Norwegian School of Economics
Bergen, Fall, 2018

Do interest rates really respond to financial stability concerns?

An analysis of monetary policy in Norway 1999-2018

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Master thesis, MSc in Economics and Business Administration,
Economics & Finance

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Abstract

This master thesis estimates monetary policy reaction functions for the Norwegian economy from 1999 to 2018 using a Taylor rule. In a Taylor rule the interest rate is typically set dependent on inflation and the output gap. Our primary focus is to determine whether Norges Bank also target key financial indicators when setting the interest rate. We study, therefore, whether Norges Bank has set the interest rate over and above what inflation and output gap developments, would suggest, in their attempt to mitigate the build-up of financial imbalances. We find that a model containing financial variables, using different specifications and different estimation methods, are not able to outperform a Taylor rule containing only inflation and output gap concerns. Furthermore, high degree of policy inertia makes differences between the interest rate predictions almost negligible. However, we find a surprisingly high output gap coefficient for the whole sample, which may indicate that Norges Bank include financial stability concerns to their monetary policy. On the other hand, when we concentrate the study and look at post-2011 results (the year Norges Bank changed governor), we receive a much lower output coefficient. Post-2011 results suggest that the interest rate setting has been more concerned with the exchange rate, foreign interest levels and low output, rather than working purposefully to counteract the build-up of financial imbalances.

Preface

First and foremost, we would like to thank our supervisor Gernot Doppelhofer for all the help he provided, both in answering our questions and commenting on our drafts. We would also like to thank Øyvind Anti Nilsen for his answers on methodological questions. In early phases of our work we were lucky enough to discuss the topic with both Svein Gjedrem and Birger Vikøren from Norges Bank. Their opinions on the topic gave both inspiration and valuable insights. We would additionally like to thank Norges Bank for providing us with the output gap series for Norway from 1999-2018.

This thesis concludes our time at the Norwegian School of Economics, and we are thankful to everyone who made the experience a pleasant one. We are both grateful for all our memories we got as members of Ukekoret Optimum.

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1. Introduction

"The wrong way to judge progress would be to expect an end to financial crises. Systemic banking meltdowns are a feature of human history […]. There is no question that they will occur again" (Economist, 2018). Moreover, the costs of a financial crisis are substantial, as the aftermath suffers from low activity and high unemployment. This is why we want to centre our thesis around financial stability. Meaning, if there is no question that a financial crisis will occur again, then the focus should be on reducing the potential magnitude of an *inevitable* crisis. One approach that has gained attention is that central banks should tighten monetary policy to counter the emergence of financial imbalances. This is commonly referred to as "leaning against the wind". Following the financial crisis, Norges Bank has increasingly taken the risks related to financial imbalances into account (Evjen & Kloster, 2012). The robustness criterion added in 2012 supported that growing financial instability should be tackled by raising the interest rate.

John Taylor formulated a monetary policy rule based on how the United States' Federal Reserve conducted monetary policy in the years 1987-1992. Taylor (1993) suggested that the interest rate should be set to minimize the gap between inflation to the inflation target and the output to its estimated long-run sustainable rate. Norway adopted inflation targeting in 2001 (informally in 1999). We contribute to the debate by testing whether adding financial variables can make better interest rate predictions than the simple Taylor rule. We expect that Norges Bank has followed a higher interest rate path than the recommended Taylor rate path. The inclusion of counteracts of a financial imbalance build-up implies a tighter monetary policy.

Our research question is whether Norges Bank target key financial indicators when setting the interest rate. In general, which variables, over and above inflation and output gap, have affected the Norwegian interest rate since 1999? Furthermore, can we improve our models of the interest rate setting by especially adding key financial indicators? We answer these questions by using both a Vector AutoRegressive approach (VAR) and a Generalized Method of Moments approach (GMM). The estimation process focuses especially on comparing forecasts and, investigating changes in coefficients between our models.

Guarding against the build-up of financial imbalances have become a more explicit concern over time, and it was included to the monetary policy reports as a criterion for an appropriate interest rate path in 2012. Norges Bank witnessed a change of Governor the year before. When conducting a structural break analysis, literature point to leadership rotation as a natural breaking point. We therefore use 2011 in our structural break analysis to test if Norway's monetary policy show a heightened focus towards securing financial stability in the time after the governor change.

In our GMM analyses we find that Norges Bank has put more weight on keeping output close to target, than inflation close to target over the sample period. Thus, we receive a high and statistically significant output coefficient for the full sample analysis, while inflation is lower and (most times) statistically insignificant. A higher output gap coefficient works, in fact, as an indication that Norges Bank includes concerns about financial stability in their monetary policy. We find, however, that models that add financial variables, (for instance housing prices or credit levels) overall, are unable to outperform a Taylor rule specification that only concerns for inflation and output gap deviations. Furthermore, high degree of policy inertia makes differences between the interest rate predictions almost negligible. From the VAR analysis, we find support for a sluggish response in the interest rate to changes in house prices and credit levels. However, these responses are only true under strong assumptions. The GMM estimations, on the other hand, are more robust and we trust these findings to a larger extent.

Our research question touches also upon the ongoing debate of whether monetary policy, by adding a financial stability concern, overestimates its potential (Svensson, 2018). The sceptics acknowledge that the interest rate is a powerful tool; with the potential to alter investment levels and the relative size of debt obligations. However, it is still *one* instrument, and it should not be overburdened. Svensson argues that financial imbalances should be addressed with a separate tool; micro- or macroprudential policies. The opposite view is that monetary policy can do a lot more (Evjen & Kloster, 2012). This is typically referred to as leaning against the wind (LAW). By raising interest rates at a precautionary stage, key financial indicators won't be able to grow unsustainably. Thus, reducing the *mop-up* after a crisis, and its associated cost.

The thesis proceeds as follows. Section two describes the fundaments of monetary policy and financial stability with Norway as our focus. We also discuss whether monetary policy or macroprudential policy should play the essential role in dealing with financial instability. Section three provides the theoretical framework for monetary policy. In section four we outline the econometric methodology used to fit the Taylor rule and to make predictions. Section five contains a description of the data, and empirical results are gathered in section six. Finally, section seven concludes.

2. Monetary policy and financial stability

The role of monetary policy has evolved a lot since the beginning of modern banking; from primarily printing money to setting the interest rate (Grytten & Hunnes, 2016). The main target for central banks nowadays is low and stable inflation, and low unemployment (Mishkin, Laubach, Bernanke & Posen, 2001). In recent times, however, the role of most central banks has been further expanded. For most developed economies central banking now includes considerations about the level of financial stability (IMF, 2018a).

Financial stability concerns can be implemented to a central bank's monetary policy in several ways. In fact, just targeting the inflation can help to stabilize the financial system indirectly as high inflation is regarded as a sign of imbalance (Evjen & Kloster, 2012). However, this is less efficient than targeting financial stability explicitly, and it doesn't necessarily tackle a financial imbalance build-up. For instance, the last financial crisis in 2008-2009 experienced low and stable inflation, yet imbalance was allowed to build up over time (Constancio, 2015). A more drastic approach to deal with the gradual build-up of financial instability is to "lean against the wind". This means to tighten monetary policy even beyond what inflation targeting would suggest (Evjen & Kloster, 2012). Others voice that the responsibility should lie in the hands of macroprudential policies (Svensson, 2018).

In subsection 2.1 we go through the theoretical fundament of monetary policy. In general, we study the relationship between the interest rate and inflation and production levels. Subsection 2.2 looks at previous estimations of the so-called Taylor rule. We split this into international and Norwegian estimations. Subsection 2.3 studies financial stability. We emphasize the importance of our chosen subject by looking, especially, at the substantial costs related to a financial crisis. Subsection 2.3 also addresses the ongoing debate on whether monetary policy or macroprudential policy should oversee the issues of financial instability.

2.1 Monetary policy

Central banks, through their monetary policy practice, play a crucial role in ensuring economic and financial stability (IMF, 2018a). The main instrument for the central bank is the key policy rate, which is the rate commercial banks earn on deposits at the central bank (Norges Bank, 2018b). Lowering the key policy rate would lead to cheaper capital, all else equal (Fisher, 1930). Whenever price of capital is low, more capital is demanded. The opposite is true when the price of capital is high. Furthermore, the demand for capital is tightly linked with both the investment level and the general purchasing power in the economy. Thus, the interest rate has a strong effect on production levels. The key policy rate, in its ability to alter general activity in the economy, is one of the most efficient and powerful tools available in the market.

The different channels in which monetary policy works through, will be discussed in subsection 2.1.3. Now, it is enough to state that the key policy rate is typically lowered in times when production and employment are below healthy measures (Norges bank, 2018a). This would help boost economic activity. On the other hand, the interest rate is typically raised in times when prices and production go above its natural boundaries. Thus, dampening economic activity.

2.1.1 Flexible inflation targeting

Stability has always been a priority for central banks around the world, although the means of getting there have evolved. We concentrate on the central bank of Norway, Norges Bank. One reason is that Norges Bank has practiced inflation targeting for many years. Secondly, they have long experience in looking at other financial variables when making interest rate decisions. Today, most central banks in mature economies (as well as many emerging ones) have adopted flexible inflation targeting, either explicit or implicit.

Norway formally adopted inflation targeting in March 2001. Informally, the practice began even earlier, in 1999 (Andreassen, Grauwe, Solheim & Thøgersen, 2001). Back in 2001, the regulation stated that the monetary policy objective should be low and stable inflation, approximately 2,5 percent yearly inflation (Regjeringen, 2018b). Another goal of the original practice was to stabilize the development in output and employment. This involved countercyclical behaviour to smooth out business cycles. The initial regulation also included the goal of stabilizing the Norwegian currency.

The regulation has changed several times over the years, most recently in 2018. First and foremost, the inflation target was reduced to 2 percent, in March 2018 (Norges Bank, 2018b). Second, the regulation expanded to also include counteracts of financial instability (Scheel, 2018). Financial stability has been a priority for Norges Bank for years, even though it was added to the regulation first in 2018. The explicit mentioning of exchange rate stability was, however, removed in the updated regulation. The argument was that exchange rate concerns may conflict the desire for economic stability. Norway witnessed during the oil-price shocks, and the accommodating political changes, that a drastic adjustment in the Norwegian exchange rate was necessary in order to re-balance. Nevertheless, the exchange rate still means a lot for inflation, production and employment levels in a small, open economy. Thus, it remains an implicit goal. A healthy development in output and employment still reigns high.

The fact that Norges Bank has more than one objective should come as no surprise. The ability to be flexible arises, by definition, when more than one objective is included. This means that while low and stable inflation is Norges Bank's main focus it does consider other objectives. The most well-known additional considerations today are, as mentioned, high and stable production and employment as well as counteracting the build-up of financial imbalances (Regjeringen, 2018b).

2.1.2 Goal of flexible inflation targeting

The main goal of stabilizing inflation is important because the cost of inflation can become significant (Woodford, 2012). Bigger and more unexpected changes in price levels will have larger undesired effects. One way to deal with this is to make the inflation target visible. This creates a nominal anchor for the monetary policy. Inflation targeting, thus, helps to stabilize inflation expectations. Unwanted costs of inflation consist mainly of two broad kinds (Ackley, 1978). The first relates to changes in the growth of production. A typical example is a deflationary spiral. The second kind speaks to redistribution of wealth and income, in which a wage-price spiral is a common illustration. Deflation is particularly harmful because it is beneficial for consumers and companies to suspend their investments. A wage-price spiral begins when a wage increase, on its own, leads to higher demand. Increased demand naturally raises the price level. The spiral continues whenever the price level increase is used as an argument for even higher wages. Forming inflation expectations will minimize the chance for deflationary spirals and wage-price spirals, both with large associated costs.

The thought behind stabilizing output and employment is done primarily to smooth out business cycles. The economy benefits from market stability. It provides workers with stable flows of income and it reduces the possibility of businesses having to do frequent adjustments to the size of their operations. Countercyclical behaviour is, thus, meant to avoid the costs of sudden jumps in output and, thereby, employment (Barlevy, 2004). The cost can become huge as employment is tightly linked to output; a higher production level demands more hands at work. Further, a low unemployment rate also provides more households with a spendable money supply. Fluctuations in the level of production affect, therefore, not only the number of employed workers, but also the amount of total household spending in the economy. Norges Bank watches the business cycle closely as it has the tendency to propagate in a negative spiral. Spirals magnify costs.

