the role that housing plays in the monetary transmission mechanism if they are to appropriately set policy instruments (Mishkin 2007). However, central banks debate whether using monetary policy to foster financial stability through house prices is advisable. Although a rise in interest rates tends to lower house prices, it may come at a significant cost through reduced economic output and inflation. This implies a very costly tradeoff when macroeconomic and financial stability goals are in conflict (Williams 2015).

The international research done on the effect of monetary policy on house prices is vast, but the VAR studies using Norwegian data are more limited. A common empirical finding regarding the impact of monetary policy on house prices, is that

policy actions have sizable and significant effects on house prices in advanced economies. That is, an increase in interest rates tends to lower real (inflation-adjusted) house prices. Assenmacher-Wesche and Gerlach (2008) used panel data from 18 OECD countries in a structural VAR to find the impact of monetary policy shocks on inflation, output and asset prices. Their results indicate that monetary policy has large and predictable effects on residential property prices, and that these effects are roughly coincident with its effect on real economic activity. More precisely, a 25-basis point increase in short-term interest rates reduced real GDP by about 0.125 percent and real residential property prices by about three times as much, or 0.375 percent, after one or two years. Empirical analyses performed on Norwegian data are consistent with these findings. Bjørnland and Jacobsen (2010) study the role of house prices in the monetary transmission mechanism in small open economies using structural VAR models. They found that house prices fall by 3-5 percent within the first quarter following a monetary policy shock that raises the interest rate by one percentage point. Robstad (2017) got similar results when investigating the responses of house prices and household credit to monetary policy shocks in Norway, using a number of Bayesian structural VAR models. His findings suggest that the effect of a monetary policy shock on house prices is large. However, the impact of the shock varies depending on the identification method used. He finds that the effect of monetary policy is amplified when using a Cholesky identification scheme with house prices ordered last and therefore argues that there are important contemporaneous effects of monetary policy on house prices. A contractionary monetary policy shock of one percentage point leads to 2-5 percent decline in house prices when house prices are ordered last, while the effect is only 0-3 percent when interest rate is ordered last.

2.4 Household Credit

Household borrowing has grown considerably in many countries over the past two decades, both in absolute terms and relative to household incomes. The extent of the increase in household borrowing has raised concerns about its sustainability and the possible implications for the financial system and the macroeconomy if it is not sustainable (BIS 2004). Household debt has been high on the policy agenda following the 2008 financial crisis (Gelain, Lansing and Natvik 2015) and it has also become an increasingly popular area of study. The findings regarding the

response of credit to a monetary policy shock are contradicting both theoretically and empirically.

The conventional view on the dynamics between the interest rate and credit level is that a monetary tightening will reduce the household's debt burden, leading to a decline in credit. The reason is that macroeconomic models typically assume that households refinance their debt each period, with the implication that the entire stock of debt responds swiftly to shocks and policy changes (Gelain, Lansing and Natvik 2015). In a case study of Sweden, Svensson (2014) argues that a higher policy rate has a negative impact on nominal debt as well as on the price level. Since real debt is the ratio between the two, and a higher policy rate has a negative impact on both, it is a priori likely that the impact of a higher policy rate is small. But it is not a priori obvious whether the impact will be positive or negative. That depends on the policy rate's relative impact on nominal debt and the price level. Svensson (2013b) shows that under assumptions that are realistic for Sweden, the policy rate should have a slower impact on nominal debt than on the price level, leading to an increase in real credit which challenges the conventional view. The reason for this is that only a limited fraction of the population adjust their stock of debt in any given period. Gelain, Lansing and Natvik (2015) study the interaction between monetary policy and household debt dynamics using a dynamic stochastic general equilibrium model and find that real credit increases following a monetary policy shock. They show that persistence is an important indisputable feature of debt and that credit responds more sluggishly to a monetary policy shock when long-term debt contracts are introduced. While Svensson finds that real debt and the debt-to-GDP ratio slowly move back to their initial levels after a few years, Gelain, Lansing and Natvik (2015) find that in the medium to long run the policy tightening is likely to cause a mild, but prolonged reduction of debt, more in line with the conventional view on the dynamics of debt. They argue that as inflation and output return to their steady state some time after the initial impulse, real debt and the debt-to-GDP ratio will drop moderately below their steady state levels, and then return to steady state only after a considerable period. One reason is that this response is heavily influenced by the amortization process of debt.

The empirical evidence on the household credit response of monetary policy provides support for both the conventional and the unconventional view. Bauer and

Granziera (2016) perform an empirical VAR study on data from 18 advanced economies and find that a tighter monetary policy increases real debt and debt-to-GDP in the short run. They argue that real private debt will rise on impact as nominal debt barely responds and inflation falls. Laséen and Strid (2013) use a Bayesian VAR model to study the effect of a monetary policy shock on Swedish data. They find that a contractionary monetary policy shock leads to a decline in real household debt, which supports the conventional view. To our knowledge, there exist only two papers studying the effect of a monetary policy shock on credit using Norwegian data. Robstad (2017) uses structural Bayesian VAR models and finds that a contractionary monetary policy shock leads to a modest and negative effect on real household credit. Assenmacher-Wesche and Gerlach (2008) perform a VAR study using data from 17 different countries including Norway and find that there is no significant effect on real credit after a monetary policy shock.

3.0 DATA

This chapter describes the variables we use in our high frequency identification method and in our VAR analysis. An overview of the sources we have used and the adjustments made to the variables can be found in Appendix A.1. The data includes measures of economic activity, domestic prices, asset prices, credit and interest rates. We analyze daily and monthly data over the period 2000:01 to 2016:12. This particular period is chosen because of the stable monetary policy regime and relatively low volatility in the financial market. A fairly stable monetary policy regime is essential when estimating the effects of a monetary policy shock (Robstad 2017). Policy shocks represent the random, unsystematic component of the monetary authorities' actions, which is difficult to measure if the anticipated, systematic behavior of the monetary authority is unstable (McCallum 1999).

3.1 High Frequent Data

In the high frequency section of our analysis we use intra-daily interest rate series which consist of a number of interest rate swaps and forward rate agreements.

Interest Rate Swaps

An interest rate swap (IRS) is an agreement between two counterparties in which one stream of future interest payments is exchanged for another based on a specified principal amount. Interest rate swaps usually involve the exchange of a fixed

interest rate for a floating rate or vice versa (Investopedia 2017b). The fixed rate in the agreement is often used as an indicator of market interest rate expectations. The interest rate swaps used in Norway have a maturity of one to ten years, and are related to the six-month Norwegian Interbank Offered Rate (NIBOR) (Bernhardsen 2011). We use the one-, two-, three-, five-, and ten-year interest rate swaps. The monthly averages of the one- and two-year rates are illustrated in Figure 8 in Appendix D.

Forward Rate Agreements

A forward rate agreement (FRA) reflects the expected money market rate and is a contract between a bank and a company. The bank provides the company in advance with an agreed rate on loans and investments, regardless of how the market fluctuates (DNB 2017). Three-month FRA rates are the most commonly used in Norway. They are quoted daily and apply for the three-month periods between International Money Market (IMM) dates (Bernhardsen 2011). IMM dates are the four quarterly dates of each year which most futures contracts and option contracts use as their scheduled maturity date or termination date (Syrstad and Rime 2014). The FRA rates are a measure of the market's expected three-month rate two days before the IMM date (Bernhardsen 2011) and are related to the three-month NIBOR. The FRAs we use are:

- The current three-month NIBOR rate (NOK3MD)
- The expected NIBOR rate at the next IMM date (NOK3F1)
- The expected NIBOR rate in two IMM dates from now (NOK3F2)
- The expected NIBOR rate in three IMM dates from now (NOK3F3)
- The expected NIBOR rate in four IMM dates from now (NOK3F4)

3.2 VAR Data

In our VAR analysis we include monthly data on both economic and financial variables, in addition to monthly averages of the daily interest rate data. Graphs and descriptive statistics of the variables can be found in Appendix A.2. We start off with a simple VAR model consisting of a measure of domestic prices, economic activity, the exchange rate and an interest rate. The variables are chosen in order to capture the monetary policy effects in a small open economy.

Inflation

Norway officially adopted inflation targeting in March 2001, where the inflation target was set to 2.5 percent. Since then, inflation has remained fairly stable. However, consumer price inflation volatility has been somewhat higher since the introduction of the inflation target than in the preceding ten years, reflecting an increase in energy price volatility in this period. Measured by the rise in the consumer price index adjusted for tax changes and excluding energy products (CPI-ATE), the increase in volatility is more modest (Norges Bank 2017b). When implementing monetary policy in Norway, the central bank considers in particular the development of the CPI-ATE as an indicator for the underlying inflation rate (Norges Bank 2004). We therefore use inflation as the annual growth rate of the CPI-ATE index in our VAR models, where the index is set to 2015 = 100. Alternatively, we could have used the monthly growth rate of CPI in the VAR. However, annual inflation is considered to be a more direct measure of the target rate of importance to the policymakers (Bjørnland and Jacobsen 2010).

The Unemployment Rate

The unemployment rate for people aged 15-74 is our measure of economic activity. The unemployment rate is a convenient indicator when using monthly data as it moves in a cyclical manner and is largely related to the general business cycle (Eurostat 2017). Norway has experienced increased unemployment over the past three years due to the decline in oil prices, slow economic growth and lower import growth. However, the unemployment rate in Norway is low compared to other European countries. The Norwegian labor market was affected by the recent financial crisis, yet the effects were comparatively mild (Trygstad and Olberg 2012). In our sample period the unemployment rate has a mean of 3.6 percent and a standard deviation of 0.65.

Exchange Rate

The period between December 1992 and March 2001 was a time of transition for monetary policy in Norway. Over that period, the Norwegian authorities moved away from the objective of maintaining a fixed exchange rate against a currency index, and replaced it with a floating exchange rate within an inflation targeting regime (Kleivset 2012). Since the Norwegian economy is small and very open, the krone exchange rate is of relatively great importance to economic development

(Bernhardsen and Røisland 2000). We use the import weighted nominal exchange rate index (I-44) as our exchange rate. The I-44 index is a nominal effective exchange rate index calculated on the basis of the NOK against the currencies of Norway's main trading partners, i.e. a geometrical average weighted with imports from the 44 main trading partners. The index is set at 1995 = 100 and a rising index value denotes a depreciating NOK (Norges Bank 2017). Due to low oil prices and low interest rates the past few years, the NOK has depreciated and the exchange rate index increased rapidly until it reached a level of 109 in January 2016. The index mean in our sample is 94, with a standard deviation of 5.98.

In our main model we include the variables house prices, household credit and a credit spread. We include these variables in order to address our question of interest and because asset prices and financial variables may have an important role in the transmission of monetary policy.

TED Spread

Our credit spread is the Norwegian TED spread. The TED spread is the difference between the three-month money market rate (NIBOR) and three-month treasury bills, and it explains how investors perceive risk (Bernhardsen 2011). Since the risk of a bank defaulting typically is higher than the risk of the government defaulting, the TED spread also measures the estimated risks that banks pose on each other. Consequently, the TED spread is an indicator of interbank credit risk and the perceived health of the banking system (Financial Times 2017). We include a credit spread in our analysis in order to test whether monetary policy operates through a credit channel. In our sample period the TED spread has a mean of 0.56 percent and a standard deviation of 0.34 percent. The spread reached its maximum level of 2.83 percent under the financial crisis in 2008, where both the NIBOR and the rate on treasury bills increased rapidly.

House Prices

As a measure of the price level of housing we use the house price index created by Eiendom Norge, Eiendomsverdi and Finn.no. The index is set to 2003M04=100 and is compiled after last month's end. It includes homes that are advertised on Finn.no and consist of approximately 70 percent of all houses sold in Norway during a year (Eiendom Norge 2017). The house price index has increased steadily over the

sample period with an increase of approximately 213 percent from January 2000 to December 2016, except for the temporary fall during the 2008 financial crises. The index reached its maximum level of 258 in December 2016 and exhibits high volatility with a standard deviation of approximately 48. The rapid increase in house prices over the past few years has become an important concern for policy makers.



Figure 1: House price index (untransformed). 2003=100. Monthly data 2000:M01-2016:M12

Household Credit

The credit measure we use in our main analysis is C2, which is an approximate measure of the magnitude of the gross domestic debt of the public, households, non-financial enterprises and general government, in NOK and foreign currency. The purpose of the indicator is to contribute to the basis of information for the monetary policy. It provides an overview of the development of credit at an early stage and is an important indicator of economic activity (SSB 2017). Since we are interested in the housing market in relation to the credit market, we decompose the credit indicator and focus on household credit alone. The household credit level experienced an all-time high in December 2016 with a credit level of 3.07 NOK billion, which is at the same time as the house price index reached its maximum level. The series has a mean of 1.79 NOK billion and a standard deviation of 0.69 NOK billion. To test whether different credit measures yield different results we also include C1, C2 and C3 for the general public. C1 is the indicator of the general public's gross domestic debt in NOK, while C3 gives an indication of the total gross debt, i.e. the sum of the public's gross domestic and gross external debt (SSB 2017b).

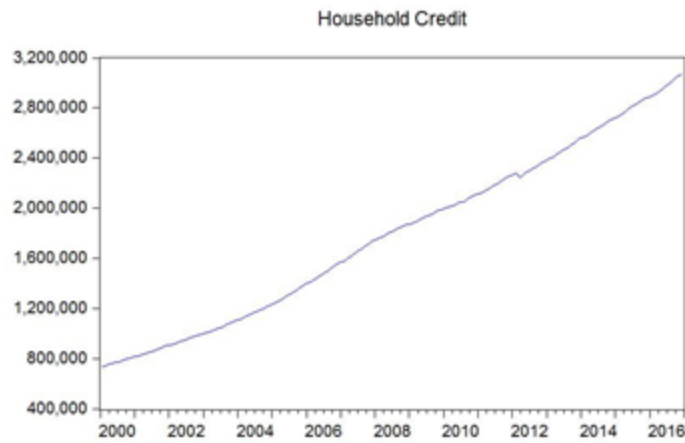


Figure 2: The credit indicator C2 for households (untransformed). Monthly data 2000:M01-2016:M12

We can as a preliminary observation see that most of the variables exhibit clear trends, which indicates non-stationarity. We use a Dickey-Fuller test to check whether the data contains a unit root and can confirm that all variables are nonstationary. A key question is how to specify a model when many of the variables may be trending. Sims et al. (1990) demonstrate that even when variables might have stochastic trends and might be cointegrated, the log levels specification will give consistent estimates. While one might be tempted to pretest the variables and impose the unit root and cointegration relationships to gain efficiency, Elliott (1998) shows that such a procedure can lead to large size distortions in theory (Ramey 2016). We therefore convert all variables except the interest rates and the TED spread into log levels, in addition to making sure that we are working with a stable model. As long as the estimated VAR model is stable, we can recover the moving average form of the model and perform a structural analysis without differencing the data first. To determine whether a given VAR model is stable or covariance-stationary, the effect of the shocks must eventually die out. This will be the case if the eigenvalues of the companion form matrix are all less than one in absolute value (Bjørnland and Thorsrud 2015).

4.0 METHODOLOGY

In this chapter we present our methodology. We begin with describing our VAR framework and the identification problem, followed by a description of the popular Cholesky identification method. We finalize the chapter with presenting our main approach, which involves high frequency identification and the use of forward rate agreement changes as external instruments.