The goal to counteract the build-up of financial imbalances will be discussed in more depth in section 2.3. For now, it is enough to acknowledge that household and corporate indebtedness is linked with the build-up of financial imbalances. One way to sustain debt levels from becoming fragile is to raise interest rates at a precautionary stage.

2.1.3 Monetary policy in an open economy

There are different channels through which monetary policy influences real economic activity and the rate of inflation. To give an overview we look to the article "*Monetary Policy under Inflation Targeting*" (Sveen & Røisland, 2017). The fundamentals were touched upon in subsection 2.1.1. In this subsection, we deconstruct the relationship between the interest rate and activity levels even further.

A decrease in the key policy rate increases output which, in turn, increases the rate of inflation. The process goes from the interest rate channel to aggregate demand, and the demand channel to inflation. In other words, cheaper capital raises demand for capital and higher demand puts pressure on real prices and wages. Both the interest rate channel and the demand channel are easy to grasp. The exchange rate channel to demand, on the other hand, is not as intuitive. Before addressing the latter, it is useful to emphasize the importance of both the interest rate and the demand channel. The fact that we devote less time to them should not be mistaken with the ranking of their importance. Output gap, which is a measure we obtain from the demand side of the economy, is something that Norges Bank weight heavily before setting the interest rate (Evjen & Kloster, 2012) even more so, after financial stability became a concern. Our empirical findings suggest that output gap, after about two years, becomes the most significant variable in predicting the interest rate, see subsection 6.1.

Since Norway is considered a small, open economy, the effect of changing exchange rates must also be discussed (Sveen & Røisland, 2017). The exchange rate influence activity levels, but also the price level of imports, and through that the inflation rate. A weaker exchange rate gives higher inflation for several reasons. First, it increases competitiveness which in turn lead to higher activity, putting pressure on prices and wages. Second, imported input factors get more expensive, hence leading to higher production costs. Eventually, this will reflect in the price of goods and services. Third, imports of goods and services will also become more expensive. The consumer price index will increase accordingly.

We still need to clarify which direction the exchange rate goes when the key policy rate change (Sveen & Røisland, 2017). The explanation relies on the relationship between the Norwegian exchange rate and foreign interest rates. A lower foreign interest rate makes it more likely that investors keep their assets in the Norwegian krone, as it yields a relatively higher return than other currencies. When the demand for the Norwegian krone is high, it appreciates. Conversely, when the Norwegian interest rate is lower, relative to other currencies, then the Norwegian krone depreciates. In theory we believe that an arbitrage-free condition exists. Thus, all assets are priced appropriately and that there are no gains, beyond the market gains, without also adding risk.

Sveen and Røisland (2017) conclude that the mechanisms for an open economy looks remarkably similar to those for a closed economy. A situation where inflation is above target still requires that the central bank increases the nominal interest rate. The difference lies in the central bank's reflections on the exchange rate channel, which only appears when looking at a small, open, economy.

2.1.4 Quadratic loss function

Underlying for Norges Bank's monetary policy is a specification of a loss function: (Evjen & Kloster, 2012):

$$L = \frac{1}{2}[(\pi_t - \pi^*)^2 + \lambda(y_t - y_t^*)^2]$$

In its most simplistic form, the central bank wishes to minimize the loss function above (Sveen & Røisland, 2017; Norges Bank, 2012). To do so, it minimizes the difference between actual inflation and the inflation target and the difference between actual output and potential output. This effort of minimization leads to the implicit determination of the interest rate. In other words, the mathematical procedure finds the (only) interest rate that upholds the minimization constraint. The work of Woodford (2003) has shown that the standard loss function can be interpreted as a quadratic approximation of a micro-founded loss function.

The alternative, to representing monetary policy as the outcome of an optimization process, is to assume that monetary policy follows an instrument rule (Ilbas, Røisland, & Sveen, 2013). The most well-known being the basic Taylor rule. Taylor first investigated how central banks behaved, and he found a positive point that monetary policy typically was dependent on two variables, namely inflation and output gap. Only later when he formulated the Taylor rule (1993) did he confirm normatively that central banks also ought to behave in this manner. The Taylor rule is essentially an instrument used to determine what interest rates will be, or should be, as shifts in the economy occur. When inflation is high or when output exceeds long-term levels, then the rule recommends that the central bank should raise interest rates. On the other hand, when inflation and output levels are low, interest rates should be decreased. The relationship is given by:

$$r_t^T = 1{,}5\,\pi_t + 0{,}5\,(y_t - y_t^*)$$

Although different from the loss function, it should be clear that the two methods have the same idea in mind. Importantly, we see that the inflation gap and the production gap appear both in the loss function and the Taylor rule (with some algebraical differences). In other words, both methods wish to prevent deviations in the inflation to target and production to its potential. For the Taylor-interest rate it implies that the central bank doesn't "*lean against the wind*" (LAW). Leaning against the wind describes a tendency to raise interest rates beyond the level that is needed to maintain price stability. More detailed descriptions of the Taylor rule will be present in part 3. LAW will be further discussed later in this part.

In the first quarter of 2012, the monetary policy report adjusted the loss function to include a measure for financial stability (Norges Bank, 2012). The new criterion was that: "*monetary policy is robust".* In depth it meant that: "*interest rates should be set so that monetary policy mitigates the risk of a buildup of financial imbalances (...)".* The updated loss function was given by (Norges Bank, 2012):

$$L = (\pi_t - \pi^*)^2 + \lambda(y_t - y_t^*)^2 + \gamma(i_t - i_{t-1})^2 + \tau(i_t - i_t^*)^2$$

With this new function Norges Bank puts more weight on the output gap. In other words, the loss magnifies whenever the output gap grows. Note that the last segment adds weight to the interest rate gap. The latter is defined as the deviation between the actual and a *normal level* of nominal interest rates (Evjen & Kloster, 2012). The normal level of nominal interest rate is defined as the combination of the real interest rate and the inflation target, more on this in section 6.1.1 (Bernhardsen & Kloster, 2010). In terms of the loss function, the loss increases when the difference between the interest rate and the normal level of the interest rate grows. The idea is that a lower interest rate, over time, can increase the risk of corporate and household indebtedness (Evjen & Kloster, 2012). Furthermore, it postulates that the price of assets moves to unsustainable levels. High debt levels make borrowers more *vulnerable* and increase the risk of long-term instability in the real economy. Adding the interest rate gap can, therefore, mitigate the risk of a financial imbalance build-up, by restoring a balance between borrowers' debts and the value of leveraged assets. Note, also that the loss function treats changes to the interest rate symmetrically. The costs of a higher interest rate than normal levels are typically either due to an appreciation in the Norwegian exchange rate, or low-growth resulting from reduced economic activity (Sveen & Røisland, 2017).

Counteracts of the build-up of financial imbalances, translates into a simple Taylor rule by increasing the value in front of $(y_t - y_t^p)$; from 0,5 to something higher. To understand why increasing the weight on the output gap reduces the possibility of a gradual build-up of financial instability, we refresh the relationship between the interest rate and the investment level. We know, through empirical evidence, that financial imbalances build up during booms (Grytten & Hunnes, 2016). Therefore, raising the cost of lending (by raising the interest rate), is a way central banks try to sustain especially debt levels (but also asset prices), from growing unsustainably.

The link between the interest rate and lending costs, are well-described in Hall (2001). He states that even a small increase in the key policy rate increase lending costs by a substantial amount. If the projected interest rate path in Norway is upheld, we expect a mortgage of three million NOK with a repayment period of 25 years to increase by 48 000 every year (Fossheim & Graff, 2018). In fact, all loans will become more expensive. A higher interest rate also lowers the availability of credit in the market. Both factors drive the levels of investment down. The investment level, as we know, has a direct effect on the gross national product, and thereby the output gap. Thus, a higher weighting on the output gap has the potential function of dampening economic activity in times before financial imbalances become *irreversible* – at least in theory.

Recent monetary policy reports have removed the explicit presence of the new loss function. One reason might be that it received critique from the independent evaluator of monetary policy in Norway, the Norges Bank Watch, in 2013 (Boye & Sveen, 2013). Despite the critique, hindering the build-up of financial imbalances has remained a priority for Norges Bank. Generally, counteracts of the build-up of financial imbalances have been included to the criteria for an appropriate interest rate path since 2012 (Regjeringen, 2018a; Norges Bank 2012). Additionally, the robustness of banks has become a heightened concern in the years following the financial crisis (Norges Bank, 2018b). In fact, monetary policy reports ever since 2013 devote a complete chapter on a financial stability assessment, in order to decide on the countercyclical capital buffer requirement for banks. The countercyclical capital buffer is an initiative that is part of Norway's macroprudential policy, more on this in section 2.3.

2.2 Previous estimation methods of the Taylor rule

There are numerous ways to estimate a monetary policy reaction function. The most well-known approach is via some form of Taylor rule specification (Clarida, Gali, & Gertler, 1998). Results from a Taylor rule will vary on the choice of method, as well as the included variables. We summarize here to the most important contributions done in this field. It illustrates how previous studies approached problems similar to our own research question.

2.2.1 International estimations

In estimating interest rate rules generalized method of moments (GMM) has become somewhat of a standard (Seitz, Gerberding, & Worms, 2006). When estimating monetary policy in a GMM setting we, as many others, look to the article "*Monetary policy rules in practice some international evidence"* (1998) by Clarida, Gali and Gertler. They extended their analysis further in "*Monetary policy rules and macroeconomic stability: evidence and some theory"* released in 2000. Both analyses are based on large economies, such as Germany and the US. For German data, Siklos, Werner and Bohl (2004) add to the discussion. Chadha, Sarno and Valente (2004) add their contributions regarding US data. The empirical results differ as a result to a multitude of factors, and it is therefore useful to cross-check Clarida, Gali and Gertler's work with these additional sources.

Clarida, Gali and Gertler (1998) conclude that all the countries in their study have coefficients that suggest inflation targeting. Similarly, Siklos, Werner and Bohl (2004), and Chadha, Sarno and Valente (2004), also get reasonable parameter values in their forward-looking Taylor rule estimations. This means that the baseline specification of the reaction function does a good job in characterizing monetary policy for these countries. Jia (2011) did a similar estimation for Sweden. His results suggest that Sveriges Riksbank target the exchange rate as a third monetary policy concern, alongside responding to changes in expected inflation and output deviations. Although the exchange rate concern is implicit, it may describe why Sweden missed its monetary policy inflation objective in the years prior to Jia's investigation.

Other popular methods feature maximum likelihood, see Gozgor (2012) and de Losso (2012). They estimate a forward-looking Taylor rule. Backward-looking estimations with smoothing commonly use non-linear methods, such as nonlinear least squares (Hofmann & Bogdanova, 2012) or two stage non-linear least squares (Weise & Krisch, 2010). A backward-looking estimation without smoothing goes back to the theoretical fundament of Taylor's original paper (Taylor, 1993). His estimation can be done with ordinary least squares. If OLS suffers from endogenous explanatory variables, a two-stage least squares estimation should be used instead (Castelnuovo, 2007). In general, the key findings from these papers are that a Taylor rule estimation, although not being able to uncover the whole truth, is a reasonable way to portray a monetary policy reaction function in many countries.

2.2.2 Norwegian estimations

Monetary policy reaction functions have been estimated for Norwegian data as well. Our thesis is inspired by the master thesis of Skumsnes (2013) but also, to some extent, Helseth (2015). Their theses are in turn inspired by Clarida, Gali and Gertler's work (1998, 2000). We find similar inspiration from these articles. There are lots of other empirical studies, apart from Skumsnes (2013) and Helseth (2015), that give valuable insights for Norway.

For instance, Puckelwald (2012) estimated both a forward-looking and a backward-looking Taylor rule. The results yield different levels of significance to relevant regressors, depending on which additional information variables are included in the model. The backward-looking model is estimated using Ordinary Least Squares (OLS). Bernhardsen and Bårdsen (2004) also estimated a backward-looking reaction function with OLS. A small sample size created some tension, but they reported, at least, a highly significant smoothing coefficient. This supports most central banking behaviour. Adding trade weighted exchange rate gave a significant coefficient but with wrong sign, due to a suspected simultaneity issue. Bernhardsen and Gerdrup (2007) did a lot of the same as Bernhardsen and Bårdsen (2004), only without a smoothing parameter. With a longer sample period their estimated parameter values got more aligned to economic theory, nevertheless, lacking a significant coefficient for the output gap.

Gagnon and Ihrig (2001) did an IV-estimation, looking at the pass-through of exchange rate changes into domestic inflation. They find a highly significant smoothing parameter, but not much else of evidential relevance.

Moving to more recent findings, we looked particularly at four different master theses. Skumsnes (2013), although stating clearly that the evidence is somewhat ambiguous, finds that inflation targeting has been an important objective for Norges Bank in the sample period 1999-2012. Additionally, he finds that Norges Bank reacts to both inflation changes and output gap changes. The results also suggest that Norges Bank follows a Taylor principle, meaning that an increase in inflation is met by a higher increase in the interest rate. Further, Skumsnes found evidence that Norges Bank put more weight on keeping the inflation rate close to the target than keeping the output gap close to zero. Our results challenge this viewpoint, see section 6.2. Helseth (2015) cross-checks the results from Skumsnes, as he investigates weak identification in a forward-looking Taylor rule. His results, using GMM, suggest that the Taylor rule is weakly identified. We don't find this by using the standard Hansen's J-test for overidentification, but Helseth uses more sophisticated methods. Thus, we keep his analysis in mind when interpreting our results.

Skaaland and Vik (2016) estimated a backward-looking model using nonlinear regression to see whether Norges bank has "*leaned against the wind*". They conclude that a LAW-behaviour has been present in the years after 2012, but decreasingly so after 2014. Finally, Aas (2016) estimated a forward-looking reaction function, by 2SLS, for the sample period 1999-2008. He used GMM for robustness checks. His findings also support the Taylor principle, meaning that the inflation coefficient is significant and greater than unity. For the full sample estimation, however, his results became inconsistent with theory.

2.3 Financial stability – an overview

Ten years ago, a weakened banking system allowed for the rise of highly indebted borrowers, many without the ability to repay loans if lending costs were to rise, or if the value of investments object, especially houses, fell (IMF, 2018b). Ten years on, the global banking system is considered stronger, but the dangers of indebtedness remain. Housing prices, in many countries, have also reached levels comparable to what was present during the last financial crisis. In subsection 2.3.1 we establish a rudimentary understanding of the term: *financial stability*. Subsection 2.3.2 examines the cost of a financial crisis. The discussion on central banks' role in preventing future crises is found in subsection 2.3.3. It focuses especially on how to appropriately tackle the build-up of financial imbalances. In subsection 2.3.4 we highlight the link between our research question and the ongoing debate on monetary policy versus macroprudential policy. Lastly, in subsection 2.3.5 we look at how Norway is dealing with financial stability.

2.3.1 Financial stability

The ambition to make financial stability concerns operational are shared by many central banks today. It is helpful to define the term before discussing implementational challenges. We use a well-recognized definition by the European central bank: "Financial stability is a state whereby the build-up of systemic risk is prevented" (European Central Bank, 2018). To grasp it fully, we must also define systematic risk:

> Systemic risk can best be described as the risk that the provision of necessary financial products and services by the financial system will be impaired to a point where economic growth and welfare may be materially affected (European Central Bank, 2018).

Systemic risk is known to be associated with booming financial cycles (Grytten & Hunnes, 2016). We need to address the mechanics behind how a boom can arise and intensify. Obviously, a boom doesn't manifest overnight, the transformation happens gradually. This raises a question: if a government can see a danger growing, why does it not cut of its means before the economy reaches a harmful state. The reason why such actions seldom take place is that the build-up of financial instability often gets misinterpreted. Frequently, dangers are being confused as healthy signs of an economy in blossom. For instance, Blanchard, Summers and Cerutti (2015) found that many recessions come after a time where the output gap and inflation does not appear to have been unusually high. Thus, the economy may be on an unsustainable path, nonetheless, if financial imbalances (in most cases related to indebtedness) are allowed to build up. In such instances the dangers are usually reacted to (or at least identified) too late. The struggle is also that central banks must allow for some level of growth, even if it comes with a few warnings: "*we clearly do not want the stability of the graveyard*" (Friedman, 1953).

2.3.2 Finncial crisis build-up and the cost of a financial crisis

Financial crises come in many forms. However, data collected on historical crises have allowed us to identify some common features and patterns; substantial changes in credit volumes and asset prices; disruption of external financing to actors in the economy; large score balance sheet problems, of firms, households and sovereigns alike (Claessens & Kose, 2013). Furthermore, we want to stress the apparent *unavoidability* of financial crises. It is, as a result, appropriate to illustrate a common financial crises build-up.

The typical starting point is when investors, who borrows from the bank, are driven by speculatory motives (Grytten & Hunnes, 2016). If times are good, as they usually are when optimism and investment opportunities are present, banks are eager to lend out money. This is after all how banks do business. Thus, when the outlook is stable, money is pouring into the economy. As prices continue to rise, more people join in on the action. Note that the rise in credit volumes correlate somewhat with the rise in asset prices. Increased earnings (through rising asset prices) and a higher credit supply usually leads to increased consumption as well. Consequently, different parts of the economy may boom. Prices will, however, not increase indefinitely. Stocks and other investment objects have a fundamental value. Over time prices must return. When such awareness enters the market, optimism is likely to dampen. Alertness pays off and those who sell early make a profit. Those who hesitate ends up far worse. The worst-off often finds themselves sitting with worthless investment objects and huge loans that they aren’t able to repay.

Even non-speculating consumers with healthy debt levels might be affected. Noticeably, this has to do with the downward spiralling effects of a crisis (Grytten & Hunnes, 2016); borrowers struggle to pay back their loans; banks become sceptical and reduce funding of new loans; this affects the general purchasing power in the economy; businesses are letting people go because demand is low; demand gets even lower when more people are unemployed. This repeats itself if not handled properly. Often, a financial crisis spreads to the real economy. This is mainly due to the prescribed interconnectedness of markets. When it spreads, the costs are multiplied many times over.

Reinhart and Rogoff (2009) have studied the link between financial crises and crises that spread to the rest of the economy. Their sample consisted of all the major banking crises after the second world war (18 in total) in the developed world, and they put particular weight on the biggest five (Spain 1977, Norway 1987, Finland, 1991, Sweden, 1991, and Japan, 1992). They find that a *typical* financial crisis has long-term effects on asset-prices, employment, production and public debt. Some key numbers from their study are; an average fall of 35 percent on real housing prices over a period of six years after the crisis hit; stock-prices fall on average by 55 percent within three and a half years; unemployment rise by 7 percent over a four-year period; production fall by 9 percent over two years (then stabilizing a bit); and government debt rise by 86 percent within three years of the outbreak.

2.3.3 How to tackle the build-up of financial imbalances

The essence from section two can usefully be summarized at this stage. First and foremost, thinking that the economy never will experience another financial crisis is highly ignorant. Second, the build-up of financial instability is one of the main drivers that eventually will send the economy back to disorder. A crisis is likely to hit the economy within a couple of decades, historically speaking (Grytten & Hunnes, 2016). Within 40 years this statement can almost be considered a fact. This does not make the role of politicians and economists wasteful. On the contrary, they have the collective power to affect how deep the impact of a future crisis will be. This gives them a shared responsibility in minimizing the cost and duration of a recession. Put in other terms, a future crisis doesn't have to shake the ground like the events of 2008 did. Undoubtably a lot more can be done in crisis prevention and crisis management (IMF, 2018b). A frequently asked question, when it comes to crisis prevention, is whether counteracts of the build-up of financial imbalances can be handled within the limits of monetary policy, or if the responsibility should lie elsewhere (Svensson, 2018). We address this next.

If the answer to the first part of the question is yes, then financial stability is a suitable third goal for monetary policy, beyond price stability and real economic stability. From section 2.1, we saw that monetary policy essentially is limited to setting the interest rate. Accordingly, if financial stability is accounted for it would involve a tighter policy than justified by standard flexible inflation targeting. This practice goes under the name "*lean against the wind*" (LAW). Commonly, it involves raising the interest rate in times when key financial indicators are growing unsustainably. Key financial indicators can be anything from credit levels, housing prices or measurements concerning bank stability, more on this in section 2.3.5. The market mechanism resulting from raised interest rate has been thoroughly examined, see primarily section 2.1.3.

The critique to LAW is both loud and vast. This is spearheaded by former deputy governor of the Swedish Riksbank Lars Svensson. He states that "Monetary policy can achieve price stability, but it cannot achieve financial stability" (Svensson, 2018). This is somewhat supported by recent data (Constancio, 2015). During the build-up to the Global Financial

Crisis the economy experienced price stability but not at all financial stability. Financial imbalances, thus, may build up even when inflation is low and stable if the economy, simultaneously, face a deregulated financial system, allowing for a credit boom. This speaks to a desynchronized relationship between a business and a financial cycle.

Svensson fronts that macroprudential policies are much more applicable at stabilizing key financial indicators (Svensson, 2018). Macroprudential policy can be defined as “a subset of a broader financial-stability policy that includes both macro- and microprudential policy as well as resolution”. Further, the goal of macroprudential policy is financial stability. Thus, it works purposefully to secure the ability to transform saving into financing, allowing risk management, and transmitting payments with *sufficient resilience* to disturbances that threaten these functions. There are, on the other hand, doubts circling monetary policy’s ability to achieve sufficient resilience of the financial system. For instance, it is obvious that monetary policy can’t ensure that there is sufficient capital and liquidity buffers in the financial system.

Svensson (2016) concludes that the gains, in terms of reduced probability and depth of a future crisis, is likely to be less than the cost of LAW. One reason might be that the interest rate doesn’t work purposefully enough to take financial stability into account. Recall, financial stability can at best be defined as an added third goal for monetary policy. This is side-lined whenever deviations in the estimated long-run sustainable rate, to either inflation or output, is apparent. Secondly, there aren’t, in most cases, any conflict between the goal of stable production and inflation, on the one hand, and financial stability on the other hand. Hence, simply adding weight to the output gap might serve the same purpose.

2.3.4 How the debate fits our research question

It is helpful to refresh why this debate is interesting. Back in 2012 the central bank of Norway’s monetary policy report (MPR) stated that: “interest rates should be set so that monetary policy mitigates the risk of a build-up of financial imbalances (…)” (Norges Bank, 2012). This implies that Norges Bank, at least back in 2012, wished to follow some sort of LAW policy. In truth, we believe that their wish to counteract financial imbalances started even earlier. Norges Bank states that they have taken the risks related to financial instability into account for many years, and increasingly so after the financial crisis of 2008 (Evjen & Kloster, 2012).

Our findings will naturally shed some light on the debate from subsection 2.3.3. If we find that Norges Bank hasn’t “*leaned against the wind*” after 2011 (we determine 2011 as the structural break point later in this subsection), then it works as an indication that Svensson is right. In other words, it is hard for monetary policy to achieve financial stability, because there are so many considerations that come before. We know for instance that exchange rates concerns are important for Norway, see subsection 2.1.3. In part six we will see that foreign interest rates also play an important role in Norges Banks interest rate decision making. If our results point in the other direction, however, it works as an indication that counteracts of financial imbalances can work through monetary policy. The case could naturally be that Norges Bank has lowered the interest rate *less* than what would have been recommended if financial stability was of no concern. We see, for example, that the Norwegian interest rate lies above its closets neighbours. This case would also suggest LAW policy behaviour.

There have been some concrete situations, historically, that illustrates a tension between conventional inflation targeting and the general argument of leaning against the wind. The most dramatic deviation from a linear Taylor rule was perhaps when Norges Bank in 2008 cut the interest rate by 150 basis points in one meeting. Furthermore, the fact that the interest rate (for the most part) continued to fall, despite the encouragement from MPR 3/10 and MPR 3/11 to gradually raise it, points to that financial stability concerns are easily side-lined when other concerns are more pressing. In fact, the third quarter of 2018 witnessed the first interest rate increase in Norway after a seven-year decline. One reason why Norges Bank has kept the interest rate low in recent years is due to the oil-price shock in 2014, which lead to low activity and higher unemployment in Norway. Norges Bank responded to this with high priority, even though low interest rate levels naturally allowed for credit growth among consumers and businesses that were not affected by the oil-industry crisis. Today, household debt is the most important source of vulnerability in the Norwegian economy (Norges Bank, 2018b).