4.1 The SVAR model

Our choice of model is a structural vector autoregressive (SVAR) model, which has become a popular tool in the analysis of the monetary transmission mechanism and sources of business cycle fluctuations (Gottschalk 2001). SVAR models were introduced in 1980 as an alternative to traditional large-scale macro-econometric models when the theoretical and empirical support for these models became increasingly doubtful (Kilian 2011). Macroeconomic models come in many forms and can vary a lot, not only in terms of the complexity of their representation of economies, but also in the way the quantitative measurements of causes and effects are obtained. A trade-off usually arises between theory and data when choosing a macroeconomic model. Calibrated models like real business cycle (RBC) models and dynamic stochastic general equilibrium (DSGE) models emphasize theory replication, while VAR models emphasize data replication (Bårdsen, Lindquist and Tsoyococ 2006). Although the use of estimated DSGE models has increased over the last decade, structural VAR models continue to be the workhorse of empirical macroeconomics and finance (Kilian 2011). VAR models are intended to represent a ‘true’ model of the economy. Since the sampling information alone does not reveal what the ‘truth’ is, some a priori held views have to be imposed to identify the empirical model and one has to take a stand on the way the economy works. From this standpoint the identifying restrictions are derived, and finally the corresponding empirical model is estimated. SVAR models differ in their approach to identification, and we must therefore review the identification problem that all empirical macroeconomic models have to confront in the estimation of structural parameters (Gottschalk 2001). The identification problem will be explained in further detail in section 4.1.1.

Central in the SVAR literature is the construction and interpretation of the impulse response function (IRF), which describes how a given structural shock affects a

variable over time. The forecast error variance decomposition (FEVD) assesses the importance of different shocks by determining the relative share of variance that each structural shock contributes to the total variance of each variable. Both the FEVD and the IRFs provide useful information to the researcher (Bjørnland and Thorsrud 2015). An important preliminary step in impulse response analysis is the selection of the VAR lag order (Ivanov and Kilian 2005). It is useful to start from the point where a fixed lag is used, which is when the lag length is set to coincide with the frequency of the data; e.g. 4 for quarterly data and 12 for monthly data. However, the fixed lag rule takes no account for the characteristics of the data and suffers from problems with size and/or power (Patterson 2011). In times series econometrics, alternative methods for determining the lag length are often based on minimizing an information criterion. Different information criterion functions evaluate the trade-off between increased model fit, by including more lags, and increased parameter uncertainty as the model becomes larger. Two popular information criterion functions are the Bayes and the Akaike information criterion (BIC and AIC). The BIC is more conservative, and will penalize the size of the model more than the AIC criterion. Thus, the BIC will generally suggest models with fewer lags than the AIC (Bjørnland and Thorsrud 2015). Ivanov and Kilian (2005) find that for structural and semi- structural impulse responses in monthly VAR models, the AIC tends to produce the most accurate impulse response estimates for all realistic sample sizes. We therefore follow the AIC when choosing the optimal number of lags.

4.1.1 Econometric Framework

The general structural form of the VAR we are considering is given by:

$$(1) \quad \mathbf{A}\mathbf{Y}_t = \sum_{j=1}^t \mathbf{C}_j \mathbf{Y}_{t-j} + \boldsymbol{\varepsilon}_t$$

\mathbf{Y}_t is a vector of economic and financial variables which we have discussed earlier, \mathbf{A} and \mathbf{C}_j $j = 1$ are conformable coefficient matrices, and $\boldsymbol{\varepsilon}_t$ is a vector of structural white noise shocks. To obtain the reduced form representation of the VAR we use that $\mathbf{B}_j = \mathbf{A}^{-1}\mathbf{C}_j$ and $\mathbf{S} = \mathbf{A}^{-1}$ and multiply each side of the equation by \mathbf{A}^{-1} , which yields:

$$(2) \quad \mathbf{Y}_t = \sum_{j=1}^t \mathbf{B}_j \mathbf{Y}_{t-j} + \mathbf{u}_t$$

where \mathbf{u}_t is the reduced form shock (Gertler and Karadi 2015). The reduced form VAR expresses each variable as a linear function of its own past values, the past values of all other variables being considered, and a serially uncorrelated error term. A VAR model which includes \mathbf{n} number of variables will generate \mathbf{n} numbers of equations. If the different variables in the VAR model are correlated with each other, as they typically are in macroeconomic applications, then the error terms in the reduced form model will also be correlated across equations (Stock and Watson 2001). This means that a shock in one variable is likely to be accompanied by a shock in another variable. To be able to do structural analysis and answer our research question, we need to make the shocks in the model uncorrelated (Bjørnland and Thorsrud 2015). The reduced form shock is given by the following function of the structural shocks:

$$(3) \quad \mathbf{u}_t = \mathbf{S}\boldsymbol{\varepsilon}_t$$

The variance-covariance matrix of the reduced form model equals.

$$(4) \quad E[\mathbf{u}\mathbf{u}'_t] = E[\mathbf{S}\boldsymbol{\varepsilon}\boldsymbol{\varepsilon}'_t] = \boldsymbol{\Sigma}$$

4.2 Cholesky Decomposition

The simplest and most popular way to identify the model and make the shocks uncorrelated is through Cholesky decomposition (Bjørnland and Thorsrud 2015), which we will use as a comparison to our main identification approach. It assumes a recursive structure for how the structural shocks affect the variables in the VAR system, and thereby facilitates identification. Recall from equation (3) that the reduced form shock is given by:

$$\mathbf{u}_t = \mathbf{S}\boldsymbol{\varepsilon}_t$$

To identify \mathbf{S} , the structural shocks are normalized so they all have unit variance (Bjørnland and Jacobsen 2009). The Cholesky decomposition method states that every positive definite symmetric matrix can be written as the product $\boldsymbol{\Sigma} = \mathbf{S}\mathbf{S}'$, where \mathbf{S} is the Cholesky decomposition of $\boldsymbol{\Sigma}$.

$$\mathbf{S}\mathbf{S}' = \boldsymbol{\Sigma} \quad \rightarrow \quad \begin{pmatrix} S_{11} & 0 & 0 \\ S_{21} & S_{22} & 0 \\ S_{31} & S_{32} & S_{33} \end{pmatrix} \begin{pmatrix} S_{11} & S_{21} & S_{31} \\ 0 & S_{22} & S_{32} \\ 0 & 0 & S_{33} \end{pmatrix} = \begin{pmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{12} & \sigma_{22} & \sigma_{23} \\ \sigma_{13} & \sigma_{23} & \sigma_{33} \end{pmatrix}$$

\mathbf{S} will be a lower triangular matrix with positive diagonal elements (and zero above the diagonal), while \mathbf{S}' is its conjugate transpose. Given that \mathbf{S} is a lower triangular matrix, the components of \mathbf{u}_t will now be uncorrelated, although the components of ε_t may not be (Bjørnland and Thorsrud 2015). The monetary policy shock is identified by placing direct restrictions on the impulse responses stemming from the structural shock.

$$\mathbf{Y}_t = \mathbf{B}\mathbf{Y}_{t-1} + \begin{pmatrix} S_{11} & 0 & 0 \\ S_{21} & S_{22} & 0 \\ S_{31} & S_{32} & S_{33} \end{pmatrix} \begin{pmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \\ \varepsilon_{3,t} \end{pmatrix} \rightarrow \mathbf{Y}_t = \mathbf{B}\mathbf{Y}_{t-1} + \mathbf{S}\varepsilon_t$$

The restrictions imply that the variable ordered on top will only react to its own shock in the first period, while the variable ordered on the bottom will react to all shocks. A question of ordering will therefore arise, where one should use economic theory to decide on the ordering of the variable or the type of restrictions imposed (Bjørnland and Thorsrud 2015).

The timing restrictions imposed in the Cholesky identification scheme may be reasonable for the interactions between interest rate and economic activity variables such as output and inflation. However, they are problematic once additional financial variables and asset prices are present. The problem is simultaneity: Within a period, policy shifts do not only influence financial variables, they may be responding to them as well. Even if the central bank is not directly responding to the financial indicators, it may be responding to underlying correlated variables left out of the VAR (Gertler and Karadi 2015). The Cholesky identification method is therefore not optimal when analyzing the joint response of economic and financial variables to monetary policy surprises and we will proceed to present our main identification method.

4.3 High Frequency Identification

Following the work of Gertler and Karadi (2015), our main approach involves combining the traditional VAR model analysis with high frequency identification (HFI). This hybrid approach employs HFI measures of policy changes as external instruments in a set of VARs to identify the effects of monetary policy shocks and is dictated by the need to identify policy changes that can be considered exogenous with respect to both economic and financial variables in the VAR. The HFI approach addresses the simultaneity issue by using intra-daily data. In particular,

we construct policy shocks that are changes in the interest rate forward agreements that occur on the day of a policy announcement from Norges Bank. To isolate the impact of news about monetary policy, we measure the changes within a 30-minute window of the announcement. More specifically, we look at the change in the forward rate agreements (FRAs) from 15 minutes before to 15 minutes after the announcement. Any changes in the FRAs within such a tight window surrounding the policy announcement are likely to reflect a pure monetary shock, while it is unlikely that any other events dominate fluctuations during this time period. We assume that all information that is public at the beginning of the 30-minute window is already incorporated into financial markets, and, therefore, does not show up as spurious variation in the monetary shock. Such spurious variation is an important concern in VARs (Nakamura and Steinsson 2016).

4.3.1 External Instrument Methodology

An increasingly important line of research in structural VARs uses information in variables not included in the system to identify structural impulse response functions. The narrative approach of Romer and Romer (1989) is the seminal reference in this literature. Their reading of the minutes of the Federal Reserve Board allowed them to pinpoint some moments at which monetary policy decisions were made in a way that they argued was exogenous, i.e. independent of other economic shocks at the time. A large number of subsequent papers have adopted their approach of obtaining external information to construct time series that the authors argue are exogenous. The standard implementation is to treat these constructed time series as shocks. However, these series are not, strictly speaking, the shocks of interest; rather, they are correlated with (or are pieces of) the actual shocks of interest, and are, the authors argue, uncorrelated with the other shocks in the economy. Because these constructed series are correlated with the shock of interest and are uncorrelated with the other structural shocks, it seems natural to treat the constructed time series as external instruments (Olea, Stock and Watson 2014).

In order to identify monetary policy shocks using external instruments, we use the reduced form representation of the VAR as our starting point. Recall from equation (3) that $\mathbf{u}_t = \mathbf{S}\varepsilon_t$. Let \mathbf{s} denote the column in matrix \mathbf{S} that corresponds to the impact on each element of the vector of reduced form residuals \mathbf{u}_t of the structural policy

shock ε_t^p . Accordingly, to compute the impulse responses to a monetary policy shock, we need to estimate:

$$(5) \quad \mathbf{Y}_t = \sum_{j=1}^t \mathbf{B}_j \mathbf{Y}_{t-j} + \mathbf{s} \varepsilon_t^p$$

Since we are not interested in computing the impulse responses to other shocks, we do not have to identify all the coefficients of \mathbf{S} , but rather only the elements of the column \mathbf{s} . In order to obtain estimates of the other coefficients in the VAR model we can simply use OLS estimation, but when we want to estimate the coefficients in \mathbf{s} we need some restrictions.

Let \mathbf{Z}_t be a vector of instrumental variables and let ε_t^q be a vector of structural shocks other than the policy shock. To be valid instruments for the policy shock, \mathbf{Z}_t must be correlated with ε_t^p but orthogonal to ε_t^q , as follows (Gertler and Karadi 2015):

$$(i) \quad E[\mathbf{Z}_t \varepsilon_t^p] = \phi$$

$$(ii) \quad E[\mathbf{Z}_t \varepsilon_t^q] = 0$$

Condition (i) requires that at least one element of \mathbf{Z}_t , i.e. at least one of the instruments, is correlated with ε_t^p , meaning that \mathbf{Z}_t is relevant. Condition (ii) requires that \mathbf{Z}_t is uncorrelated with all other structural shocks so that \mathbf{Z}_t is exogenous. These conditions are almost the standard conditions for a valid instrument – almost because ε_t^p is unobserved, whereas the standard relevance condition is stated in terms of the covariance between two observables (Olea, Stock and Watson 2012). In the extreme case where the relevance condition does not hold, the instrument estimation will not be a consistent estimator and we would not be able to identify the parameters of interest. Generally however, instruments that explain little of the variation in the endogenous regressors are called weak instruments. A weak instrument poses a serious threat to the validity of the regression and can create inconsistent or unreliable estimates. The relevance of the instrument can be computed by an F-test in the first stage of the two stage least squares (TSLS) procedure. The first stage F-test provides a measure of the information content of the instruments in explaining the endogenous regressor. The more information, the higher the F-statistic (Bjørnland and Thorsrud 2015). Stock,

Yogo and Wright (2002) find that the first-stage F-statistic must be large, typically exceeding 10, for TSLS inference to be reliable.

If we have instruments that satisfy the relevance and exogeneity conditions, we can obtain estimates of the elements in the vector \mathbf{s} in equation (5). First, we obtain estimates of the reduced form residuals \mathbf{u}_t from the ordinary least squares regression of the reduced form VAR. Then let u_t^p be the reduced form residual from the equation for the policy indicator and let \mathbf{u}_t^q be the reduced form residual from the equation for the other variables $q \neq p$. Also, let $s^q \in \mathbf{s}$ be the response of \mathbf{u}_t^q to a unit increase in the policy shock ε_t^p . Then we can obtain an estimate of the ratio s^q/s^p from the two-stage least squares regression of \mathbf{u}_t^q on u_t^p , using the instrument set \mathbf{Z}_t . Intuitively, the first stage isolates the variation in the reduced form residual for the policy indicator that is due to the structural policy shock. It does so by regressing u_t^p on \mathbf{Z}_t to form the fitted value \hat{u}_t^p . Given that the variation in \hat{u}_t^p is due only to ε_t^p , the second stage regression of \mathbf{u}_t^q on \hat{u}_t^p then yields a consistent estimate of s^q/s^p

$$(6) \quad \mathbf{u}_t^q = (s^q/s^p) \hat{u}_t^p + \xi_t,$$

where \hat{u}_t^p is orthogonal to the error term ξ_t , given the assumption of condition (ii) that \mathbf{Z}_t is orthogonal to all the structural shocks other than the shock to the policy indicator ε_t^p . An estimate for s^p is then derived from the estimated reduced form variance-covariance matrix using equations (4) and (6). We are then able to identify s^q . Given estimates of s^p , s^q and \mathbf{B}_j , we can use equation (5) to compute responses to monetary policy surprises (Gertler and Karadi 2015).

4.3.2 Estimating the Surprise, the Policy Indicator and the Instrument

The potential instruments we use to identify monetary policy shocks consist of changes in forward rate agreements on policy announcement days. We consider five different instruments and will ultimately choose only one based on the performance of the variables as external instruments in the VAR analysis, which is illustrated in section 5.1. To ensure that the changes in forward rates reflect only news about the policy decision, we measure these shocks within a 30-minute window of the announcement. We can express the changes in the forward rates as follows:

$$(7) \quad F_{\text{Change}} = F_{15 \text{ min post}} - F_{15 \text{ min prior}}$$

We also consider two different long-term market interest rates as indicators for monetary policy. The use of an external instrument is assumed to isolate the variation in the policy indicator that is due to unanticipated monetary policy shocks. In order to evaluate our choice of a policy indicator along with instruments for policy shocks, we examine the daily response of four long-term interest rate swaps to surprises in two policy indicators, using the changes from equation (7) as instruments. We therefore transform the intra-daily time series into a daily time series by subtracting the IRS at 5PM the day before the announcement from the IRS at 5PM the day of the announcement. We chose 5PM to capture the workday response of the policy announcement. This exercise allows us to analyze the implications of different policy indicators and instruments for market interest rates in a setting where all the instruments have good explanatory power. This then sets the stage for an evaluation of which variables to include as indicator and instrument in the VAR analysis that follows.