Also, it is fitting to use the basis of this discussion to determine the breaking point for our own structural break analysis. In other words, which year was pivotal for the eventual instalment of the criterion on *counteracts of financial imbalances*. There are some post-2008 developments that seem important. For instance, monetary policy reports back in 2010 and 2011 make explicit mentions of the relationship between low interest rates and the risks of a financial imbalance build-up (Norges Bank, 2010; Norges Bank, 2011). Both reports urge that the key policy rate should be gradually raised towards normal levels. Furthermore, Norge Bank changed their governor back in 2011. Only one year later, in 2012, monetary policy reports began to include counteracts of the build-up of financial imbalances as a criterion for an appropriate interest rate path.

We choose to use the central bank leadership rotation as the breaking point in our pre- post analysis on monetary policy behaviour. This is supported, among others, by Clarida, Gali and Gertler (1998, 2000). Although the weight of guarding against financial imbalances have been more explicit after 2008 (and expressed as a literal criterion in 2012), we believe that it also has been an implicit concern in many pre-crisis years as well. Therefore, it might be that the structural break analysis won't yield dramatic changes, considering how well anchored financial stability concerns seem to be in the Norwegian monetary policy.

2.3.5 How is Norway dealing with financial stability?

Norwegian monetary policy reports have, ever since 2013, included a financial stability assessment chapter (Norges Bank, 2018b). Particular weight is given to four key indicators of financial imbalances (Norges Bank, 2018c):

1. Credit-to-GDP ratio for mainland Norway
2. The ratio of house prices to disposable income
3. The estimated real commercial property prices
4. Banks' wholesale funding ratio.

First, credit-to GDP ratio is defined as credit levels for mainland Norway as a share of mainland GDP. Second, the ratio of house prices to disposable income is defined as average house prices in relation to the sum of household disposable income (Norges Bank, 2013). Third, the estimated real commercial property prices are based on the real selling prices per square meter for prime office spaces in Oslo (Norges Bank, 2018c). Fourth, banks' wholesale funding ratio is defined as total liabilities less consumer deposits and equity (Norges Bank, 2013). How Norges Bank measure these indicators are discussed in section 5.3.

The four indicators have historically risen ahead of periods of financial instability (Norges Bank, 2018c). Further, the key indicators are compared with historical trends. The gap between the key indicators and the estimated trends can, thus, serve as a measure of financial imbalances. A *ribbon heatmap* has also been added to monitor systemic risk build-up in the Norwegian financial system (Arbatli, Rønnaug, & Johansen, 2017). This tool is constructed out of 39 indicators and capture a wide range of financial vulnerabilities. By including a broad set of indicators, the heatmap is able to capture the complexity of financial cycles, both in terms of vulnerabilities and the associated risks. Norges Bank has stated that the heatmap is meant to complement the four indicators.

The heatmap also includes the build-up of risks in the Norwegian financial system leading up to the banking crisis in Norway (1988-93) and the financial crisis (2008-09) (Arbatli, Rønnaug, & Johansen, 2017). Many of the dangers that lead to the past two crises have re-emerged in present times, especially, *household debt*. In fact, Norges Bank has stated that household debt is the most vulnerable state of the Norwegian financial system today (Norges Bank, 2018b). One way to deal with higher debt levels is by raising the interest rate, more on this at the end of this subsection. Interestingly, the four key financial indicators, along with the heatmap, is meant, primarily, to serve as an input for macroprudential policy (Norges Bank, 2018c). Hence, Norges Bank uses this information to advice on the countercyclical capital buffer, regarded as an additional capital requirement for banks (Anh, 2011). The buffer is currently at two percent (Norges Bank, 2018b). This is meant to strengthen bank solidity and to make sure that their lending strategies do not amplify a downturn. The buffer requirement holds in times when financial imbalances build up but is reduced during economic setbacks. The latter is done to prevent that stricter lending practices prolong a recession.

The key policy rate was raised from 0,5 percent to 0,75 percent in September 2018 (Norges Bank, 2018b). This comes after a seven-year decline. Even a small increase, such as this, will put pressure on the least solvent borrowers. The interest is expected to reach two percent within 2021. An interest rate increase is welcomed at this point, as household debt has increased for a long period; otherwise credit demand would not dampen. Raising the interest, as thoroughly examined, is one way the central bank can deal with the build-up of financial imbalances. Furthermore, Norway's decision to raise the interest is counter-current behaviour compared to its closest neighbours. Most European countries keep the interest rate low (Hovland, 2018). This hints toward some sort of a LAW policy.

In accordance to the discussion above, Norges Bank's strategy seem to inhabit some sort of a middle ground between a stricter monetary policy and the use of macroprudential policy. They have set a higher interest rate, compared to its European neighbours, while also issuing a countercyclical capital buffer.

3. Theoretical framework

In this part we present the original Taylor rule. Further, we expand this into a forward-looking Taylor-rule with smoothing. How to make it forward-looking and how to add smoothing will be discussed separately.

3.1 The original Taylor rule

This section outlines the original Taylor rule proposed by John Taylor (1993). He formulated a fairly simple rule based on how the Federal Reserve conducted monetary policy in the years 1987-1992. As briefly discussed in subsection 2.1.4, Taylor suggested that central banks should set the interest rate with the goal of minimizing the deviations between inflation and output to their respective targets. Both concerns are weighted equally. The inflation target is set by Norges Bank and the output target is the desired growth rate in output. When inflation and output are at target levels, the nominal interest should be equal to the real interest rate added with the inflation level (Fisher equation). The rule represents a simplification of the complete information set that the central bank uses to decide on the interest rate. However, as discussed in section 2.2, it proves to be a good approximation of monetary policy conduction for many countries. The original Taylor-rule is backward-looking, meaning that the central bank sets the interest rate based on inflation and output from past periods. The original equation can be formulated in the following way:

$$r = p + 0{,}5y + 0{,}5(p - p^{*}) + 2 \qquad (1)$$

r is the federal funds rate, p is the four-quarter inflation rate, y is a measure of output gap, $p*$ is the inflation target. The constant at the end represents the unknown real interest rate. Taylor assumed that the real federal funds rate was 2 percent in his analysis. The original rule can be rewritten, since the inflation target is two percent:

$$r = 1 + 1{,}5p + 0{,}5y \qquad (2)$$

Intuitively, the Taylor rule implies that whenever inflation and output are at their long-run sustainable levels we get a Federal funds rate equilibrium of four, and a real rate equilibrium of two.

Taylor suggested that central banks should stabilize inflation by increasing nominal interest rates more than proportional to an increase in inflation. This relationship has later been referred to as the “Taylor principle”. Conversely, when the nominal interest rate response is less than proportional to the inflation increase, then the interest rate raise is insufficient to keep the real rate from declining. Failing to increase the real interest rate might heighten the possibility of self-fulfilling burst of inflation and output (Bernanke and Woodford, 1996; Clarida et al., 1997)

3.2 A forward-looking Taylor rule

The original Taylor rule works well as a baseline. On the empirical side, however, we have several authors who highlight that central banks seek to target forecasts (Clarida, Gali & Gertler, 1998). Furthermore, in a New Keynesian model, it is also assumed that central banks should stabilize expected inflation and not realized inflation.[1] This moves away from a Taylor rule based on lagged values. The new baseline specification, based on the work of Clarida, Gali & Gertler (1998) and (2000), includes a central bank that considers expected inflation and expected output gap, in respect to their targets, when setting the interest rate. It is essentially a forward-looking version of the simple backward-looking Taylor rule that we examined in section 3.1.

In a Forward-looking Taylor rule we start with the assumption that the central bank has a target for the nominal interest rate, here called i_t^*. The interest rate will be at i_t^* if the central bank achieves their target for output and inflation. Specifically, the target depends on both expected inflation and expected output:

$$i_t^* = i^* + \beta\left(E\left[\pi_{t,k} \middle| \Omega_t\right] - \pi^*\right) + \gamma E[y_{t,q} | \Omega_t - y_t^*] \tag{3}$$

i_t^* is the *equilibrium* nominal interest rate and exists only when both inflation and output are at their targets. $\pi_{t,k}$ gives us the percentage change in the inflation rate between period t and period $t + k$. Further, π^* is the target rate for the inflation, and $y_{t,q} - y_t^*$ is the difference between actual output and the potential output. Finally, Ω_t is the amount of information that

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[1] See for example discussion in Romer (1996) on page 231, or Clarida, Gali, Gertler (1999)

the central bank has at time *t*. It appears two places in the equation. Basically, it tells us that the central bank uses all the information available when forecasting inflation and output.

Note that this Taylor rule set-up remains close to its original form. The main difference is that inflation and output are based on expected values rather than lagged values. The tight connection to the original Taylor rule can best be illustrated by setting *k* and *q* equal to *-1*. Essentially, this makes the equation backward-looking again. A forward-looking rule is more realistic because it allows for the central bank to make projections based on a broad array of information that goes far beyond lagged inflation and output.[2]

The target horizon (*k)* for Norges Bank was initially two years, before it changed to 1-3 years in 2005 (Norges Bank, 2017; Regjeringen, 2018b). Norges Bank have ever since 2007 aimed at stabilizing inflation near the "medium term" target. Thus, in the context of the Norwegian central bank we typically set *k* between 4-12 quarters. We must also decide the horizon for the output gap. Clarida, Gali and Gertler (2000) find that *q* usually is one or two. The horizon is rather short, but we trust their empirical findings.

There are several reasons why we would want to modify the Taylor-rule further (Clarida, Jordi, & Gertler, 2000). First, the equation implies an immediate adjustment to the interest, leaving no room for smooth changes. It is, however, widely recognized that central banks tend to smooth the interest rate.[3] The fact that Norges Bank prefers gradual changes in the interest rate is mentioned under the section "monetary policy objectives and trade-offs" in their Monetary Policy Reports (Norges Bank, 2018b). The central bank attempts to avoid large fluctuations because it often leads to large fluctuations in asset prices. Second, interest rates are known to be "upward-rigid". Therefore, the equation should reflect that large increases in the interest is less likely than large decreases. Third, its mechanical set-up does not allow for randomness in policy actions. Fourth, the central bank doesn't have perfect control over the interest rate, as the equation suggest. Finally, smoothing helps to avoid loss of reputation for a central bank.

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[2] Differences between adaptive and forward-looking expectations in a New Keynesian model setting is discussed in Romer (1996) on page 231.

[3] Advantages of smoothing are discussed in a paper by Sack & Wieland (2000). They present results from several papers. They point specifically to three explanations; market-participants have forward-looking behaviour; measurement error with macroeconomic variables; finally, relevant structural parameter uncertainty.

Relaxing the initial assumptions somewhat, make us able to extend our model:

$$i_t = (1-\rho)i_t^* + \rho i_{t-1} + v_t \tag{4}$$

We see that the target i_t^* from (3) is our starting point, but that it is adjusted by the factor $(1-\rho)$. Only a fraction, depending on the size of ρ, remains after the central bank has accounted for smoothing. v_t captures exogenous shocks to the interest rate, with a mean of zero. By combining the smoothing and the nominal interest rate target (i_t^*), we get the actual nominal interest rate (i_t).

Next, we combine this with equation (3). For ease of notation, we define $\alpha = i^* - \beta\pi^*$ and $x_t = y_t - y_t^*$. We can then rewrite equation (3):

$$i_t^* = \alpha + \beta\left(E\left[\pi_{t,k}\middle|\Omega_t\right]\right) + \gamma E\left[x_{t,q}\middle|\Omega_t\right] \tag{5}$$

Combining the adjustment (4) with (5) yields a forward-looking Taylor rule with smoothing:

$$i_t = (1-\rho)\left(\alpha + \beta E\left[\pi_{t,k}\middle|\Omega_t\right] + \gamma E\left[x_{t,q}\middle|\Omega_t\right]\right) + \rho i_{t-1} + v_{1t} \tag{6}$$

Going back to the example of a shock to inflation will yield valuable insight to the parameter ρ. Consider that β = 1,5. Thus, a one percentage point change in inflation would lead to a 1,5-percentage point change in the interest rate, all else equal. Adding value to p, apart from zero, will change this. If we set ρ equal to 0,8, then, because of smoothing, the economy would only experience an interest rate increase of 0,3 percentage points.

3.3 Adding variables to the Taylor rule

We can, for completeness, add other variables to the equation. This attempts to examine which additional variables Norges Bank consider when setting the interest rate. In short, we can expand the target function with an additional regressor, h_t.

$$i_t^* = \alpha + \beta E\left[\pi_{t,k}\middle|\Omega\right] + \gamma E\left[x_{x,q}\middle|\Omega_t\right] + \eta E[h_t|\Omega_t]) \tag{7}$$

Combining (7) with our objective function (6) yields:

$$i_t = (1-\rho)\left(\alpha + \beta E\left[\pi_{t,k}\middle|\Omega\right] + \gamma E\left[x_{x,q}\middle|\Omega_t\right]\right) + \eta E[h_t|\Omega_t]) + \rho i_{t-1} + v_{2t} \tag{8}$$

We can redo this procedure until we have the amount of regressors that we want. Adding two regressors will look like:

$$i_t = (1 - \rho)\left(\alpha + \beta E\left[\pi_{t,k}\middle|\Omega\right] + \gamma E\left[x_{x,q}\middle|\Omega_t\right]\right) + \eta_1 E[h_{1t}|\Omega_t] + \eta_2 E[h_{2t}|\Omega_t) + \rho i_{t-1} + v_{3t} \tag{9}$$

Adding one more lag of the interest rate to our model will look like this:

$$i_t = \left(1 - (\rho_1 + \rho_2)\right) * \left(\alpha + \beta E\left[\pi_{t,k}\middle|\mathit{\Omega}_t\right] + \gamma E\left[x_{t,q}\middle|\mathit{\Omega}_t\right]\right) + \rho_1 i_{t-1} + \rho_2 i_{t-2} + v_{4t} \tag{10}$$

This can be done if we believe that a second-order partial adjustment model fits the data better.

4. Econometric procedure

This section presents the econometric methodology used to fit the Taylor rule and to make predictions. Ultimately, we want to identify a model which predicts the interest rate setting by Norges Bank. Section 4.1 outlines the basis behind the VAR model. We explain why OLS can be challenging in 4.2. Section 4.3 looks at GMM in general, before we study how GMM can be implemented in a Taylor rule setting in section 4.4.

4.1 VAR model

In the first part of our analysis, we follow Stock & Watson (2001). This paper describes vector autoregressive models (VAR) and how these models perform at different macroeconomic tasks. Two of these tasks are describing the data and making forecasts. A general reduced form VAR model of order p can be written as (Bjørnland & Thorsrud, 2015):

$$y_t = a_0 + A_1 y_{t-1} + A_2 y_{t-2} + \cdots + A_p y_{t-p} + \epsilon_t \tag{11}$$

Where y_t is a vector of variables, a_0 is a (K x 1) vector of intercept terms, A is a (K x K) coefficient matrix, and ϵ_t is a (K x 1) vector of error terms. We assume that the VAR model is a good approximation to the true dynamics of the endogenous variables. If they are, the error terms are white noise.

Stock & Watson (Vector Autoregressions, 2001) estimate a model with three endogenous variables in a reduced form VAR model. We attempt to make a similar model. However, instead of the GDP-deflator, we use the CPI-ATE and instead of the unemployment rate, we use the output gap. The variables will be explained further in the data section. Our model will look like this:

$$\begin{bmatrix} Output\ gap_t \\ Inflation_t \\ Interest\ rate_t \end{bmatrix} = a_0 + A_i \begin{bmatrix} Outputg\ gap_{t-1} \\ inflation_{t-1} \\ Interest\ rate_{t-1} \end{bmatrix} + \cdots + A_p \begin{bmatrix} Output\ gap_{t-p} \\ Inflation_{t-p} \\ Interest\ rate_{t-p} \end{bmatrix} + \begin{bmatrix} \epsilon_{1,t} \\ \epsilon_{2,t} \\ \epsilon_{3,t} \end{bmatrix} \tag{12}$$

a_0 is a vector of intercept terms. A_i and up to A_p are 3x3 matrices of coefficients. Note that we use the same variables as in our baseline Taylor rule from the previous section. We use the weight of 0,5 for both the inflation gap and the output gap as Taylor originally proposed (Taylor, 1993). Further, the Norwegian interbank rate (NIBOR) is used as a proxy for the interest rate. The first model we estimate is backward-looking; thus, we can use OLS.[4] We use four lags of the interest rate, inflation and the output gap. This is reasonable because we use quarterly data. Stock & Watson (2001) do the same in their paper. Our estimation is based on a two-stage approach. First, we fit the original model. Second, we make a regression with financial variables on the residuals from the model. The models we estimate can be written as:

$$i_t = r^* + \pi + 0{,}5(\bar{\pi}_t - \pi^*) + 0{,}5(\bar{x}_t) + lagged\ values\ of\ i, \pi, x + \epsilon_t \tag{13}$$

r* is the desired real interest rate.[5] $\bar{\pi}_t$ and $\bar{x}_t$ are calculated by taking the four-quarter average of inflation and the output gap. Further, π^* is the inflation target. Additionally, ϵ_t is the error term in the equation, and it can to thought of as a “shock” to monetary policy.

Equation (13) would, in fact, have been the last equation in a structural VAR model (SVAR) (Stock & Watson, 2001). In a SVAR model, the variable at the bottom of the vector can be affected contemporaneously by all the other variables. The ranking of the variables is motivated by economic theory. We believe that the interest rate is the fastest moving among the three variables; hence, it is considered the least exogenous variable. The interest rate is, therefore, ranked in a manner that allows it to react in the same quarter to both inflation and output gap shocks. The contemporaneous coefficients are predetermined in our first analysis, with values of 0,5. Subsequently, we can analyse the models with OLS without worrying about the identification difficulties. Later, we explain how to identify the system when we allow the contemporaneous coefficients to differ from 0,5. When the contemporaneous effects are predetermined, we need to be careful with the interpretation of the results as these are only true under strong assumptions.

The error term in equation (13) shows how much the interest rate deviates from the original Taylor rule. We can estimate the shock by making a regression with $i_t - 0.5(\bar{\pi}_t - \pi^*) - 0{,}5(\overline{x_t})$ as our dependent variable. The right-hand side variables consist of a constant, and four lags of the inflation gap, the output gap and the interest rate. Our VAR analysis also feature a forward-looking Taylor rule. This include four quarter ahead inflation gap and one quarter ahead output gap in the Taylor rule. The forward-looking rule use the same coefficients of 0,5

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[4] When using OLS, we don’t take into account the correlation between errors across equations. Since this is an efficiency issues, it does not lead to biased coefficients. However, we need to be careful with inference since standard error probably are wrong.

[5] To relate to section 3, we can write $i^* = r^* + \pi$. This is just the Fisher equation.

for output and inflation. To estimate the point forecasts, we use a reduced form VAR model. In such a model, variables are not allowed to affect each other contemporaneously. Consequently, the forecasts are based on four lags of the three other variables. When estimating the forecasts, we do it out-of-sample by a recursive window. The latter means that one more observation is added each time we make a new forecast. A multivariate forecast like this outperforms univariate models, such as a AR(4) model (stock & Watson, 2001). We came to the same conclusion when testing for this, but these results will not be presented in our thesis.

Furthermore, we conduct a first analysis to see if other variables can explain the error term. Key financial variables are our primary focus, but we also include variables like exchange rate and foreign interest rates. Additionally, we also want to test if we get a better forecast by adding different variables to our system. Forecasts are compared by looking at the root mean square error (RMSE). A lower RMSE means that the model fits our data better (Bjørnland & Thorsrud, 2015, s. 204).

Lastly, we want to make contemporaneous links between the variables. However, this demands that we change our reduced form VAR to a recursive VAR. Hence, we make the error terms in the system orthogonalized by Cholesky decomposition. This is necessary to identify the model.[6] The ordering of the variables will be based on economic theory and results from Granger causality tests. However, since we are most interested in responses to the interest rate, we exclusively let the interest rate respond contemporaneously to all the other variables. The exact ordering will be addressed in section 6.1 In short, the test of Granger causality is a simple F-test to test whether lags of any of the other variables are jointly significantly different from zero (Bjørnland & Thorsrud, 2015, s. 207). Rejection of the null is a sign of causality, but we must be careful when interpreting the results. Results are presented in appendix C. Based on the recursive VAR model, we can make orthogonalized impulse response functions (IRF). The orthogonalized responses rely on the identification of the system, in other words, the ordering of the variables in the vector. The response functions show how the interest rate changes over time when we get shocks (or innovations), to the other variables in the system.

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[6] We will not go into details about Cholesky decomposition here. See Bjørnland & Thorsrud (2015) for a further discussion. We will also recommend chapter three and four in “New Introduction to multiple time series analysis” by Lütkepohl (2005) for detailed mathematical discussion.

Formally, The IRFs measure the variables reaction at time $t + h$ for $h = 0, \ldots, H$ to a one-unit shock of the disturbance vector of d_i. i is the three endogenous variables, and d is the shock.

Finally, we compare the forecast error variance decomposition (FEVD) of the shocks. This shows how much of the interest rate variance that is described by the other variables in the y_t vector (Bjørnland & Thorsrud, 2015). The FEVD work like a partial R^2 by forecast horizon for the forecast error.

4.2 Problems with OLS

We want to find the best way to estimate the Taylor rule for Norway and we start by looking at why OLS is problematic. The original Taylor rule is linear in parameters; thus, linear methods would be most applicable, given that the assumptions between the explanatory variable and the error term holds. Here we think of methods such as ordinary least squares, or two stage least squares (2SLS) if we expect endogeneity issues. We have already discussed why we prefer a forward-looking Taylor rule and that a smoothing parameter should be included. When a smoothing parameter is included, parameters are no longer linear. This is a clear violation of the OLS and 2SLS assumptions regarding unbiased and consistent estimators. Hence, non-linear estimation methods should be used when facing interest rate smoothing.

In addition, when we use a forward-looking Taylor rule, we believe that the central bank uses the expected inflation rather than the current inflation. This is supported by Clarida, Gali and Gertler (1998) who did not find any statistically significant evidence that central banks operate in a backward-looking manner. For this reason, a forward-looking specification surpasses a backward-looking specification. Nonetheless, using a forward-looking specification comes with a challenge. The explanatory variable will be correlated with the error term at time t. As a result, even if we used a linear forward-looking rule, the zero conditional mean assumption of OLS would be violated. In other words, the explanatory variable is endogenous. Luckily, there are methods that can deal with these issues. The generalized method of moments (GMM) can handle non-linear equations with endogenous explanatory variables, provided that you have valid and relevant instruments available. Hence, GMM would be a natural method for estimating a forward-looking Taylor rule. Other strengths of GMM features the ability to deal with residual heteroskedasticity and residual autocorrelation. Further, GMM does not rely on strong distributional assumptions. For instance, it can handle situations with skewed distributions.

4.3 Generalized method of moments (GMM)

GMM makes use of a set of moment conditions. The purpose behind these moment conditions is to solve for the parameters of our model. When estimating, we need at least as many moments as parameters. In this case, the model is exactly identified. If there are more moment conditions than parameters, the model is overidentified. This means that the orthogonality conditions will no longer exactly hold. The GMM estimator tries to make them as close to being satisfied as possible, see the minimization problem (16) below. While both yield valid results, we must test for over-identifying restrictions whenever the number of moment conditions surpasses the number of parameters. The moment conditions can be formulated in the following way (Drukker, 2010):

$$E[m(y_t, x_t, z_t\ , \theta) = 0] \tag{14}$$

m is q *x* 1 vector of functions. Specifically, the expected values of m are zero in the population. Further, y_t is the left-hand side variable, and x_t is the explanatory variable vector. Additionally, z_t is q *x* 1 vector of instrumental variables and θ is k *x* 1 vector of parameters, where k ≤ q. The sample moments from the population moments are:

$$\bar{m}(\theta) = \frac{1}{T} \Sigma_{t=1}^{T} m(y_t, x_t, z_t, \theta) \tag{15}$$

The goal is to solve the over-identified system of moment conditions. When $k < q$, the GMM choses the parameters that minimize the following objective function with respect to the parameter vector θ:

$$\hat{\theta}_{GMM} \equiv \Sigma_{t=1}^{T} argmin_{\theta} \bar{m}(\theta)' W \bar{m}(\theta) \tag{16}$$

Only, when $k = q$ can we get an explicit formula where the moment conditions are exactly satisfied. Then the GMM estimator solves $\bar{m}(\theta)$ so that $\bar{m}(\theta)' W \bar{m}(\theta) = 0$. When the system is overidentified, we minimize with the use of numerical optimization methods. This is because a large number of moment conditions require a numerical minimization.