Let i_t^n be the interest rate on an n month interest rate swap (IRS) that serves as the policy indicator, let ΔR_t be the change in a long-term IRS on a policy announcement day, and let $(i_t^n)^u$ be the same-day unanticipated movement in i_t^n . Accordingly, the equation we consider relates ΔR_t to $(i_t^n)^u$ as follows (Gertler and Karadi 2015):

$$(8) \quad \Delta R_t = \alpha + \beta(i_t^n)^u + \varepsilon_t$$

We estimate the equation using two-stage least squares with various interest rate forward agreements as instruments. A problem with equation (8) is that ΔR_t and $(i_t^n)^u$ may be simultaneously responding to news that is not related to monetary policy. However, changes in expectations about future interest rates using a tight enough window around monetary events should be dominated by the information about monetary policy (Cesa-Bianchi, Thwaites and Vicendoa 2016). The instrumental variables estimation isolates the variation in the policy indicator i_t^n that is caused purely by monetary policy surprises and orthogonal to the error term ε_t . This will give us consistent estimates of β .

5.0 RESULTS

In this chapter we present our results where we begin with an analysis of our policy indicator and instrument choice. We then use a simple VAR to illustrate how the external instrument approach works and how it compares to the Cholesky identification. This is followed by our main analysis of the impact of monetary policy on house prices and household credit, before we evaluate different measures of credit. We conclude this chapter with four robustness exercises where we first replace the policy indicator and instrument in our simple VAR. Next, we show that our main model is robust to alternative model specifications, where we estimate a number of candidate VARs and compare their performance. We then substitute annual inflation with CPI-ATE in our main model, followed by a robustness check with various lag lengths.

5.1 Policy Indicator and Instrument Choice

In order to choose the appropriate policy indicator and instrument for policy shocks that we ultimately use in the monthly VAR, we begin with a high frequency variant of the external instruments approach where we examine the daily response of various long-term interest rate swaps using equation (7) and (8). This exercise allows us to analyze the impact of the policy indicators on different long-term market interest rates, using different instruments. The policy indicators we consider are the one and two-year interest rate swaps (IRS) which are related to the six month NIBOR. We also consider five instruments, namely the 3MD, 3F1, 3F2, 3F3 and 3F4 as explained earlier in the data chapter. The dependent variables in the regressions are the two, three, five and ten-year IRS'. Beyond being key to our specific VAR analysis that follows, the results regarding the optimal policy indicator and instrument could be useful for later studies using the HFI approach on Norwegian data.

Table 1 presents the results². The dependent variable in each regression is the one-day change in the variable stated at the top of each column in the table. The independent variable, which is placed first in the left column, is the high frequency change in the policy indicator, computed using different FRA rates as instruments. The coefficients represent the impact of a 100-basis point increase in a given policy

²Table 1 is equivalent to Gertler and Karadi's (2015) Table 1 on page 57

indicator on a corresponding long-term interest rate, which is due to an exogenous monetary policy shock. All the coefficients are significant at the 1 percent level.

Table 1: Interest rate effect of monetary policy shocks (Daily, 2000-2017)

Indicator and instruments	2-year	3-year	5-year	10-year
1YR, 3MD	0.920028 (0.074225)	0.852068 (0.076011)	0.677438 (0.071393)	0.519556 (0.077300)
1YR, 3F1	1.038083 (0.050570)	0.955769 (0.051427)	0.697373 (0.048447)	0.477465 (0.052485)
1YR, 3F2	1.020923 (0.051104)	0.932945 (0.052035)	0.675863 (0.049284)	0.440575 (0.053596)
1YR, 3F3	1.017752 (0.051453)	0.937540 (0.052453)	0.688548 (0.049584)	0.451146 (0.053876)
1YR, 3F4	1.061097 (0.053140)	0.978185 (0.053894)	0.724158 (0.050535)	0.483091 (0.054667)
2YR, 3MD		0.926132 (0.030119)	0.736323 (0.057536)	0.564717 (0.075399)
2YR, 3F1		0.920706 (0.018209)	0.671790 (0.034800)	0.459949 (0.045086)
2YR, 3F2		0.913825 (0.018914)	0.662011 (0.036095)	0.431545 (0.047038)
2YR, 3F3		0.921187 (0.018992)	0.676538 (0.036242)	0.443277 (0.047305)
2YR, 3F4		0.921862 (0.018545)	0.682461 (0.035334)	0.455275 (0.046020)

Note: standard errors in parentheses and all the coefficients are significant at the 1 percent level

From Table 1 we can see that the interest rate effects of monetary policy shocks appear to be more persistent with the one-year rate as the policy indicator than with the two-year rate. Overall, the effects also appear to be stronger when we use the one-year rate as the policy indicator which is quite surprising because one would expect the two-year rate to have a stronger impact on changes in long-term IRS' than the one-year rate. The effects with the one-year rate as the policy indicator are stronger when instrumented by 3F4 but more persistent when instrumented by 3MD. We can see that 3MD has the strongest effect when we use the two-year rate as the policy indicator. Although Table 1 shows that the potential indicators and instruments all have a large and significant impact on long-term market rates, it seems difficult to draw a clear conclusion regarding a choice of a policy indicator and instrument purely on the basis of the high frequency variant of the external instruments approach.

Next, we will turn to the issue of policy indicator and instrument choice in the monthly VAR. From Table 1, it seems possible to use both the one-year rate and the two-year rate interchangeably with high frequent dependent variables. This appears to not be the case for the monthly VAR. Table 2 summarizes the results from the first stage regression residual of a particular policy indicator regressed on the different instruments. The residuals are computed from the simple VAR including inflation, unemployment, a policy indicator and the exchange rate. The upper half of the table consider the one-year rate as the policy indicator, while the lower half consider the two-year rate. The R^2 and the F-statistic for each regression are reported at the bottom of the corresponding column.

Table 2: Effects of high-frequency instruments on the first stage residuals of the four variable VAR including inflation, unemployment, a policy indicator and the exchange rate (Monthly, 2000-2016).

Instrument	1-year (1)	1-year (2)	1-year (3)	1-year (4)	1-year (5)
3MD	0.5605*** (3.3036)				
3F1		0.5421*** (3.0727)			
3F2			0.3204* (1.9203)		
3F3				0.3657** (2.2192)	
3F4					0.4297*** (2.7679)
Observations	132	132	132	132	132
R²	0.0775	0.0677	0.0276	0.0365	0.0557
F - statistic	10.9141	9.4412	3.6875	4.9247	7.6614

Instrument	2-year (6)	2-year (7)	2-year (8)	2-year (9)	2-year (10)
3MD	0.7550 (1.4663)				
3F1		0.3287* (1.6991)			
3F2			0.0876 (0.4838)		
3F3				0.1070 (0.5964)	
3F4					0.2098 (1.2339)
Observations	132	132	132	132	132
R²	0.0163	0.0217	0.0018	0.0027	0.0116
F - statistic	2.1502	2.8868	0.234	0.3556	1.5226

Note: *t*-statistics in parentheses

Significant at the 1 percent level (***)

Significant at the 5 percent level (**)

Significant at the 10 percent level (*)

From Table 2 we can see that the one-year rate appears to be the preferred policy indicator, where three of the coefficients are significant at the 1 percent level. The instrument that works best is 3MD, which explains 7.25 percent of monthly innovation in the one-year rate. Table 2 shows that only one of the instruments for the one-year rate has an F-statistic above the recommended threshold of 10, which is 3MD with an F-statistic of 10.08. For the two-year rate, none of the instrument combinations meets the recommended threshold. The results from Table 1 and 2 leads us to choose the one-year rate as the policy indicator and the current money market rate change (NOK3MD) as the instrument. The monthly averages are illustrated below. This means that we can now estimate our monthly VAR using the external instrument approach in a setting where there is unlikely to be a weak instrument problem.

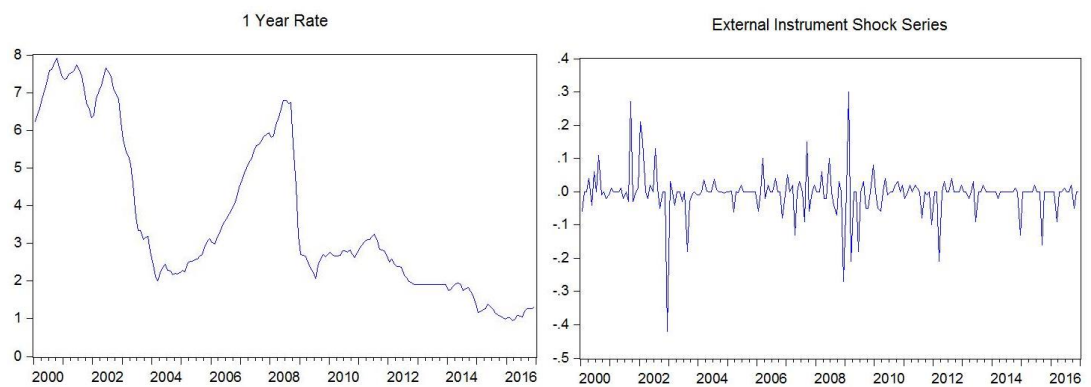


Figure 3: Left: The one-year interest rate swap, in percent. Monthly average of the daily series 2000:M01 - 2016:M12. Right: NOK3MD change around policy announcements. Monthly average of the daily series. 2000:M01-2016:M12.

5.2 Results From the Simple VAR

In this section we illustrate how the external instrument approach works, as well as how it compares to the popular Cholesky identification. We construct a simple VAR model that will help us evaluate whether the external instrument approach gives results that are in line with economic theory and common empirical findings regarding the monetary policy transmission mechanism. The simple VAR includes the variables inflation, unemployment, one-year rate and the exchange rate. The inflation rate and the unemployment rate allow us to identify the response of a monetary policy surprise on the macroeconomy. Considering that Norway is a small open economy, it is also plausible to include the exchange rate because it plays a

significant part in the formulation of monetary policy (being an important influence on the overall level of price), and is itself also influenced by monetary policy (Bjørnland and Jacobsen 2009). Under the Cholesky scheme we consider, inflation is ordered first followed by unemployment, the one-year rate and the exchange rate. It is common to order the interest rate last under the assumption that monetary policy responds to all variables contemporaneously and that the other variables react with a lag (Robstad 2017). However, when the VAR methodology is applied to an open economy framework, additional complications arise. On the one hand, the exchange rate is an important transmission channel for shocks that the central bank may want to respond to. It is also a forward-looking asset price that will reflect expected future return on the asset. Hence, it should be ordered above the interest rate. At the same time, the exchange rate is an asset price, which like any asset price reacts immediately to news. Hence, it should be ordered below the interest rate in the Cholesky ordering (Bjørnland and Thorsrud 2015). The simultaneous relation between monetary policy and the exchange rate innovations makes it difficult to correctly identify monetary policy shocks only by means of recursiveness assumptions (Bagliano and Favero 1999). The problem of potential simultaneity between exchange rates and interest rates has not yet been resolved convincingly in the empirical VAR literature, nor is it clear whether the problem is empirically relevant (Bagliano, Favero and Franco 1999). We follow the traditional approach for open economy VAR models with recursive ordering and place the exchange rate last, assuming a lagged response in monetary policy to exchange rate shocks (Eichenbaum and Evans 1995).

Figure 3 shows the impulse responses of from the simple VAR. The left panel shows the case where policy shocks are identified using standard Cholesky identification, while the panel on the right shows the case using the external instrument approach. The panels report the estimated impulse responses along with 95 percent confidence bands, computed using wild bootstrap that generates valid confidence bands under heteroscedasticity and strong instruments (Gertler and Karadi 2015). Table 4 in Appendix B presents different information criterion tests for lag length in the simple VAR. The Akaike information criterion (AIC) recommends four lags, while the Schwarz information criterion (BIC) recommends only two lags. Ivanov and Kilian (2005) find that for structural and semi- structural impulse responses in monthly VAR models, the AIC tends to produce the most

accurate impulse response estimates for all realistic sample sizes. Considering that two lags seems to be very small in a model using monthly data, combined with the findings of Ivanov and Kilian, we follow the AIC when choosing the optimal number of lags. In order to test if the model is correctly specified, we must check if the residuals are white noise, that is, uncorrelated (Escanciano, Lobato and Zhu 2013). We use autocorrelation with a 99 percent confidence interval to analyze the residuals of a least squares fit to noisy data. As seen in Figure 13 in Appendix B, there is some residual autocorrelation at the lag length of four. However, it is only statistically significant for the residuals at lag zero. From this, we can conclude that the residuals are white noise.

As stated earlier, we use the change in the current three-month forward rate agreement to identify the monetary policy shock in the external instrument approach. In order to ensure that the instrument remains valid in the alternative specifications we report the F-statistic from the first stage regression of the one-year rate on the instrument. We find an F-value of approximately 13, which is above the recommended threshold value of 10. We must also determine whether the VAR model is stable or covariance-stationary where the effect of the shocks eventually die out. This will be the case if the eigenvalues of the companion form matrix are all less than one in absolute value (Bjørnland and Thorsrud 2015). In our model the maximum eigenvalue is 0.9810 and the model is therefore stable.

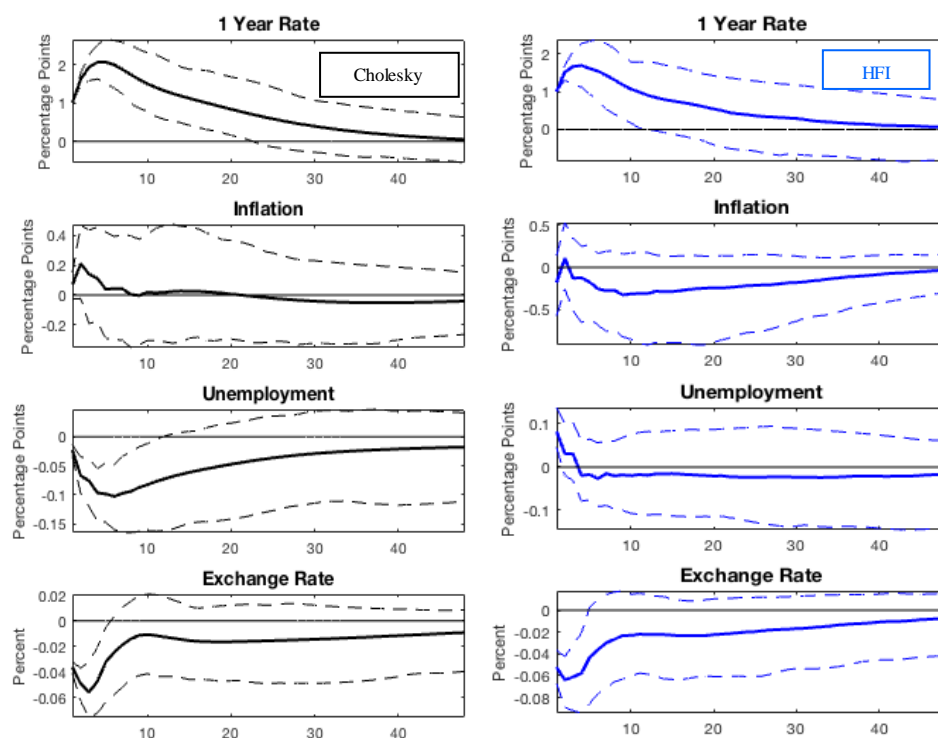


Figure 4: Impulse response functions to a monetary policy shock. VAR estimated in log levels with 4 lags and a constant over the period 2000:01-2016:12. The VAR includes the variables one-year rate, inflation, unemployment and exchange rate. The left panel is specified with a recursive identification where the exchange rate is ordered last. The right panel uses the external instrument approach where the one-year rate is instrumented NOK3MD. The one-year rate, inflation and unemployment are measured in percentage points, while the exchange rate is measured in percent. The IRFs are estimated using 48 steps. The first stage results are F-statistic: 12.9137 and R^2 : 6.12 percent. The solid lines are median estimates, while the dotted lines report the 95% confidence intervals computed using wild bootstrap with 200 replications.