4.4 GMM and the Taylor rule

From equation (6) in section 3.2, we had:

$$i_t = (1-\rho)\big(\alpha + \beta E[\pi_{t,k}|\Omega] + \gamma E[x_{x,q}|\Omega_t]\big) + \rho i_{t-1} + v_{1t} \tag{17}$$

The next step, since we want to focus on realized rather than expected variables, is to eliminate the unobserved forecast variables. To do so we follow Clarida, Gali Gertler (1998) and introduce an auxiliary variable ε_{1t}:

$$\epsilon_{1t} = -(1-\rho)\big(\beta(\pi_{t,k} - E[\pi_{t,k}|\Omega_t]\big) + \gamma(x_{t,q} - E[x_{t,q}|\Omega_t])) + v_{1t} \tag{18}$$

The logic behind this step is that we end up with an expression that is a combination of the forecast errors and the exogenous error term. Thus, it is orthogonal to the variables in the information set. We solve the equation for v_{1t}:

$$v_{1t} = (1-\rho)\big(\beta(\pi_{t,k} - E[\pi_{t,k}|\Omega_t]\big) + \gamma(x_{t,q} - E[x_{t,q}|\Omega_t])) + \epsilon_{1t} \tag{19}$$

By inserting (19) into (17) we make the expectation term disappear:

$$i_t = (1-\rho)\big(\alpha + \beta E[\pi_{t,k}|\Omega] + \gamma E[x_{x,q}|\Omega_t]\big) + \rho i_{t-1} + (1-\rho)\big(\beta(\pi_{t,k} - E[\pi_{t,k}|\Omega_t]\big) + \gamma(x_{t,q} - E[x_{t,q}|\Omega_t])) + \epsilon_{1t} \tag{20}$$

Thus, we are left with:

$$i_t = (1-\rho)\big(\alpha + \beta\pi_{t,k} + \gamma x_{t,q}\big) + \rho i_{t-1} + \epsilon_{1t} \tag{21}$$

The reason for this algebraic manipulation is to get to a point where we can write the policy reaction function in terms of observed variables. Lastly, we define Z_t to be a vector of variables within the central bank's information set at the time it chooses the interest rate. This vector of variables is orthogonal to ϵ_t. Variables included in the instrument set need to be uncorrelated with ε_{1t}. Furthermore, instruments can take the form of either lagged values or current values, as long as this condition is upheld. Instruments will be considered if they help forecasting the regressors of interest, here inflation and output gap. The restriction can be formulated the following way $E[\epsilon_{i1}|Z_t] = 0$, which we can write as:

$$E\big[i_t - (1-\rho)[\alpha + \beta\pi_{t,k} + \gamma x_{t,q}] - \rho i_{t-1}|Z_t\big] = 0 \tag{22}$$

Equation (22) provide us with the orthogonality conditions. To estimate the parameter vector $[\beta, x, \rho, \alpha]$ we use generalized method of moments (Hansen, 1982) (Clarida, Gali, & Gertler, 1998). In our baseline model we include four lagged values of inflation, output gap and interest rate. We only use lags because we believe that current values of inflation and output gap are endogenous with respect to the interest rate. Since we use four lags, the number of variables in the instrument set exceeds the number of parameters being estimated. When the number of orthogonality conditions surpasses the parameter vector, the model is overidentified.

In order to assess the validity of our specification, as well as the instruments used, we must test for over-identifying restrictions (Hansen, 1982). Under the null hypothesis the values for $[\beta, x, \rho, \alpha]$ exist, such that the residual ϵ_t, is orthogonal to the variables in the information set Ω_t. Plainly, the central bank sets the interest rate based on the idea that equation (17) holds. This include the assumption that the expected values, on the right-hand side, are based on policy makers use all the relevant information at that time. The alternative hypothesis, however, give evidence that some relevant "explanatory variables" are omitted. We believe we have omitted variables if the central bank reacts differently to the information that variables in the instrument set give, with respect to future inflation and output. Hence, the orthogonality condition is violated, if some of the omitted variables are correlated with $\mathbf{Z}_t$. If so, this leads to a rejection of the model if we have a sufficiently large sample.

A central bank might regard other factors as important when setting the interest rate, beyond those included in our baseline model. For example, we could think of policies that aim at keeping the house prices within reasonable bounds. Being listed as one of Norges Bank's four main indicators of financial imbalances may imply that this concern influences their policy independent from the information they have on inflation and output. Note that this is one possibility, and there might be various factors that influence the interest rate setting. To implement this into the policy reaction function, we must tweak the baseline policy function somewhat. We have from (8) the policy function with one added regressor h_t:

$$i_t = (1-\rho)\big(\alpha + \beta E\left[\pi_{t,k}|\Omega_t\right] + \gamma E\left[x_{x,q}|\Omega_t\right]\big) + \eta E[h_t|\Omega_t]) + \rho i_{t-1} + v_{2t} \tag{23}$$

The procedure of getting a function of observed values mirrors what we did before reaching equation (21). A slightly rewritten, expanded, Taylor rule looks like:

$$i_t = (1-\rho)\big(\alpha + \beta\pi_{t,k} + \gamma x_{t,q} + \eta h_t\big) + \rho i_{t-1} + \epsilon_{2t} \tag{24}$$

For completeness, it is straightforward to add additional regressors by following this same procedure. An expanded Taylor rule with two added regressors, beyond inflation and output will look like:

$$i_t = (1-\rho)\left(\alpha + \beta\pi_{t,k} + \gamma x_{t,q} + \eta_1 h_{1t} + \eta_2 h_{2t}\right) + \rho i_{t-1} + \epsilon_{3t} \qquad (25)$$

Again, we can also add one more lag of the interest rate to our model. We will do this by extending equation (25).

$$i_t = \left(1-(\rho_1+\rho_2)\right) * \left(\alpha + \beta\pi_{t,k} + \gamma x_{t,q} + \eta_1 h_{1t} + \eta_2 h_{2t}\right) + \rho_1 i_{t-1} + \rho_2 i_{t-2} + \epsilon_{4t} \qquad (26)$$

5. **Data**

This section presents the data used in our empirical analysis. Subsection 5.1 discusses the appropriate sample period. Subsection 5.2 addresses the original Taylor rule variables; the interest rate, inflation and the output gap. Furthermore, we know that Norges Bank considers a broad range of indicators when evaluating the level of financial imbalance, see subsection 2.3.5. (Norges Bank, 2018c). Particular weight is given to four key indicators, three of which are released publicly by Norges Bank. We discuss, in section 5.4, the three available indicators; credit-to-GDP ratio, the ratio of housing prices to disposable income, and the banks' wholesale funding ratio. Some other variables, apart from the key indicators, are also important determinants of the interest rate. Subsection 5.4, therefore, includes foreign interest rate, the exchange rate and equity return.

5.1 Sample period

Our sample period stretches from 1999q1 to 2018q3. Norway has officially targeted inflation since 2001, but many claims that it began in 1999; the year Svein Gjedrem was appointed as the new governor of Norges Bank (Andreassen, Grauwe, Solheim, & Thøgersen, 2001). This argument, along with the benefit of having more observations, gives us reason to start our analysis in 1999. Data further back than 1999 are not included, because we prefer that all parts of the sample period are under the same monetary policy regime.

5.2 Taylor rule variables

Recall the original Taylor rule from subsection 3.1. The interest rate estimation is based on the difference between the inflation to the inflation target, and the difference between actual and potential output. In our experience, findings depend heavily on which data we use for inflation and how the trend component for the output gap series is determined. In the following subsubsections, we will explain the choice of variables used to estimate the Taylor rule on Norwegian data.

Variable	Mean	Std. Dev.	Min	Max	Obs
Interest rate (NIBOR)	3,42	2,21	0,81	7,45	79
Inflation	1,76	0,80	0,16	3,28	79
Output gap	0,10	1,38	-2,10	3,30	79

Table 1 Descriptive statistics of variables from original Taylor rule

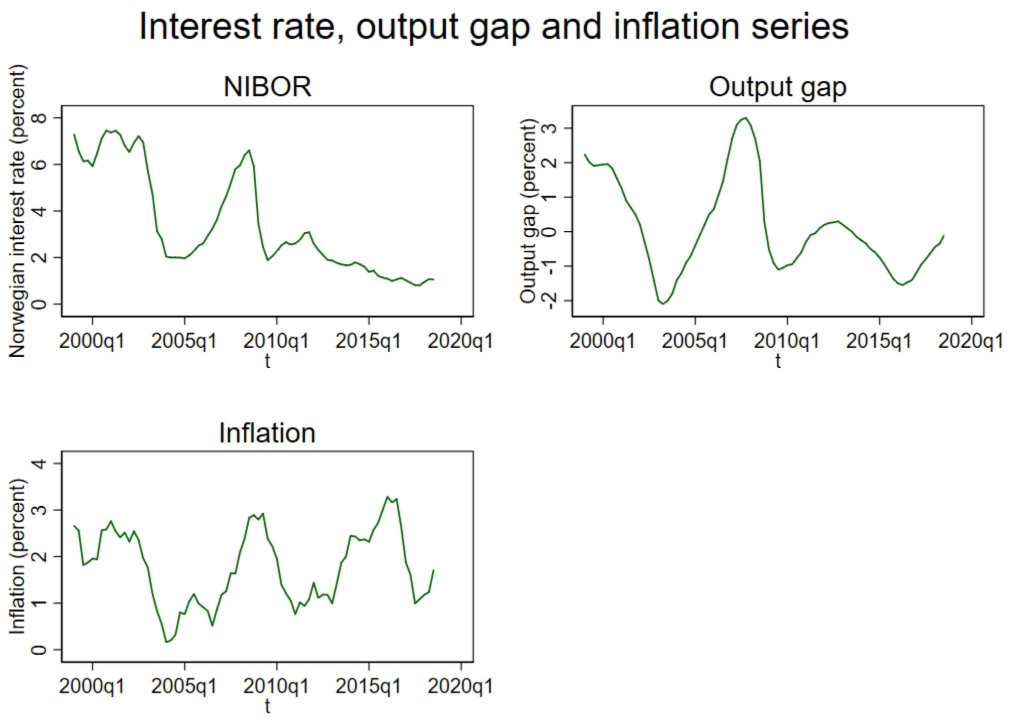

Figure 1 Interest rate, output gap, inflation data series between 1999q1 and 2018q3

5.2.1 The interest rate

We use the three-month Norwegian interbank offered rate (NIBOR) as a measure for short term nominal interest rate. NIBOR reflects which rate a bank require when they lend to other banks. It is calculated by taking the trimmed mean interest rate from six panel banks that operate in Norway. The panel banks for NIBOR are DNB Bank ASA, Danske Bank, Handelsbanken, Nordea Bank Norge ASA, SEB AB and Swedbank. The NIBOR-statistic, supplied by Norges Bank, is released with a monthly frequently. Hence, we calculated three-month averages to secure consistency with the other quarterly released data series. Trimming means to exclude the most extreme values, at both ends.[7]

We use NIBOR as a proxy for the short-term nominal interest rate in our Taylor rule estimation. NIBOR is the only variable kept in levels. The decision is based on the advantageous a variable in levels give in terms of simplifying the coefficient interpretations. Many papers support this choice (Robstad, 2014; Bjørland & Jacobsen, 2009; Skumsnes,

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[7] If more than seven banks submit; the two highest and the two lowest interest rates are omitted. The lowest and the highest are omitted when five, six or seven banks have submitted their interest rate. The rules can be found in “Nibor-rules” available from Norske Finansielle Referanser AS (NoRe) online. The rate is available from Oslo Børs.

2012; Helseth, 2015). Figure 1 shows how the NIBOR has evolved over time. We can see a clear negative trend. Over the sample period the highest value is 7,45 percent and the lowest value is 0,81.

5.2.2 **Inflation**

We seasonally adjusted consumer price index, adjusted for tax changes and excluding energy commodities (CPI-ATE) to create our measure for inflation. The one-year inflation is calculated as the four-quarter log difference of the CPI-ATE. Quarterly values are made by taking three-month averages of the data collected from Statistics Norway.[8] Inflation, defined this way, is often referred to as core inflation. A key characterization of a small, open economy, such as Norway, is that these countries are price takers. Basically, it means that their policies do not affect world prices. Thus, energy commodity prices are exogenously given. It is, as a result, reasonable to exclude this.[9] Similarly, we exclude direct impacts on the consumer price index from tax changes, as the central bank typically doesn't want to respond to this. From figure 1, we can see that inflation has been below the target of 2,5 percent for most of the sample period with a mean inflation rate of 1,76 percent.

5.2.3 **Output gap**

The natural starting point when estimating the output gap is to find a reasonable measure for the gross domestic product (GDP). This can be a challenge because Statistics Norway release many variations of GDP. Also, there are no rules on how potential output should be estimated. We were fortunate enough to receive the actual output gap series estimated, and used, by Norges Bank. They seasonally adjust gross domestic product for mainland-Norway and use a three-quarter moving average. Mainland Norway consists of all domestic production activity except from exploration of crude oil and natural gas, in addition to oil and gas-related services and the transport via pipelines and ocean transport (Statistics Norway, 2014). There are several reasons why Norges bank prefer GDP mainland-Norway, opposed to other measures of GDP.

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[8] Statistics Norway doesn't publish these numbers online further back than 2002m12. Before 2002m12, the number can be found in inflation reports by Statistics Norway until late 2000 (Statistics Norway, 2017). Our series between 1999m1 and 2000m10 is estimated numbers by Norges Bank. Graphically, the CPI-ATE can be seen in all Monetary Policy Reports posted by Norges Bank, but with different horizons (Norges Bank, 2018b). The CPI-ATE from 1999 and onwards is visible in the charts in the Inflation Report from 3/03.

[9] For a further explanation and discussion about the different measures for the consumer price index in Norway, see Lilleås (2001). A list of taxes that are adjusted are also presented.

Plainly, Norges Bank wants to react to what it knows. The oil and gas industry are shock-driven and far beyond the control of Norges bank. Thus, large fluctuations, led by exogenous shocks to supply and demand, is something that would disturb, rather than strengthen, the estimation.

The output gap is commonly estimated by simple univariate methods. Univariate methods usually pose few challenges in practice and yield reasonable results (Hagelund, Hansen, & Robstad, 2018). The most well-known is the so-called Hodrick Prescott (HP) filter (Hodrick & Prescott, 1997). A known struggle for a *simple* HP filter is, however, to handle real time data (Hamiltion, 2017). Another disadvantage is that it only uses GDP data in estimating the output gap. Norges Bank uses HP filters in their trend estimations, but by more advanced methods (Sturød & Hagelund, 2012).

Specifically, Norges Bank uses multivariate models to estimate the output gap (Hagelund, Hansen, & Robstad, 2018). It means, essentially, that they use other variables in addition to GDP. Their output gap estimations cover data such as unemployment, wage growth, inflation, investment, credit growth and house prices. Allowing more variables to enter the estimation give multivariate models better real-time properties and better real-time forecasting properties, compared to simple univariate methods. In other words, it creates a more trustworthy trend. Further, a univariate model's forecasting properties are limited to GDP growth, because its trend is solely based on GDP data. Multivariate models, on the other hand, have good forecasting properties on the development in GDP growth, as well as the other variables included in the model. The output gap is simply the percent deviation in actual output from the estimated trend, $100\left(\frac{y-\tau}{\tau}\right)$. From the figure 1, we see that the output gap has fluctuated a lot over the sample period. For the last ten years, it has been below zero for most of the period.

5.3 Norges Bank's key indicators

Norges Bank reviews a set of indicators when addressing the issue of financial instability (Norges Bank, 2018c). Additional weigh is given, particularly, to four key indicators. We focus on the three indicators where the data series is publicly available. For the definitions of the key financial indicators, see subsection 2.3.5.

1. Credit-to-GDP ratio for mainland Norway
2. The ratio of house prices to disposable income
3. Banks’ wholesale funding ratio.

First, the credit is the sum of households’ debt (C2) and total non-financial enterprises debt (C3) for mainland Norway (Norges Bank, 2013).[10] Second, house prices are calculated based on different sources.[11] Third, the Banks’ wholesale funding ratio is total liabilities less customer deposits and equity, as a percentage of total liabilities. Wholesale funding mainly refers to federal funds, foreign deposits and brokered deposits. When high, and rising, it may reinforce an increase in debt and asset prices (Norges Bank, 2013). In turbulent times, banks’ funding costs increase substantially, or their access to wholesale funding often dries up. This usually leads to a tightening of banks’ lending policies, hence when it is increasing, we would expect the interest rate to increase.

The indicators are also released in a gap format, i.e.; credit gap, house price gap and wholesale funding gap. Historically, large positive gaps between the series and the trend serve as an indication of financial imbalances in the economy. On a cautionary note, the gap series are not stationary. We use instead a four-quarter log difference for both the credit-to-GDP ratio and the housing prices/disposable income. This provides us with yearly changes. For the Banks’ wholesale funding ratio, yearly changes are calculated directly. From the table below, we see that all three variables have a positive mean. Figure 2, on the other hand, show large sample period fluctuations. After the financial crisis the fluctuations have been reduced.

Variable	Mean	Std. Dev.	Min	Max	Obs
Yearly change in credit-to- GDP ratio	2,67	2,44	-0,25	10,10	78
Yearly change in housing prices to disposible income ratio	1,84	5,56	-13,65	16,18	78
Yearly change in wholesale funding ratio	1,57	4,20	-6,63	13,71	78

Table 2 Descriptive statistics for the three key financial indicators

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[10] Data series for the three financial indicators are explained in detail in Norges Bank Paper No. 1, 2013 (Norges Bank, 2013)

[11] House prices are based on data from Eiendonsverdi, Finn.no, Norwegian Association of Real Estate Agents (NEF), Real Estate Norway, Statistics Norway and Norges Bank. The house price index is seasonally adjusted.

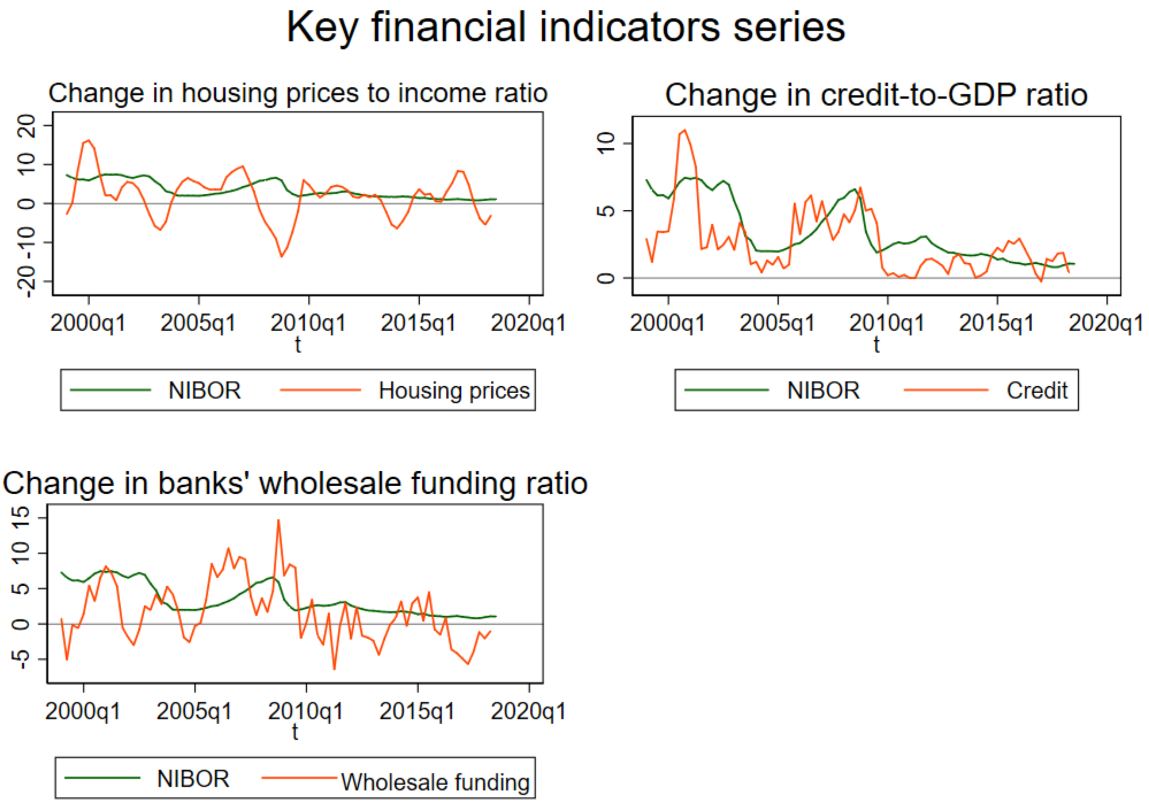

Figure 2 Yearly growth rates in housing prices to disposable income ratio, credit-to-GDP ratio and wholesale funding ratio

5.4 Additional information variables

We include, in addition to the financial indicators, the Euro Area interest rate, the exchange rate and the stock market returns, to the analysis. First, we have the 3-month interbank lending rate in the Euro Area. This works as a proxy for the foreign interest rate and is obtained from the OECD database. Here we use four quarter difference to get the yearly growth rate. The series is shown in the panel below, to the left. We have also added the short-term money market rate for the US to illustrate the close relationship between these series. It appears that the American interest rate is leading the other two. The correlation between the Norwegian and the Euro Area interest rate is as high as 0,88. Between Norway and the US it amounts to 0,64. In the following we focus on the relationship between the Euro Area interest rate and the NIBOR.

Second, we include the import weighted currency, the I-44. It works as a measure of the Norwegian exchange rate and it is calculated by comparing the Norwegian currency against 44 of its biggest trade partners. An increase in I44 means that the Norwegian krone depreciates. We use four-quarter log difference. The third variable we add is the quarterly average of the

Oslo Stock Exchange Benchmark Index. Again, we calculate a four-quarter log difference. The variable works as a proxy for the equity return in Norway.

Variable	Mean	Std. Dev.	Min	Max	Obs
Yearly change in exchange rate	0,16	5,38	-11,60	12,14	79
Yearly change in Euro Area interest rate	-2,21	1,08	-4,11	2,04	79
Spread between long and short term bills	0,36	1,10	-2,40	2,77	79
Yearly change in equity prices	9,25	24,70	-71,66	55,22	79
World commodity price infaltion	5,10	23,03	-56,27	44,20	79

Table 3 Descriptive statistics from additional variables

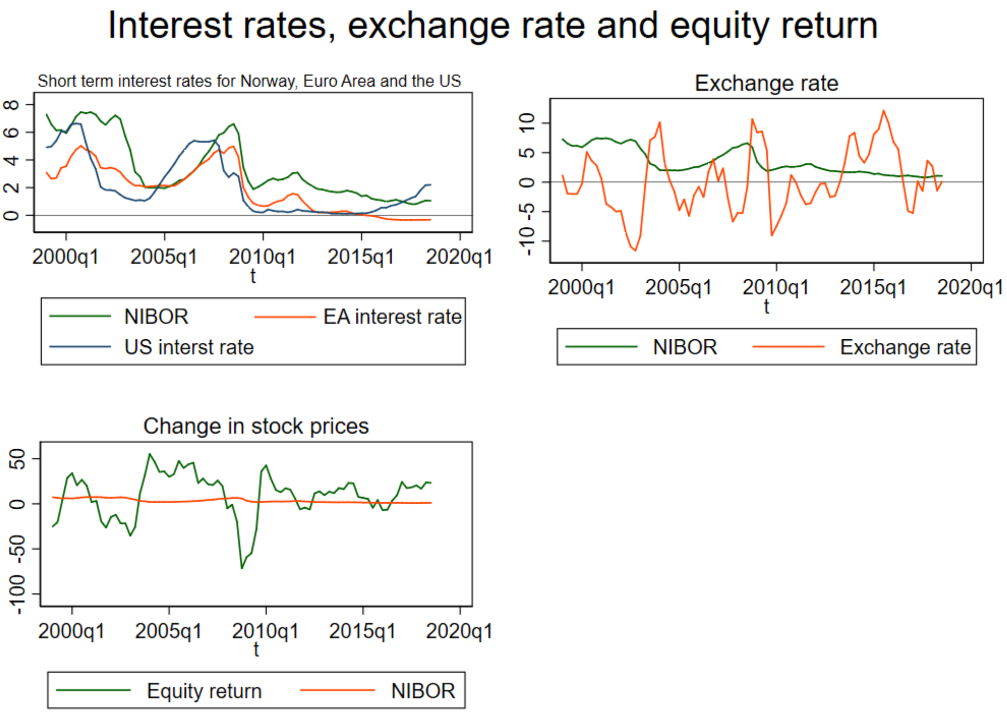

Figure 3 Interest rates, exchange rate and equity return from 1999q1 to 2018q3

We add world commodity price inflation and the spread between long- and short-term interest rates for Norway to the instrument set in the GMM analysis. Not only are these variables exogenous and, therefore, considered *good* instruments, but they also fall in line with estimations done by Clarida, Gali & Gertler (1998, 2000) and Skumsnes (2012). The world commodity price index was gathered from the International Monetary Fund's *International Financial Statistics*. We calculate the inflation by taking the four-quarter log difference and multiply by one-hundred. The spread between long- and short-term interest rates is the difference between ten-year government bonds and the NIBOR. The latter is collected from the OECD database.