The first impulse responses show that a one percentage point surprise monetary tightening induces a roughly two percentage point increase in the one-year rate. An interesting observation is that the HFI and Cholesky case produce fairly similar movements in the impulse responses. This is quite surprising considering that we have used two different identification methods. Despite the similarities between the impulse response functions, the responses are not identical. Both Cholesky and HFI yield a small price puzzle where an increase in the interest rate leads to an increase in inflation, which is a contradiction to the standard theoretical prediction. The price puzzle in the Cholesky case lasts approximately 5 months and then dies out, implying that the effects of a monetary policy shock are short lived. With the external instrument approach the price puzzle is close to eliminated, where the overall effect is negative. As mentioned in chapter 2, Sims (1992) argues that a price puzzle may be a result of the authorities attempting to dampen the effect of anticipated inflationary pressure. Prices will then rise after the monetary contraction, though by less than they would have without the contraction. Based on the argument put forth by Sims (1992), it is possible that the Cholesky identification

scheme captures more of the systematic element of monetary policy than does the HFI approach. Gertler and Karadi (2015) managed to eliminate the price puzzle in the external instruments case. However, considering that they studied the effects of a monetary policy shock in the U.S., which is considered to be a closed economy, it is likely that the difference reflects the fact that open economy VAR models often yield price puzzles (Jacobson et. al. 2002).

The two identification methods yield different responses of unemployment to a contractionary monetary policy shock. In the Cholesky case there is an immediate decline that reaches -0.1 percentage points after approximately six months and the effect appears to be quite persistent. The argument put forth by Sims (1992) regarding the occurrence of a price puzzle may also be of relevance in this case. The unemployment rate is largely related to the general business cycle and therefore an indicator of economic activity. A low level of unemployment may imply that the economy is in an upturn which the monetary authorities wishes to dampen. If so, it is, as in the case of inflation, possible that the shocks in the Cholesky identification scheme capture the systematic monetary policy. The HFI approach on the other hand yields an initial positive response of approximately 0.1 percentage points which is consistent with economic theory. Although the effect appears to become slightly negative after approximately six months, we can see that there is higher uncertainty associated with the decline. The response of unemployment using the HFI approach appears to be lower and less persistent than what is found in previous empirical studies. This finding is more in line with the widely-spread belief among economists that monetary policy has relatively short-lived effects on unemployment. According to Alexius and Holmlund (2007), a contractionary monetary policy shock has a positive and long-lived effect on unemployment in Sweden. They find that between 22 and 35 percent of the fluctuations in unemployment are caused by shocks to monetary policy. From the variance decomposition in Appendix C we can see that approximately 10 percent of the variation in unemployment is explained by shocks to monetary policy. We can also see from Figure 17 in Appendix D that the Swedish unemployment rate appears to be of a more volatile nature than in Norway, which gives us reason to believe that the Norwegian unemployment rate is less sensitive to monetary policy shocks. It is therefore reasonable that the impulse response in our study yields a lower effect following a monetary policy shock.

Consistent with Dornbusch's (1976) exchange rate overshooting hypothesis, we can see that an increase in the interest rate causes the nominal exchange rate to appreciate instantaneously in both cases, for then to depreciate in line with uncovered interest parity. The movements of the effects appear to be nearly identical in both cases, although the effect in the external instrument case is slightly higher than in the Cholesky case. To investigate the significance of Cholesky ordering, we also tried ordering the interest rate last under the assumption that monetary policy responds to all variables contemporaneously and that the contemporaneous effect of monetary policy is zero for all variables. The results can be found in Figure 18 in Appendix D and show that the exchange rate yields puzzling cyclical behavior. Bjørnland (2008) found evidence of an exchange rate puzzle when using the Cholesky scheme both when the interest rate was ordered last and when the exchange rate was ordered last. However, her findings were consistent with the Dornbusch exchange rate overshooting hypothesis once she allowed for full simultaneity between monetary policy and the exchange rate. We therefore have reason to believe that identifying monetary policy shocks only by means of recursiveness assumptions is not sufficient.

Despite the similarities between the movements of the impulse responses in both cases, we question how well the Cholesky identification is able to identify a pure monetary policy shock. We can see that the method results in a more significant price puzzle and that it contradicts economic theory regarding the responses of unemployment, which could imply that the shocks in the Cholesky case are more influenced by systematic monetary policy than the HFI case. There is also an issue of how to properly address the simultaneity between monetary policy and the exchange rate. The reason is that monetary policy and the exchange rate react to news in each other and it is therefore not clear which variable should be ordered last (Bjørnland 2008). For these reasons we conclude that the conventional timing restrictions do not work well when examining the joint response of economic variables and asset prices. The external instruments approach appears to be better suited in this setting and we will therefore proceed to use only HFI in our main model.

5.3 Results From the Main Model

In this section we present our main model using the external instrument approach. The variables included in the model are the one-year rate, inflation, the exchange rate, the TED spread, real house prices and real household credit. The inclusion of these variables allows us to answer our question of interest, namely how house prices and household credit respond to exogenous surprises in monetary policy. We also investigate alternative measures of credit in order to obtain a deeper understanding of the overall responses of credit. Figure 4 shows the results from the model, where the impulse responses are reported along with 95 percent confidence bands and computed using wild bootstrap. For all impulse responses the initial interest rate response of the yearly interest rate is normalized to one percentage point. As in the simple VAR we follow the AIC which leads us to choose three lags³. The information criterion tests for lag length in the main model are found in Table 5 in Appendix B. The residual autocorrelation is also plotted in Appendix B and is tested up to a lag length of 20. The autocorrelation values exceed the 99 percent confidence bands for a white noise autocorrelation at zero and 13 lags, implying that there is some residual autocorrelation. However, the required assumptions for statistical inference are still largely valid for our model with three lags. The eigenvalues of the companion form matrix are 0.9896 and less than one in absolute value, which means that the model is stable. By including house prices and household credit in our main model, the first stage regression results became slightly lower with an R^2 of 5.58 percent and an F-statistic of 11.7532. However, the F-statistic is still above the recommended threshold value of 10.

³ In section 5.4 we check that our results are robust to changing lag length to 6, 9 and 12.

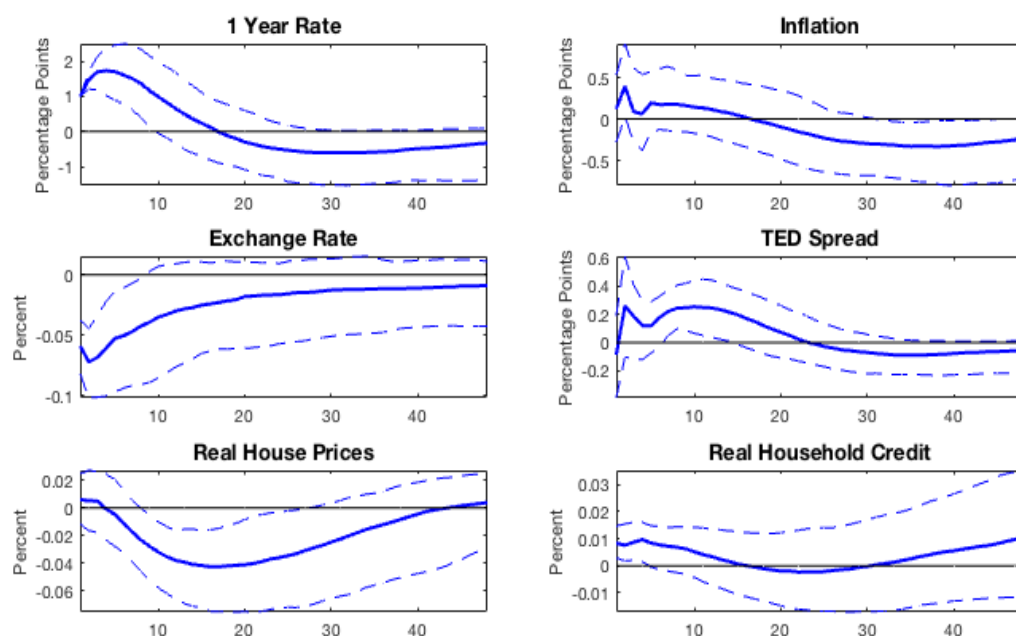


Figure 5: Impulse response functions to a monetary policy shock - main model using the external instrument approach. VAR estimated in log levels with 3 lags and a constant over the period 2000:01-2016:12. The VAR includes the variables one-year rate, inflation, exchange rate, TED spread, house prices and household credit. The one-year rate is instrumented using NOK3MD. The one-year rate, inflation and TED spread are measured in percentage points, while the exchange rate, house prices and household credit are measured in percent. The IRFs are estimated using 48 steps. The first stage results are F-statistic: 11.7532 and R²: 5.58 percent. The solid lines are median estimates, while the dotted lines report the 95% confidence intervals computed using wild bootstrap with 200 replications.

In the simple VAR we found that the price puzzle was almost eliminated when using the external instrument approach. In our main model we find that a monetary tightening of one percentage point leads to a price puzzle which lasts approximately 1.5 years. After this point inflation falls below zero and reaches a level of -0.25 percentage points. Bjørnland and Jacobsen (2010) show that by adding just a few series of relevant forward-looking asset prices and using an identification that allows for contemporaneous interaction between monetary policy and these asset prices, they were able to reduce the price puzzle. One would think that this would be the case when adding house prices to our model. However, the impulse responses show an increased price puzzle. One observation is that the responses of inflation and the TED spread show a similar pattern. It is therefore possible that the inclusion of the TED spread can, at least partially, explain the increase.

The TED spread is a measure of the spread between yields on private versus public debt. We include the spread in our analysis in order to investigate whether monetary policy operates through a credit channel. Gertler and Karadi (2015) find that a one standard deviation surprise monetary tightening induces a roughly 0.1 percentage

point increase in the excess bond premium. We find that the response of the Norwegian TED spread is positive in the medium to long run where a one percentage point surprise monetary tightening leads to an increase of approximately 0.25 percentage points. This result is consistent with previous empirical evidence regarding the response of credit spreads and confirms one important result put forth by Gertler and Karadi; that monetary policy operates through a credit channel. With a credit channel present, a monetary tightening not only raises government bond rates but also the external finance premium, which amplifies the overall effect of the policy action on private borrowing rates (Gertler and Karadi 2015). According to economic theory, the credit spread arises due to credit market frictions and agency costs associated with information asymmetries and the inability of lenders to monitor borrowers costlessly (Walsh 2010).

The behavior of house prices in response to a surprise monetary tightening is consistent with the common empirical finding that monetary policy actions have sizable and significant effects on house prices in advanced economies. That is, an increase in interest rates tends to lower real (inflation-adjusted) house prices (Williams 2015). Following the immediate effect, house prices fall by approximately 4 percent after 1.5 years. After two years it begins converging back to its initial level, which happens around the same time that the initial effect on the one-year rate dies out and reaches a level below zero. The effect on house prices seems to be statistically significant the first year. However, after one year the probability bands are wide, emphasizing the uncertainty in the responses. From the variance decomposition in Figure 15 in Appendix C we can see that the relevance of the interest rate in explaining the variation in house prices is 40 percent after two years. We can also see that the interest rate shock has a larger impact on the variation in house prices than on any other variable in the main model. Our findings are consistent with similar studies performed on Norwegian data. Bjørnland and Jacobsen (2010) found that house prices fall by by 3-5 percent within the first quarter following a monetary policy shock that raises the interest rate by one percentage point. Robstad (2017) got similar results, although the responses of house prices varied depending on the identification method used. He also found that the effect is relatively large compared to similar VAR-studies using international data, which he justifies with the fact that the Norwegian housing market exhibits

more short run fluctuations than many other countries. The volatile nature of the Norwegian housing market is illustrated in Figure 19 in Appendix D.

The conventional view on the dynamics between the interest rate and credit level is that a monetary tightening leads to a decline in credit. However, previous empirical research has resulted in many opposing views and findings on the qualitative effects of monetary policy shocks on credit. We find a modest effect of a contractionary monetary policy shock on the real value of household credit. The immediate effect is a one percent increase, which returns to its initial level after 1.5 years. After this point the effect becomes slightly negative with increased uncertainty in the responses, followed by an increase. To our knowledge there exist only two VAR studies using Norwegian credit data. Assenmacher-Wesche and Gerlach (2008) find no significant effect on real credit in Norway while Robstad (2017) finds a modest negative effect of 0-1.75 percent. These findings are consistent with our results regarding a modest response of credit. However, we find that the response of credit moves in the opposite direction, which provides support for the unconventional view. Svensson (2014) argues that it is not a priori obvious whether the impact of a monetary policy tightening will be positive or negative because the direction of the response depends on the policy rate's relative impact on nominal debt and the price level. Through the use of a theoretical model, Svensson (2014) and Gelain, Lansing and Natvik (2015) find that the real credit level should increase after a contractionary monetary policy shock. The reason for this is that only a limited fraction of the population adjust their stock of debt in any given period, which indicates that the policy rate should have a slower impact on nominal debt than on the price level. Although real household credit increases in our model in the short run, the mechanisms behind the response must be different than the argument put forth by Svensson (2014) stating that the effect on both nominal debt and the price level should be negative. Our impulse responses yield a price puzzle, which means that the increase in real household credit cannot be driven by a decrease in the price level. We therefore believe that nominal debt must increase in the short run and that it must increase more rapidly than the price level. As mentioned previously in this chapter, it is likely that the monetary authorities increase the interest rate when the economy is in an upturn as an attempt to dampen the risk of financial imbalances. It is plausible that the credit level is high, or at least increasing, at the time of the monetary tightening. Considering that a large part of the household's credit level is

given by decisions made in the past, and will not be directly influenced by the borrowing constraint today (Gelain, Lansing and Natvik 2015), it is not unlikely that nominal debt can continue to increase for some time after the interest rate increase. As the nominal credit level is assumed to ultimately decrease after the monetary tightening, we believe that the slow adjustment of households to the interest rate change could be a reflection of a relatively slow refinancing rate of debt in Norway.

A link between credit and house prices may arise via housing wealth and collateral effects on credit demand and credit supply and via repercussions of credit supply fluctuations on house prices (Goodhart and Hofmann 2008). As opposed to real house prices, the response we find on real household credit to a monetary policy shock is relatively small. House prices, like other asset prices tend to react quickly to news such as monetary policy announcements (Bjørnland and Jacobsen 2010). Household credit, on the other hand seem to react more slowly to news, which indicates that the spillovers from short run fluctuations in house prices to aggregate household credit is small in Norway. The variance decomposition in Figure 16 in Appendix C confirms that the relevance of house prices in explaining the variation in household credit is small, where house prices explain only 5-15 percent of the variation in household credit. This observation is somewhat surprising considering that a dominant share of debt in Norwegian households is mortgage loans (Norges Bank 2016). However, it is reasonable to believe that both the effect of a monetary policy shock and the spillovers from the housing market will have a higher influence on the households that are currently looking to buy a house. Given that only new loans respond on impact and that these loans constitute a small fraction of total debt, the monthly aggregate effect will appear to be low (Gelain, Lansing and Natvik 2015).

Due to the controversy regarding the response of credit to a monetary policy shock, we will proceed to examine the responses of three additional credit measures. We do this by substituting household C2 with the additional credit measures one by one, keeping the rest of the model unchanged. The credit measures we test are C1, C2 and C3 for the general public, also called total. The inclusion of these variables gives us a broader understanding of the overall effects of an interest rate increase on credit. The results of the first stage regression are presented below the figures and we can see that all F-statistics are above the recommended threshold of 10.

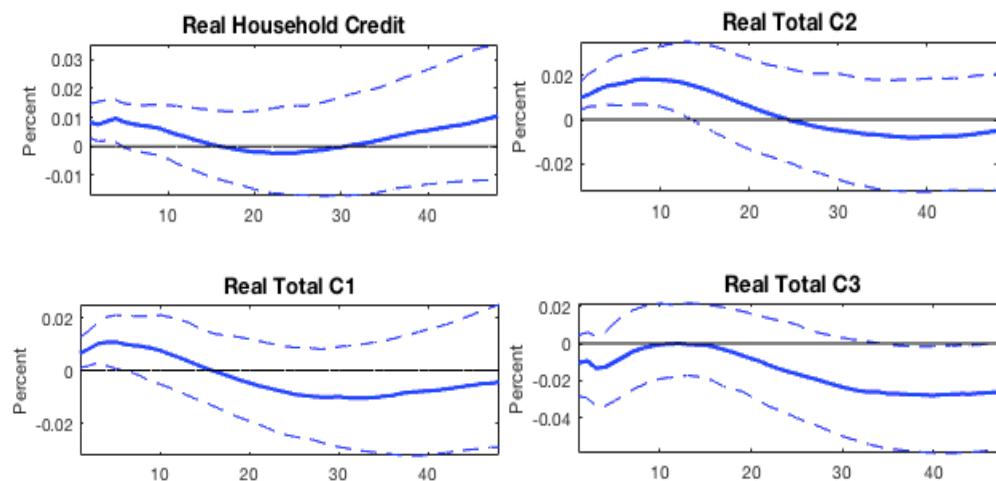


Figure 6: Impulse response functions to a monetary policy shock on four additional credit measures - external instrument approach. VAR estimated in log levels with 3 lags, and a constant over the period 2000:01-2016:12. Both models include the variables one-year rate, inflation rate, the exchange rate, house prices and the TED spread. The one-year rate is instrumented using the current three-month NIBOR forward rate agreement. The first stage results for C1, C2 and C3 for the general public are: F-statistics of 12.2237, 11.6053 and 11.0475 and an R^2 of 5.79%, 5.51% and 5.26% respectively. The solid lines are median estimates, while the dotted lines report the 95% confidence intervals computed using wild bootstrap with 200 replications.

The responses of C1 and C2 show similar movements as household credit. The initial positive effect appears to be the highest and most persistent in C2 with an increase of approximately 2 percent during the first year. The response of C1 on the other hand yields a steeper decline that reaches -1 percent after two years. As opposed to household credit, both C1 and C2 remain below the initial level after the decline which is in line with the empirical findings of Bauer and Granziera (2016). Despite our results being similar, their argument for the decline does not coincide with our findings. Similarly to Svensson (2014) and Gelain, Lansing and Natvik (2015), they argue that the initial response of both nominal debt and the price level is negative. Further, they argue that as nominal debt continues to decrease and inflation rebounds, real debt falls below trend. In our case on the other hand, the decline in real credit may be a result of nominal debt decreasing more rapidly than the price level. The response of C3 shows movements which are more in line with the conventional view on the dynamics between the interest rate and credit. Despite the hump-shaped response in the short run, the overall effect appears to be negative. C3 comprises the sum of C2 (the public's domestic gross debt) and the public's external loan debt, of which C2 constitutes the largest part (SBB 2010). It is therefore likely that the difference in the responses of C2 and C3 is a reflection of the response of the foreign debt, which in turn is more dependent on the exchange rate. As shown in Figure 20 in Appendix D, external debt exhibits high volatility

compared to C2. It is reasonable to assume that external debt is highly influenced by the exchange rate, which could explain why C3 fluctuates more than the other credit indicators. This leads us to believe that the immediate decline of C3 after a contractionary monetary policy shock could be a result of the appreciation of the exchange rate. It is also possible that the refinancing rate on external debt is higher than on domestic debt, which could contribute to the decline. The reasoning for this is that the majority of foreign debt is incurred by non-financial corporations (SSB 2017), who we believe are more likely to refinance their loans than households. Based on our analysis regarding the response of household credit to a contractionary monetary policy shock it is difficult to draw a conclusion regarding the mechanisms that drive the responses. However, our findings strongly suggest that real household credit increases in the short run, followed by a decline, which provides support for the unconventional view of the dynamics between the interest rate and the credit level.

5.4 Robustness

In this section we conduct four robustness exercises on the monthly VAR models. We begin with showing that our results are robust to using an alternative policy indicator and instrument, where we estimate the simple VAR using both the one- and two-year rates as policy indicators in addition to testing all the potential instruments. The results can be found in Table 6 in Appendix E and suggest that NOK3F1 is the second best instrument when using the one-year rate as a policy indicator, which is consistent with our findings in Table 2 in section 5.1. With the one-year rate as a policy indicator, only NOK3MD and NOK3F1 yield an F-statistic above the recommended threshold of 10. This implies that NOK3F1 is applicable as an instrument in our simple VAR. When the one-year rate is instrumented by NOK3F4 we find an F-statistic of 9.5387, which is close to the threshold. The impulse responses from the simple VAR using the one-year rate as the policy indicator and both NOK3MD and NOK3F1 as instruments can be found in Figure 21 in Appendix E. The most noticeable difference between the impulse responses is the response of inflation, where NOK3F1 yields a larger price puzzle than NOK3MD. When we use the two-year rate as the policy indicator, all the instruments yield low F-statistics between 0.23 and 3.44, implying that we have a weak instrument problem when using the two-year rate as the policy indicator. This

is consistent with our findings in Table 2, suggesting that the two-year rate does not work well as a policy indicator in our simple VAR.

In order to arrive at our main model (Figure 4, section 5.3), we estimate a number of candidate VARs and compare their performance using the F-statistic, R^2 and root mean square error (RMSE). Every individual VAR includes the main variables of interest, namely the one-year rate (instrumented by the NOK3MD), inflation, the exchange rate, real house prices and real household credit. The candidate VARs are then generated by adding one or two additional variables. The list of additional variables are: unemployment, stock market prices and TED spread. The candidate VARs are all estimated using three lags and the full sample from 2000:M1 to 2016:12. The five estimated models are reported in Table 7 in Appendix E. The results in Table 7 show that the models including either the TED spread or unemployment yield F-statistics above the recommended threshold of 10. Although both variables appear to be suitable candidates, we can see that the model including the TED spread yields the highest F-statistic and R^2 . Based on these results, combined with the fact that the TED spread allows us to evaluate whether a credit channel is present, we consider the inclusion of the TED spread to be the best alternative.

As mentioned in section 3.2, we chose to use annual inflation because it is believed to be a more direct measure of the target rate of importance to the policymakers (Bjørnland and Jacobsen 2010). Considering that we could have used the monthly growth rate of CPI-ATE in the VAR, we will check that our results are robust to using CPI-ATE in our main model. The results can be found in Figure 22 in Appendix E and show that the impulse responses yield similar patterns as in our main model, including the existence of a price puzzle. However, there are some minor changes in the error bands and the effects appear to be slightly less persistent. Overall, we consider our results robust to using CPI-ATE as a measure of the price level.

In our main model we followed the Akaike Information criterion in order to determine the optimal lag length, which led us to choose 3 lags. However, considering that 3 lags may be considered low in a monthly VAR, we check that our results are robust to varying lag lengths. As mentioned in chapter 4 one can also

use a fixed lag, which is when the lag length is set to coincide with the frequency of the data; e.g. 12 for monthly (Patterson 2011). We therefore test our model with 12 lags, which is the lag length used by Gertler and Karadi (2015). The first stage results yield an F-statistic of 5.1942 and an R^2 of 2.66 percent, which is lower than the results using 3 lags. The impulse responses are presented in Figure 23 in Appendix E and show that the effect of a monetary policy shock is both smaller and produces more volatile impulse responses. However, the overall responses are similar to the results found in our main model regarding both the direction of the responses and persistence. We also tested our model using both 6 and 9 lags. Figures 24 and 25 in Appendix E show the results, where the F-statistics are 6.8882 and 7.8341 respectively. Similar to the case with 12 lags we can see that the impulse responses become more volatile when we increase the lag length. However, as in the case using 12 lags, the overall responses are similar to the results found in our main model regarding both the direction of the responses and persistence. We therefore believe that our results are quite robust to changes in lag lengths.

6.0 CONCLUSION

This master thesis provides empirical evidence on the nature of the monetary policy transmission mechanism in Norway, where we focus in particular on the effects of a monetary policy shock on real house prices and real household credit. The topic is of high relevance in Norway today, where low interest rates, rapid rises in house prices and growing debt burdens have created an increased focus on asset price developments, especially among central banks. However, the empirical research on the topic using Norwegian data is limited. Following the work of Gertler and Karadi (2015) we use a hybrid approach which employs high frequency identification measures of policy changes as external instruments in a set of structural VARs to identify the effects of monetary policy shocks. To isolate the impact of news about monetary policy, we measure the changes within a 30-minute window of the policy announcement by Norges Bank. This is to our knowledge the first study on the topic that uses a high frequency identification strategy on Norwegian data.

We begin with an analysis of our policy indicator and instrument choice, where we consider a number of interest rate swaps and forward rate agreements. The results lead us to choose the one-year rate as the policy indicator and the change in the current three-month NIBOR rate as an instrument. We then use a simple VAR to

illustrate how the external instrument approach works, as well as how it compares to the Cholesky identification scheme. The variables included in the simple VAR are the one-year rate, inflation, unemployment and the exchange rate. We find that a contractionary monetary policy shock causes the nominal exchange rate to appreciate instantaneously followed by a gradual depreciation. The monetary policy shock results in an immediate decline in the unemployment rate in the Cholesky case, and an immediate increase with the external instrument approach. Although both methods show signs of a price puzzle, the puzzle is lower and almost eliminated with the external instrument approach. The cumulated negative response of inflation in this case is in line with conventional economic theory. Based on the responses of unemployment and inflation, the external instrument approach appears to be better able to identify unsystematic monetary policy shocks. There is also an issue of simultaneity. The conventional timing restrictions imposed in the Cholesky case become problematic as the interest rate and the exchange rate react simultaneously to news. The HFI approach solves this issue by using an instrument variable and reduced form residuals to identify the contemporaneous impact of monetary policy shocks. We conclude that the external instrument approach appears to be better suited in a setting where both economic and financial variables are present and therefore employ only the external instrument approach in our main model.

Our main model allows us to answer the question of interest and includes the one-year rate, inflation, exchange rate, TED spread, real house prices and real household credit. The results suggest that the effect of a contractionary monetary policy shock on real house prices is large, which is in line with previous empirical findings using Norwegian data. We find that a one percentage point increase in the interest rate leads to a 4 percent decline in house prices after 1.5 years and that the interest rate shock has the largest impact on the variation in house prices compared to on any other variable in the model. Our results suggest a modest and, if anything, positive response of real household credit to a monetary policy shock. This finding is in line with the unconventional view of the dynamics between the interest rate and the credit level (Gelain, Lansing and Natvik (2015) and Svensson (2014)). Following a monetary tightening of one percentage point, we find an increase in real household credit of one percent which returns to its initial level after 1.5 years. We argue that the monetary policy shock has a positive impact on both nominal debt and the price

level. Considering that real household debt is the ratio between the two, we must have that nominal debt increases more than the price level in the short run. This could be because it takes some time for households to adjust their credit levels. By replacing real household credit with various credit measures we find further support of a modest and positive effect following the policy shock. However, there is one exception which we believe is due to exchange rate dynamics and a higher refinancing rate on foreign debt. Although our results strongly suggest that the effect of a contractionary monetary policy shock has a positive effect on real household credit in the short run, we find it difficult to draw a conclusion regarding the forces driving the response. The response of the TED spread shows that a one percentage point surprise monetary tightening leads to an increase in the medium to long run. This finding provides evidence for one important result put forth by Gertler and Karadi (2015), which is that monetary policy operates through a credit channel due to credit market frictions and agency costs.

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Appendix

Appendix A.1: Data Sources and Adjustments

Nominal Interest Rate: Interest Rate Swaps (IRS) related to the six-month NIBOR.

Source: Norges Bank.

Expected Money Market Rate: Forward Rate Agreements (FRA) related to the three-month NIBOR. *Source: Norges Bank*

Money Market Rate: Real three-month money market rate (NIBOR). *Source: Norges Bank and Statistics Norway*

Treasury Bills: Real synthetic rate on three-month treasury bills. Monthly average of daily figures. *Source: Norges Bank*

Unemployment rate (LFS): Seasonally adjusted unemployment rate for persons aged 15-74. Figures from the Labor Force Survey. *Source: Statistics Norway*

Prices Norway: Seasonally adjusted consumer price index adjusted for tax changes and excluding energy products (CPI-ATE). *Sources: Statistics Norway and Norges Bank*

Nominal exchange rate: Trade-weighted nominal exchange rate index (I-44) for 44 trading partners adjusted for relative prices in Norway and abroad. *Source: Norges Bank*

Real house prices: Seasonally adjusted nominal house price index deflated by the CPI-ATE. *Sources: Statistics Norway, Eiendomsmeglerforetakenes forening (EFF), Finn.no, Eiendomsverdi and Norges Bank.*

Real Gross Domestic Debt in NOK: The credit indicator C1 for the general population chained and break-adjusted deflated by the CPI-ATE and adjusted for population growth. *Source: Statistics Norway.*

Real Total Gross Domestic Debt: The credit indicator C2 for the general population chained and break-adjusted deflated by the CPI-ATE and adjusted for population growth. *Source: Statistics Norway.*

Real Total Gross Debt: The credit indicator C3 for the general population chained and break-adjusted deflated by the CPI-ATE and adjusted for population growth. *Source: Statistics Norway.*

Stock Market Prices: Monthly average closing price of the OSEBX index. *Source: Oslo Børs*

Population: Population at the end of the period. *Source: Statistics Norway*

Appendix A.2: Graphs and Descriptive Statistics

Table 3: Descriptive Statistics

Variable	Mean	Max	Min	Std.Dev
One-year rate	3.64	7.90	0.96	2.11
Inflation	1.80	3.76	0.03	0.09
Unemployment	3.60	5.00	2.30	0.65
Exchange rate	94.12	109.10	85.00	5.98
TED spread	0.52	2.83	0.04	0.34
House prices	155.86	258.10	82.51	47.72
Household credit	1.79	3.07	0.74	0.69

Note: Household credit in NOK billion and one-year rate, inflation and TED spread in percent

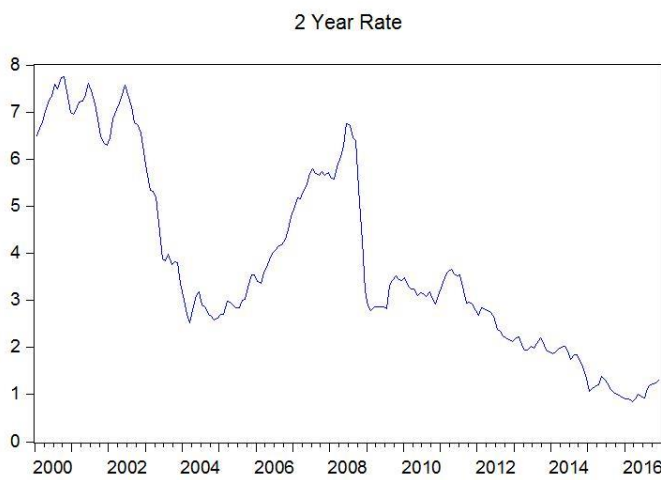


Figure 8: The two-year interest rate swap, in percent. Monthly average of the daily series 2000:M01 - 2016:M12

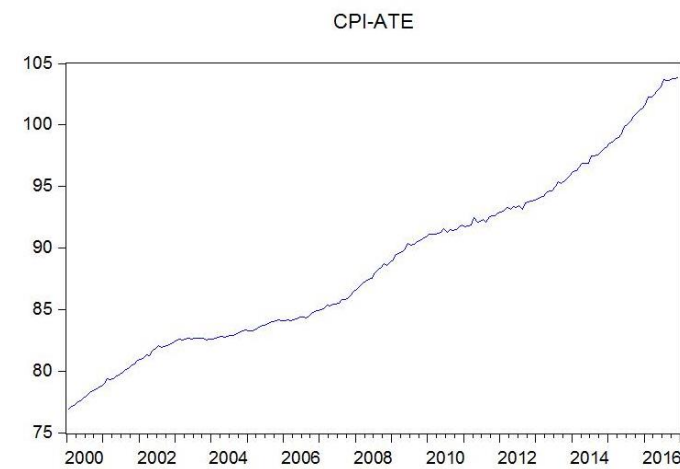


Figure 9: CPI-ATE. 2015=100 Monthly data 2000:M01-2016:M12

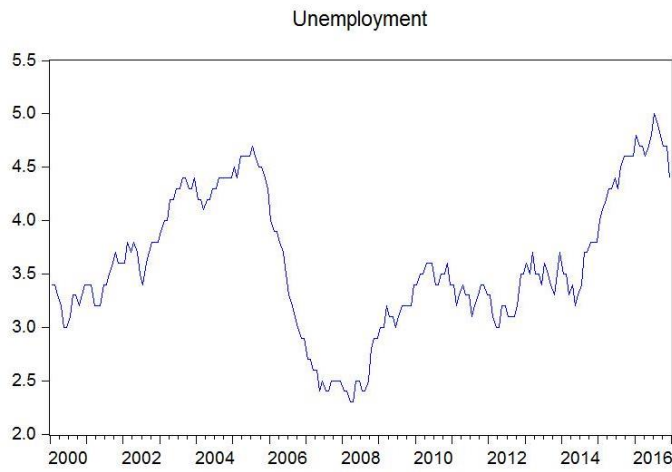


Figure 10: The unemployment rate, in percent. Monthly data 2000:M01-2016:M12

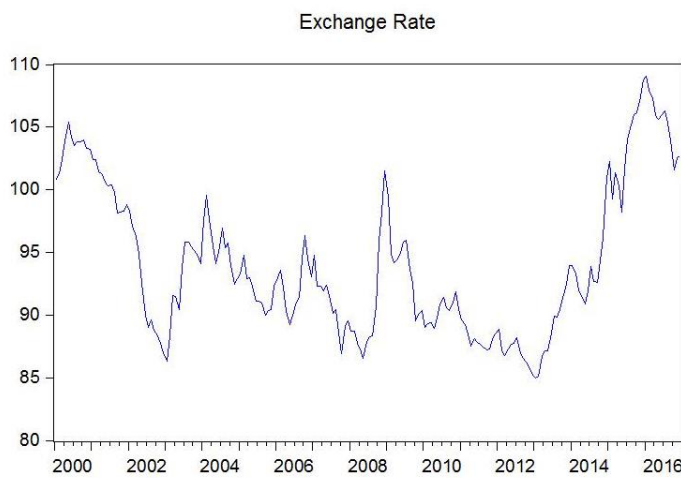


Figure 11: The import-weighted nominal exchange rate index. 1995=100. Monthly data 2000:M01-2016:M12

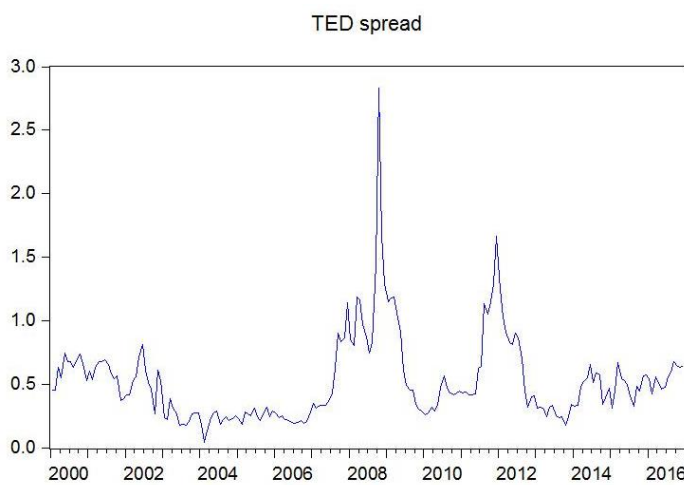


Figure 12: The TED spread measured as the difference between three-month NIBOR and the rate on three-month treasury bills, in percent. Monthly data 2000:M01-2016:M12.

Appendix B: Lag Selection and Autocorrelation

The tables below present information criteria tests for lag length in the simple VAR and main model. We consider the Akaike (AIC) and Schwarz (BIC) information criterion. The figures below plot the residual autocorrelation of the simple VAR and the Main model. We use autocorrelation with a 99 percent confidence interval to analyze the residuals of a least squares fit to noisy data. The residuals are the differences between the fitted model and the data.

Table 4: Information Criteria Tests for Lag Length - Simple VAR

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-245.2308	NA	0.000158	2.596154	2.664018	2.623639
1	942.1555	2312.930	7.91e-10	-9.605787	-9.266464	-9.468358
2	1021.889	151.9913	4.08e-10	-10.26967	-9.658893*	-10.02230*
3	1043.168	39.67691	3.86e-10	-10.32467	-9.442427	-9.967353
4	1069.019	47.12489	3.49e-10*	-10.42728*	-9.273588	-9.960029
5	1078.244	16.43082	3.75e-10	-10.35670	-8.931550	-9.779506
6	1088.437	17.73301	3.99e-10	-10.29622	-8.599611	-9.609083
7	1096.194	13.16937	4.36e-10	-10.21035	-8.242280	-9.413267
8	1120.733	40.64331	4.01e-10	-10.29930	-8.059774	-9.392277
9	1127.037	10.17883	4.46e-10	-10.19831	-7.687319	-9.181337
10	1144.078	26.80399	4.45e-10	-10.20915	-7.426704	-9.082238
11	1151.981	12.10066	4.88e-10	-10.12480	-7.070897	-8.887946
12	1172.162	30.06193*	4.72e-10	-10.16836	-6.842996	-8.821561

* indicates lag order selected by the criterion
 LR: sequential modified LR test statistic (each test at 5% level)
 FPE: Final prediction error
 AIC: Akaike information criterion
 SC: Schwarz information criterion
 HQ: Hannan-Quinn information criterion

Table 5: Information Criteria Tests for Lag Length - Main Model

Lag	LogL	LR	FPE	AIC	SC	HQ
0	119.1571	NA	1.24e-08	-1.178720	-1.076923	-1.137491
1	2174.494	3960.805	9.08e-18	-22.21347	-21.50090*	-21.92488
2	2246.459	134.1862	6.25e-18	-22.58812	-21.26476	-22.05215*
3	2305.139	105.7465	4.95e-18*	-22.82437*	-20.89023	-22.04103
4	2332.797	48.11253	5.42e-18	-22.73747	-20.19255	-21.70676
5	2351.284	31.00350	6.56e-18	-22.55504	-19.39934	-21.27696
6	2374.401	37.32548	7.60e-18	-22.42085	-18.65437	-20.89539
7	2404.393	46.54932	8.23e-18	-22.35826	-17.98100	-20.58544
8	2452.439	71.56867	7.42e-18	-22.48374	-17.49570	-20.46355
9	2470.512	25.79201	9.22e-18	-22.29700	-16.69818	-20.02944
10	2508.762	52.19568*	9.35e-18	-22.32044	-16.11084	-19.80551
11	2535.449	34.74761	1.08e-17	-22.22342	-15.40304	-19.46112
12	2572.569	46.01395	1.13e-17	-22.23509	-14.80393	-19.22542

* indicates lag order selected by the criterion
 LR: sequential modified LR test statistic (each test at 5% level)
 FPE: Final prediction error
 AIC: Akaike information criterion
 SC: Schwarz information criterion
 HQ: Hannan-Quinn information criterion

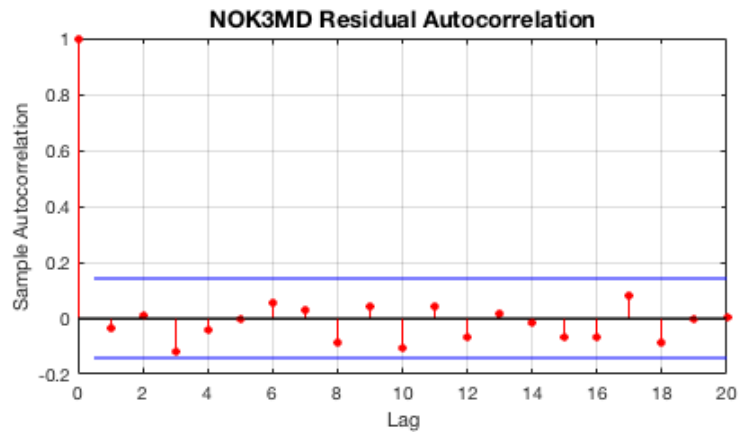


Figure 13: Residual Autocorrelation in the simple model instrumented by NOK3MD. The variables included in the model are the one-year rate, inflation, unemployment and the exchange rate. The autocorrelation sequence is plotted along with 99 percent confidence intervals.

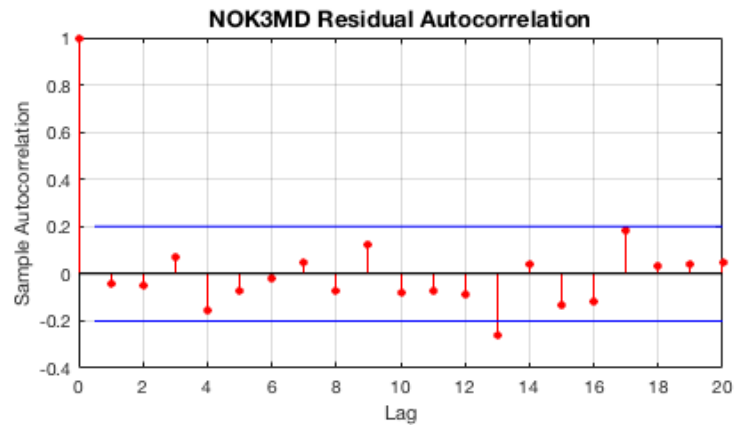


Figure 14: Residual Autocorrelation in our main model instrumented by NOK3MD. The variables included in the model are the one-year rate, inflation, the exchange rate, TED spread, real house prices and real household credit. The autocorrelation sequence is plotted along with 99 percent confidence intervals.

Appendix C: Forecast Error Variance Decomposition

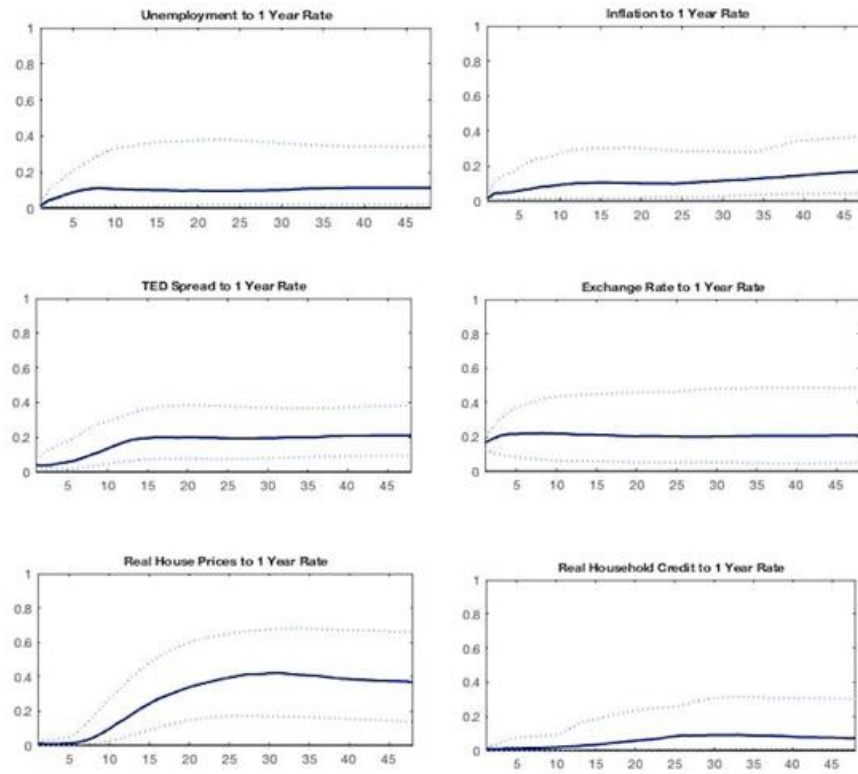


Figure 15: Variance decomposition for a shock to the one-year rate - Main Model

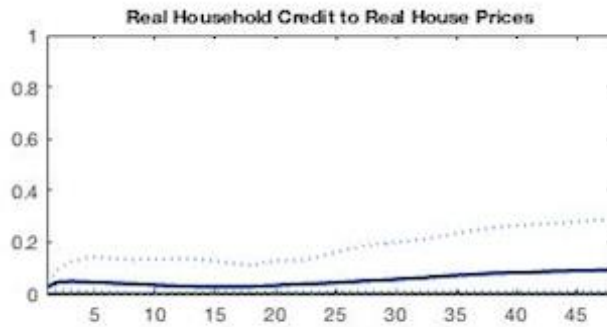


Figure 16: Variance decomposition of the response of household credit to house prices

Appendix D: Figures

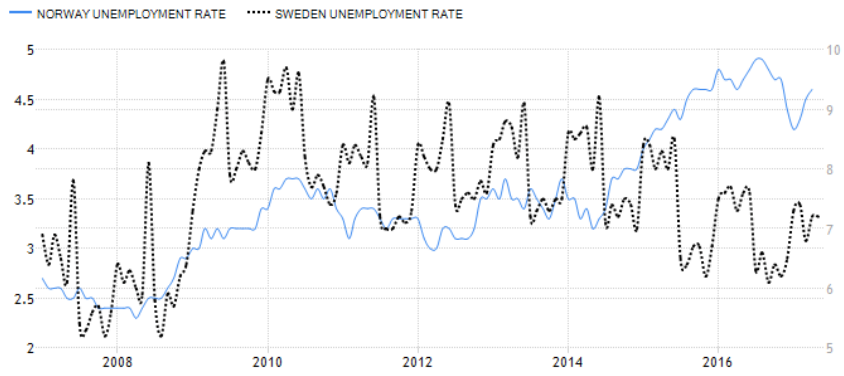


Figure 17: The Norwegian and Swedish unemployment rate. Source: Trading Economics

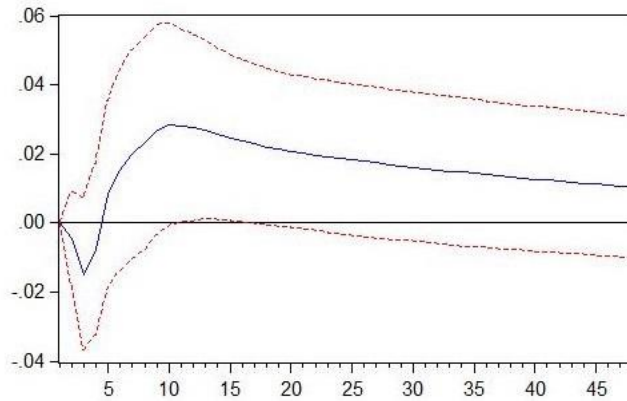


Figure 18: Exchange rate response of a one-year rate shock in the simple VAR using Cholesky identification and the interest rate ordered last.

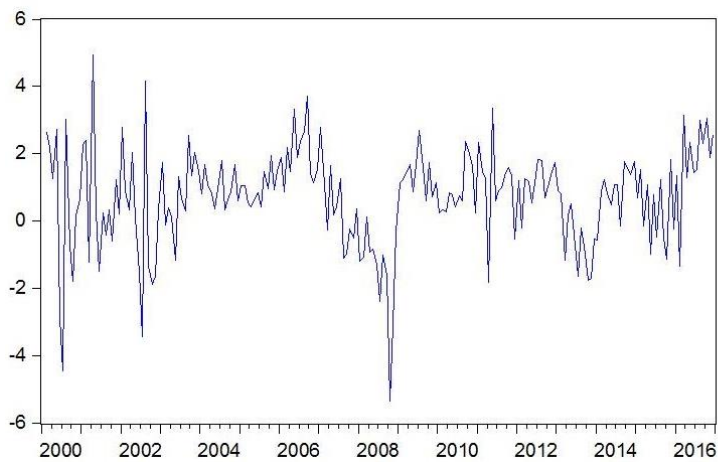


Figure 19: Real house prices. Monthly change. Percent. Sample: 2000M1-2016M12

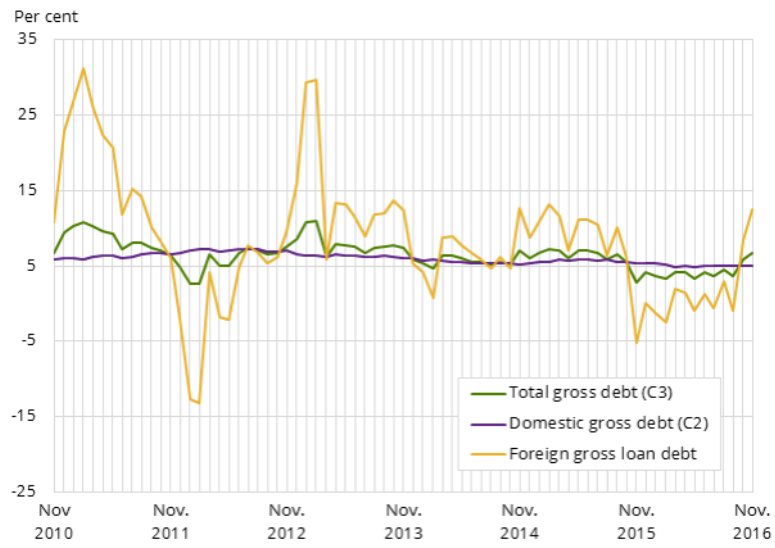


Figure 20: The credit indicator C3. Twelve-month growth. Source: Statistics Norway.

Appendix E: Robustness

Table 6: Simple VAR with different policy indicators and instruments

Indicator and Instrument	F - statistic	R ²
1YR, 3MD	12.9137	0.0612
1YR, 3F1	11.7184	0.0560
1YR, 3F2	4.7063	0.0232
1YR, 3F3	6.2097	0.0304
1YR, 3F4	9.5387	0.0460
2YR, 3MD	2.6129	0.0130
2YR, 3F1	3.4386	0.0170
2YR, 3F2	0.2339	0.0012
2YR, 3F3	0.4514	0.0023
2YR, 3F4	1.8597	0.0093

Note: The variables included in the simple VAR are inflation, unemployment and the exchange rate

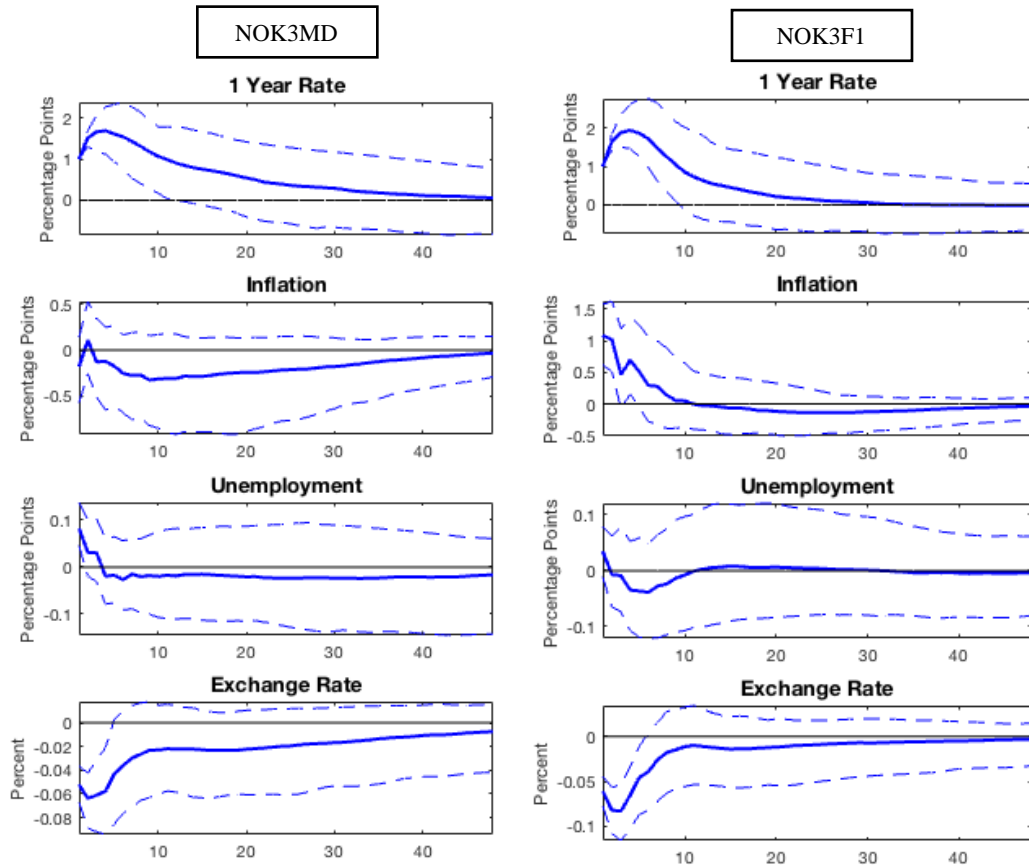


Figure 21: IRFs to a monetary policy shock - robustness check with two instruments using the external instrument approach. VAR estimated in log levels with 4 lags, and a constant over the period 2000:01-2016:12. The VAR includes the variables one-year rate, inflation rate, unemployment rate and the exchange rate. The one-year rate is instrumented using NOK3MD and NOK3F1. The monetary policy shock is set to raise the one-year rate with one percentage point. The responses of the one-year rate, inflation and unemployment are measured in percentage points, while the exchange rate is measured in percent. The IRFs are estimated using 48 steps. The first stage results are F-statistic: 12.9137 and R²: 6.12 percent with NOK3MD and F-statistic: 11.7184 and R²: 5.60 with NOK3F1. The solid lines are median estimates, while the dotted lines report the 95% confidence intervals computed using wild bootstrap with 200 replications.

Table 7: Main model with different variables

Variables	F – statistic	R ²	RMSE
TED spread	11.7532	0.0558	0.1361
Unemployment and stock prices	7.6981	0.0372	0.1352
Unemployment	10.6778	0.0510	0.1387
Stock prices	9.2984	0.0446	0.1377
Unemployment and TED spread	9.4882	0.0455	0.1328

Note: All models include the one-year rate, inflation, the exchange rate, real house prices and real household credit, and they are instrumented by NOK3MD. The candidate VARs are all estimated using three lags and a sample period from 2000:M1 to 2016:12. The root mean square error (RMSE) is the standard deviation of the residuals.

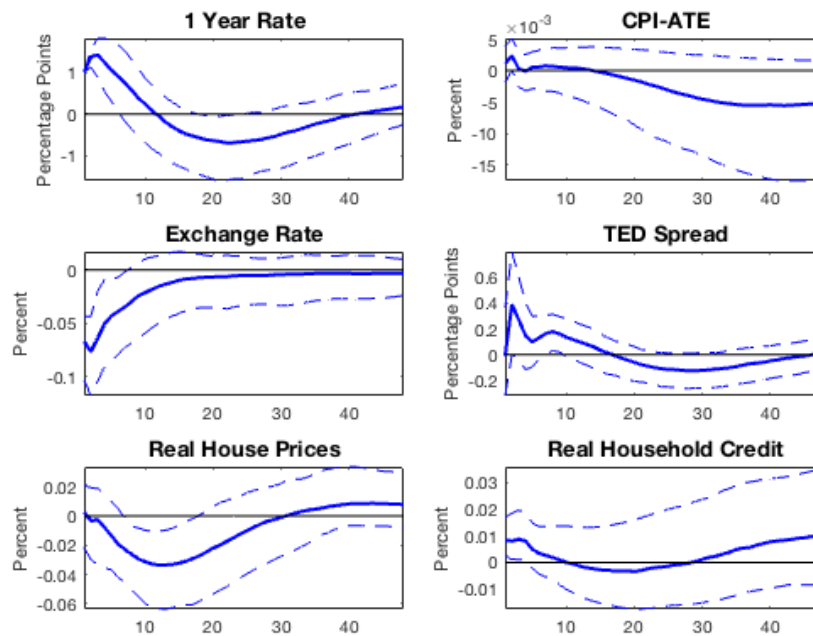


Figure 22: IRFs to a monetary policy shock - robustness check using CPI-ATE instead of inflation with the external instrument approach. VAR estimated in log levels with 3 lags, and a constant over the period 2000:01-2016:12. The VAR includes the variables one-year rate, CPI-ATE, the exchange rate, TED spread, house prices and household credit. The one-year rate is instrumented using NOK3MD. The monetary policy shock is set to raise the one-year rate with one percentage point. The responses of the one-year rate and the TED spread are measured in percentage points, while CPI-ATE, exchange rate, real house prices and real household credit are measured in percent. The IRFs are estimated using 48 steps. The first stage results are F-statistic: 9.8767 and R²: 4.73 percent. The solid lines are median estimates, while the dotted lines report the 95% confidence intervals computed using wild bootstrap with 200 replications.

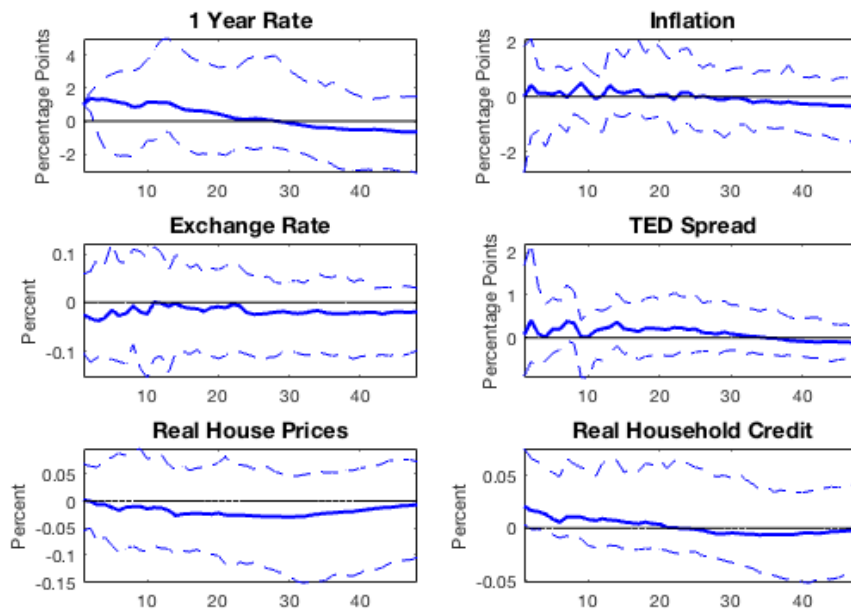


Figure 23: IRFs to a monetary policy shock - robustness check with lag length using the external instrument approach. VAR estimated in log levels with 12 lags, and a constant over the period 2000:01-2016:12. The VAR includes the variables one-year rate, inflation, the exchange rate, TED spread, house prices and household credit. The one-year rate is instrumented using NOK3MD. The monetary policy shock is set to raise the one-year rate with one percentage point. The responses of the one-year rate, inflation and the TED spread are measured in percentage points, while the exchange rate, real house prices and real household credit are measured in percent. The IRFs are estimated using 48 steps. The first stage results are F-statistic: 5.1942 and R^2 : 2.66 percent. The solid lines are median estimates, while the dotted lines report the 95% confidence intervals computed using wild bootstrap with 200 replications.

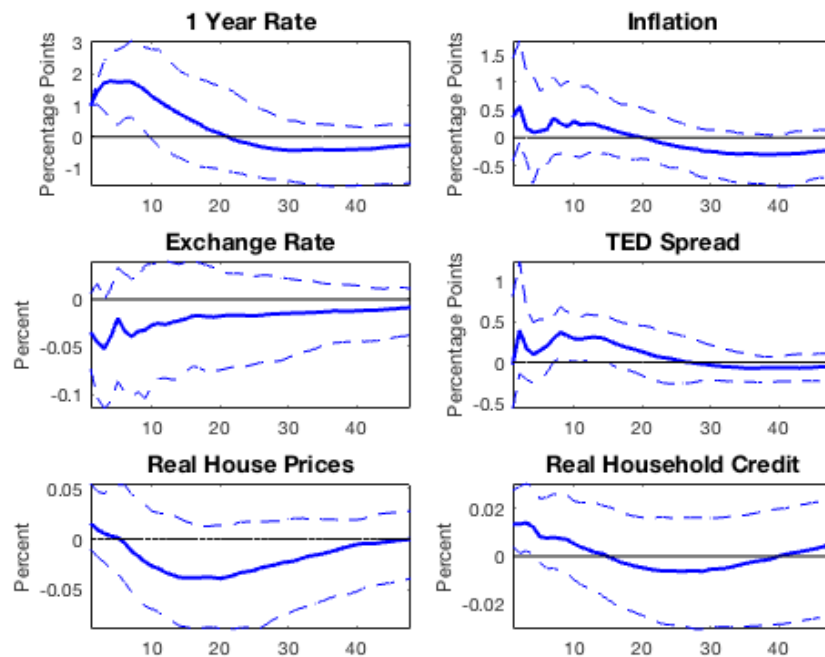


Figure 24: IRFs to a monetary policy shock - robustness check with lag length using the external instrument approach. VAR estimated in log levels with 6 lags, and a constant over the period 2000:01-2016:12. The VAR includes the variables one-year rate, inflation, exchange rate, TED spread, house prices and household credit. The one-year rate is instrumented using NOK3MD. The VAR includes the variables one-year rate, inflation, the exchange rate, TED spread, house prices and household credit. The one-year rate is instrumented using NOK3MD. The monetary policy shock is set to raise the one-year rate with one percentage point. The responses of the one-year rate, inflation and the TED spread are measured in percentage points, the exchange rate, real house prices and real household credit are measured in percent. The IRFs are estimated using 48 steps. The first stage results are F-statistic: 6.8882 and R^2 : 3.40 percent. The solid lines are median estimates, while the dotted lines report the 95% confidence intervals computed using wild bootstrap with 200 replications.

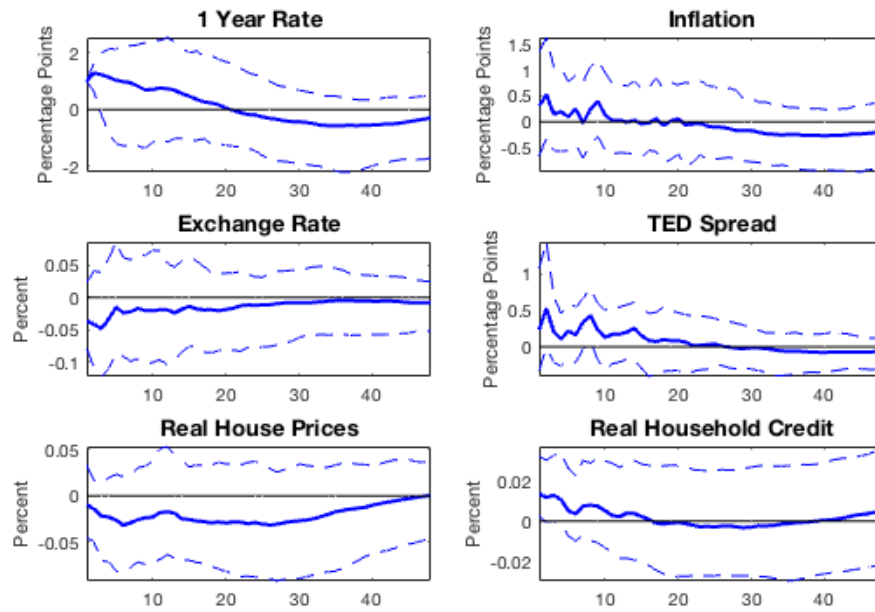


Figure 25: IRFs to a monetary policy shock - robustness check with lag length using the external instrument approach. VAR estimated in log levels with 9 lags, and a constant over the period 2000:01-2016:12. The VAR includes the variables one-year rate, inflation, exchange rate, TED spread, house prices and household credit. The one-year rate is instrumented NOK3MD. The VAR includes the variables one-year rate, inflation, the exchange rate, TED spread, house prices and household credit. The one-year rate is instrumented using NOK3MD. The monetary policy shock is set to raise the one-year rate with one percentage point. The responses of the one-year rate, inflation and the TED spread are measured in percentage points, while the exchange rate, real house prices and real household credit are measured in percent. The IRFs are estimated using 48 steps. The first stage results are F-statistic: 7.8341 and R^2 : 3.99 percent. The solid lines are median estimates, while the dotted lines report the 95% confidence intervals computed using wild bootstrap with 200 replications.

BI Norwegian Business School Preliminary Thesis Report

- Monetary policy surprises, credit growth, house prices and financial instability in Norway -

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1.0 INTRODUCTION AND ACTUALIZATION

1.1 Introduction

In 2008 the world economy faced its most dangerous crisis since the Great Depression of the 1930s. The contagion, which began in 2007 when sky-high home prices in the United States finally turned decisively downward, spread quickly, first to the entire U.S. financial sector and then to financial markets overseas (Havemann 2009). Since then there has been high interest in house prices and financial instability. Many industrialized countries have experienced extraordinarily strong rates of money and credit growth accompanied by strong increases in house prices. This observation raises a number of questions which are potentially of importance for monetary and regulatory policies (Goodhart and Hofmann 2008), particularly in Norway. In 2015 The Financial Supervisory of Norway gave a warning regarding an increased possibility of a housing price bust (Piene 2016). From the third quarter of 2015 until the same quarter in 2016, the average house prices in Norway increased with 8%. The highest increase was in Oslo and Bærum with 17.9%, which is the highest yearly increase since before the 2008 financial crisis (SSB 2016). The increase in the leverage of households has been higher than expected, and both the house prices and leverage are increasing faster than disposable income (Byberg 2016). The key interest rate is record low as a result of an unsure future, which in the worst case can lead to people investing in houses which they cannot afford once the interest rate eventually converges back to a normal level (Sættem 2016).

1.2 Topic and Motivation

The area of study in our master thesis is a combination of topics we find both very interesting and of high relevance in today's economic situation in Norway. Last year the Norwegian Minister of Finance said that *"there have been plenty of indications that there is a danger of a housing price bubble, stimulated by cheap loans. We can act as if it does not exist, but if the bubble bursts we will all be influenced by the consequences"* (VG 2016). The quote captures topics we want to learn more about, which is the link between monetary policy shocks, credit growth, house prices and financial instability.

In the wake of the recent financial crises, many policy-makers have disagreed about the role of central banks, especially when it comes to promoting financial stability (Bauer and Granziera 2016). There is no consensus regarding the factors that contributed to the build-up of financial imbalances before the crisis (Robstad 2014). We wish to analyze the dynamics between a number of economic and financial variables by imposing monetary policy shocks on the variables. This will be done in order to get an insight on how these dynamics influence the economy as a whole. The first variable of interest is credit growth. Credit growth to Norwegian households has been strong and exceeded mainland GDP growth for more than a decade. Despite a decline in credit to companies, total credit has risen since the 2008-09 crisis (OECD 2014).

Housing is the most important asset for households in industrialized countries. One can say that the recent crises and its aftermath has led to a reassessment of the importance of housing finance for the macroeconomy (Jorda, Schularick and Taylor 2014). Unlike other assets, housing has a dual role of being both a store of wealth and a durable consumption good. Consequently, a shock to house prices may therefore affect the wealth of homeowners. As the value of collateral rises, this will also rise the availability of credit-borrowing constrained agents. In total, a shock to house prices may therefore affect real growth and ultimately consumer prices (Bjørnland and Jacobsen 2009).

2.0 LITERATURE REVIEW

Similar studies have been done in the past regarding our chosen topic in a wide range of countries. There are observable differences between the studies as a result of different choices of countries, methods, variables and assumptions. We intend to use the previous research as guidance when we perform our study based on Norwegian data. One of our challenges will be to present something different within topics that have already received significant attention.

There exists extensive research on the effects of monetary policy on different economic and financial variables. Bauer and Granziera (2016) ask whether monetary policy can be used to promote financial stability. They answer this

question by estimating the impact of a monetary policy shock on private-sector leverage and the likelihood of a financial crisis. Their panel vector autoregressive (VAR) model suggest that the debt-to-GDP ratio rises in the short run following an unexpected tightening in monetary policy. As a consequence, the likelihood of a financial crisis increases, as estimated from a panel logit regression. However, in the long run, output recovers and higher borrowing costs discourage new lending, leading to a deleveraging of the private sector. They also find that the ultimate effects of a monetary policy tightening on the probability of a financial crisis depend on the leverage of the private sector: the higher the initial value of the debt-to-GDP ratio, the more beneficial the monetary policy intervention in the long run, but the more destabilizing in the short run.

An American paper written by Jorda, Schularick and Taylor (2014) also discuss if there is a link between monetary policy and financial instability. However, they look specifically at how monetary and credit conditions affect house price booms and busts. The intention is to determine whether low interest rates cause households to lever up on mortgages and bid up house prices and if this in turn increases the risk of financial crisis. The paper uses data from 140 years of modern economic history across 14 advanced economies. This has become possible by compiling two datasets, one that covers bank credit data, including real estate lending to households and non-financial businesses and one covering long run house prices. This was the first time both datasets have been combined. At business cycle frequencies, they find robust evidence in support of a direct mechanism linking short-term rates, mortgage lending and house prices. Through the term structure, long-term rates respond to short-term rates, thus affecting the price of mortgages. In response to easing monetary conditions and hence a decline in the price of mortgages, mortgage lending expands. Rising house prices improve the value of the mortgages collateral, and with it a bank's asset position and its ability to lend further. They find that loose monetary conditions are causal for mortgage and house price booms, and that this effect has become much more dramatic since WW2.

Another American paper by Gertler and Karadi (2015) provides evidence on the transmission of monetary policy shocks, where they focus in particular on how monetary policy actions influence credit costs that in turn affect economic activity. There are two considerations that motivated them to revisit the classic topic of monetary policy transmission mechanism and that is frictionless financial markets and the lack of response in term premia or credit spreads. The goal was to determine whether a significant component of the response of credit costs to monetary policy indeed reflected movements in term premia and credit spreads, consistent with some form of financial market imperfection. Their approach involves combining the traditional “money shock” VAR analysis with high frequency identification (HFI) of the effects of policy surprises on interest rates. The VARs they considered included output, inflation and a variety of interest rates. A key finding was that there is an enhanced movement in credit costs from the policy shock due to the response of term premia and credit costs. The response of credit costs is thus significantly larger than inspection of the short-rate response alone would suggest. These kinds of phenomena are absent in standard models of monetary policy transmission.

Romer and Romer (2004) have developed a measure of US monetary policy shocks which are relatively free of endogenous and anticipatory movements. To derive more accurate estimates of the effects of policy, the paper proposes and implements a new method for isolating monetary policy shocks. Their approach considers only changes in the federal funds rate that are a result of deliberate decisions by the Federal Reserve made at meetings for which there is a forecast prepared by the staff. They then remove the portions of these moves in the intended funds that represent the Federal Reserve’s usual response to the forecasts. Quantitatively their findings are consistent with textbook views of the effects of monetary policy, where contractionary monetary policy reduces both output and inflation. More importantly, the results indicate that the impacts of monetary policy on both output and inflation are large.

The international VAR literature on the topic is vast, while VAR studies using Norwegian data are more limited. Two studies which have been performed on Norwegian data were conducted by Bjørnland and Jacobsen (2009) and Robstad (2014). Both papers use a structural VAR model on Norwegian data in order to find the effects of monetary policy shocks on a number of variables. The variables of interest are GDP (mainland Norway), inflation, the real exchange rate, real house prices and interest rates. In addition, Robstad (2014) includes real household credit. Bjørnland and Jacobsen (2009) find relatively strong effects of monetary policy on real house prices when using a combination of short and long run identification restrictions to identify the monetary policy shock, which is supported by Robstad's (2014) findings. In contrast, for household credit the response to a monetary policy shock seems modest (Robstad 2014).

The most common way of identifying shocks in the VAR literature is by placing sufficient zero restrictions which are placed in a recursive (Cholesky) order. One drawback with the Cholesky identification scheme is that one may encounter a simultaneity issue (Robstad 2014). The issue of simultaneity appears to recur in all the papers. To address this, both Bjørnland and Jacobsen (2009) and Robstad (2014) have added two restrictions on the long run multiplier of the monetary policy shock. In addition, Robstad (2014) identifies a monetary policy shock using sign restrictions, which amounts to putting restrictions on the sign of the contemporaneous effect of the impulse response to the structural shock for some or all of the variables in the VAR (Robstad 2014). Gertler and Karadi (2015) dealt with the simultaneity issue by using daily data, in particular surprises in the fed funds futures that occur on FOMC days. They exploit the HFI approach to identify exogenous policy surprises but then use a full VAR to trace out the dynamic responses of real and financial variables.

3.0 METHODOLOGY

3.1 Research Method

We wish to perform an empirical study, which is based on observed and measured phenomena and derives knowledge from actual experience rather than from theory or belief (Penn State University Libraries 2017). Our chosen research method is a quantitative approach, which is the use of sampling techniques whose findings may be expressed numerically, and are amenable to mathematical manipulation enabling the researcher to estimate future events or quantities (Business Dictionary 2017). Quantitative research is especially useful for addressing specific questions about relatively well-defined phenomena (Statistics Solutions 2017).

3.2. Data collection

A common quantitative approach is known as secondary data analysis, in which a researcher analyzes data that were originally collected by another research team. Often these are large-scale, nationally-representative data sets that require extensive resources to collect; such data sets are made available by many organizations to allow many researchers to conduct independent research using high quality data (Statistics Solutions 2017). To be able to identify the wanted monetary policy shock series, our plan is to use high frequent data from Norges Bank. Other data series will be collected from Statistisk Sentralbyrå (SSB). A fundamental question in all research is the reliability of the data. Reliability is related to the data which is being used, the way it is collected and how it is processed (Johannessen, Kristoffersen and Tufte 2004). We regard the data from Norges Bank and SSB as reliable. The data we wish to collect is time series data of a number of variables, which gives us the opportunity to see the development of the variables between two or more points in time (Johannessen, Kristoffersen and Tufte 2004).

3.3 Choice of Model

Vector autoregressive models have become widely used in macroeconomics for many purposes. Researchers typically want to analyse and predict many variables at the same time and with the multivariate VAR model one can model the variables of interest together. A structural VAR (SVAR) model gives researchers the ability to study causal relations and are used today to address important questions such as: What causes business cycle fluctuations? and What is the effect of a monetary policy shock? (Bjørnland and Thorsrud 2015).

When using VARs to analyze monetary shocks, the standard identification strategy is to impose timing restrictions on both the behavior and the impact of the policy rate. Cholesky decomposition assumes a recursive structure for how the structural shocks affects the variables in the VAR system, and thereby facilitates identification (Bjørnland and Thorsrud 2015). One common way of identifying a monetary policy shock is by ordering interest rate last. This is assuming that monetary policy responds to all variables contemporaneously and that the contemporaneous effect of monetary policy is zero for all variables (Robstad 2014). These kinds of timing restrictions may be reasonable for the interactions between the rate and economic activity variables such as output and inflation. However, they are problematic once additional financial variables are present and we then have a problem of simultaneity. Gertler and Karadi (2015) dealt with this issue by using the HFI approach, addresses the simultaneity issue by using daily data of surprises in fed funds futures that occur on Federal Open Market Committee (FOMC) days. To isolate the impact of news about monetary policy, the surprises in futures rates are usually measured within a tight window (e.g., thirty minutes) of the FOMC decision.

Gertler and Karadi's specific approach involves combining the traditional "money shock" VAR analysis with HFI of the effects of policy surprises on interest rates (Gertler and Karadi 2015). Instead of including a series of monetary policy surprises directly into their VAR as an exogenous variable, they instead use the surprises as an external instrument following Stock and Watson (2012) and Mertens and Ravn (2013). First, Gertler and Karadi (2015) estimate an

unrestricted VAR and obtain the residuals from this estimation. In a second step, they recover the relation between these residuals and the unobserved structural monetary policy shock by using a series of monetary policy surprises as an instrument for the structural monetary policy shock (Paul 2015). They have two motivations for using these methods. First, they seek to study the effect of monetary policy on variables measuring financial frictions, such as interest rate spreads. The usual Cholesky ordering with the federal funds rate ordered last imposes the restriction that no variables ordered earlier respond to the funds rate shocks within the period. This is clearly an untenable assumption for financial market rates. Second, they want to capture the fact that over time the Fed has increasingly relied on communication to influence market beliefs about the future path of interest rates (Ramey 2015).

Gertler and Karadi performed their study on American data. We would like to replicate their approach on Norwegian data. Replication involves the process of repeating a study using the same methods, different subjects, and different experimenters (Heffner 2017). To our knowledge, this method has not been used before on Norwegian data under the chosen topic.

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