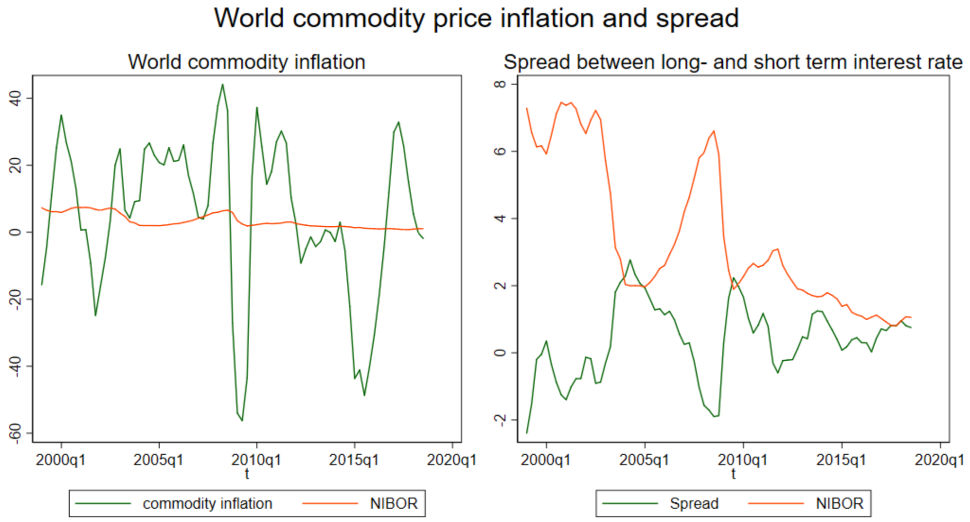

Figure 4 World commodity price inflation and the spread between long term bonds and short-term interest rate (NIBOR)

6. Empirical findings

In this part of the thesis, we estimate different specifications of the Taylor rule. Section 6.1 analyses which variables the interest rate has responded to using a vector autoregression framework. Primarily, we make forecasts and study impulse response functions. In section 6.2, we fit the best possible model using generalized method of moments estimation. In general, we study whether we can improve the model by including variables to the instrument set, or both as regressors and instruments. Our main focus is centred around the key financial indicators; credit level, housing prices and the wholesale funding ratio.

6.1 Results from a VAR framework

First, the results from an original backward-looking Taylor rule is compared to a forward-looking model. Second, a preliminary analysis is conducted to see whether financial variables can explain the error term. This uses the Taylor rule, and follows the method from the paper "Vector autoregressions" by Stock & Watson (2001). In subsection 6.1.4, we create and compare forecasts by adding variables to the original Taylor rule. We change the forecasts horizons in subsection 6.1.5, to see how this alters the estimation. In subsections 6.1.6 we compare impulse response functions and forecast error variance decompositions from a model including inflation, output gap and the interest rate, to a model that also includes the three key financial indicators. Lastly, we discuss problems with OLS.

6.1.1 **Backward-looking Taylor rule**

We start by fitting the original Taylor rule from section 4.1.[12] The model is backward-looking; hence, we can do this by simple OLS. The model contains predetermined values for the inflation gap and the output gap as originally proposed by John Taylor (1993). Our backward-looking model is illustrated together with the Norwegian interbank rate, in the figure 5 below. The dependent variable is the original Taylor rule, $i_t - 0{,}5(\bar{\pi}_t - \pi^*) - 0{,}5(\bar{x}_t)$, while the independent variables are four lags of NIBOR, inflation, the output gap, and a constant. i_t denotes the nominal interest rate. $\bar{\pi}_t$ and $\bar{x}_t$ are four quarter average values.

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[12] $i_t = r^* + \pi + 0{,}5(\bar{\pi}_t - \pi^*) + 0{,}5(\bar{x}_t) + lagged\ values\ of\ i_t, \pi, x + \epsilon_t$ (22)

There are no problems with autocorrelation in the residuals of this model. Results from a Portmanteau test supports this conclusion.[13] The test statistic (Q) for the backward-looking model is 40,9 with a p-value of 0,26. Thus, we cannot reject the null hypothesis of white noise. All the variables are, however, endogenous. We must, therefore, be cautious when interpreting the results from our backward-looking model. Heteroskedasticity is another problem. From a Breusch-Pagan test we get a test statistic of 14,76 and a p-value of less than one percent. Hence, we reject the null of constant variance (homoskedasticity). These problems will be solved for, both in the VAR and in the GMM analysis, at a later stage.

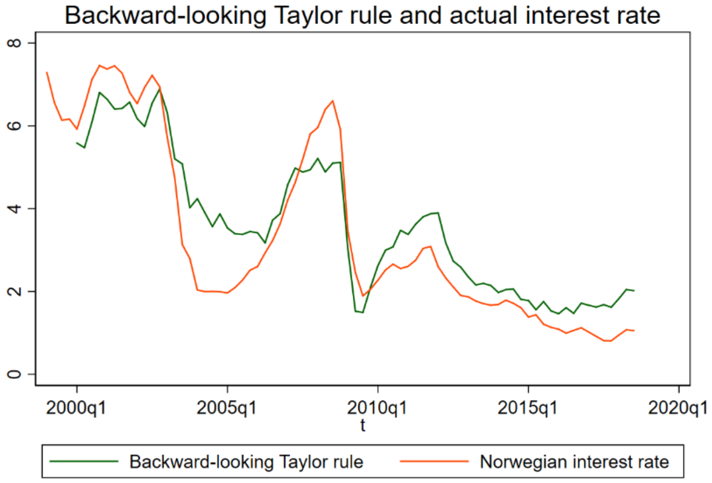

Figure 5 Norwegian short-tern money market rate (NIBOR) and predicted interest rate from the model with $i_t - 0{,}5(\bar{\pi}_t - \pi^*) - 0{,}5(\bar{x}_t)$ as the dependent variable and four lags of i_t, π, x plus a constant as the independent variables. Sample period 1999q1-2018q3.

The figure shows the actual nominal interest rate and the predicted interest rate by the original Taylor rule. First, there is a noticeable deviation between 2004 and 2008. In this period the interest rate is below the predicted Taylor rate. In subsection 5.1.4, we saw that the Norwegian interest rate follow the European and the American interest rate closely. Interestingly, the deviation we observe here is comparable to Taylor's findings; when he does the same exercise for the US economy. Taylor argues that low interest in this period might be one of the reasons for the financial crisis.[14] Ben Bernanke, as the former head of the Federal Reserve, answers this critique. In Bernanke (2015), he illustrates how sensitive the conclusions from a Taylor rule estimation are to how the model is specified. He concludes that even small changes in the

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[13] The null hypothesis in the Portmanteau test is that the variables follow a white noise process. A p-value below 0,05 means that we reject the null and conclude that the variables are not white noise. This means that autocorrelation is not a problem in the model.

[14] See for example his talk at Stanford university in 2009, available at http://www.econtalk.org/john-taylor-on-the-financial-crisis/, or "a monetary policy for the future", an opening remark at a IMF conference at Stanford university in 2015 (also available online).

Taylor rule have big impact on the interpretations. We need to keep this comment in mind throughout the analysis.

From figure 5 we see that the Taylor rate has been above the actual interest rate ever since 2010. Additionally, the interest rate has been falling since 2012. Recall, that part five revealed a changed relationship between the actual interest rate and the inflation. From theory, we believe that an increased inflation should be tackled by an increased interest rate. This has not been the case the last ten years. There are many potential reasons why this relationship seems disconnected, and why the actual interest rate has been below the Taylor rate. One reason could be the drop in the oil price in 2014. This led to a weakening of the Norwegian krone, which also led to a temporary increase in the inflation. Norway experienced a setback in production and employment as well. Thus, it appears that Norges Bank has put more weight on avoiding low activity and high unemployment, rather than handling increased inflation. However, we will later discuss the implications of the fact that inflation has been “undershooting” the target for most of the sample period. Hence, we are likely to find insignificant inflation coefficients as high inflation hasn’t been a worry for the Norwegian monetary policy on our sample period.

Furthermore, Norges Bank has concluded that the long-term equilibrium rate has come down, which is the interest rate we get when inflation is at its target and there is no output gap. There are some possible explanations for this. First, an ageing population has led to an increased supply of saving. Second, falling productivity growth has led to a reduced investment demand from businesses. Norges Bank has estimated that the current equilibrium real interest rate is 0,5 percent. With a new inflation target of two percent, it yields a nominal equilibrium interest rate of 2,5 percent.[15] Before 2009, the real interest rate was set to be 2,5. With the old inflation target of 2,5 percent, the nominal long-term interest rate was 4,5 percent. Declining interest rates could therefore be justified, as Norges Bank wish to boost economic activities, in order to stabilise inflation and output around its targets.

Another reason for a low interest rate in Norway is the low interest rates internationally. Part five illustrated the close correlation between the Norwegian and international interest rates,

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[15] The government reduced the inflation target in March 2018 from 2,5 to two percent. For more about the new regulation on monetary policy, see https://www.regjeringen.no/en/aktuelt/new-regulation-on-monetary-policy/id2592551/ or section 2.1.1 in this thesis

especially focusing on the rate for the 19 Euro Area countries. Unemployment, on the other hand, has come down, meaning that the negative output gap is about to close. This would, in theory, lead to an increased Taylor rate. Norges Bank has, based on the overall developments in the Norwegian economy, decided to increase the key policy rate from 0,5 to 0,75 in September 2018.

Household debt and housing prices have risen, however, since the end of the last financial crisis. We would expect that Norges Bank, in their wish to counteract the build-up of financial imbalances, should have reacted to such developments (in between then to now). Monetary policy reports as far back as 2010 and 2011 argued that the key policy rate should gradually be raised, as low rates over time entail the risk of a build-up of financial imbalances (Evjen & Kloster, 2012). The interest rate was raised in the period 2009-2011 but it has been declining ever since 2012. The actual interest rate has been below the original Taylor rate after 2010. From the discussion in part two we know that the central bank must raise the interest in order to tackle the build-up of financial imbalances, or at least above what only inflation and output gap concerns would predict. We would, therefore, expect an interest rate path that lies above a backward-looking Taylor Rule. The initial results from the backward-looking Taylor rule is, thus, that Norges Bank has not been “leaning against the wind” in the aftermath of the financial crisis.

6.1.2 Forward-looking Taylor rule

Many papers, including Clarida, Gali, Gertler (1999, 2000), have argued that a forward-looking model better explains the interest rate setting. As mentioned earlier, New Keynesian models are the prime examples of forward-looking models. By adding forward-looking variables, a central bank essentially takes rational expectations into consideration. Thus, it is reasonable to believe that Norges Bank is more concerned about the future inflation and output gap. Consequently, we change the measure of inflation and output gap with forecasted values. Our forecasts are based on a three variable reduced form VAR model and are done out-of-sample, dynamically, using a recursive window. The VAR model is explained in section 4.1. We start with a model from 1999q1 to 2004q3 and then we expand the window one quarter at a time. The three variables are the NIBOR, the inflation and the output gap. Inflation is forecasted four quarters ahead and the output gap one quarter ahead each period. We also add four lags of all the variables to the model, as before. Four quarters is reasonable since we look at quarterly data.[16] Our forecasting model satisfies the stability condition; hence the model is stationary.[17] Stationarity is essential, otherwise we can’t draw clear conclusions from our results. Finally, we do a small sample degrees-of-freedom adjustment.[18]

After obtaining the forecasts of inflation and the output gap, we go back to the Taylor rule featured in Stock & Watson (2001). We still use the predetermined values for inflation and output gap. Both are set to 0,5. We estimate the forward-looking Taylor rule by OLS. Four lags of the interest rate, the inflation gap and the output gap are added as independent variables. A p-value of 0,31 from the Breusch-Pagan test, means that we don’t have problems with heteroskedasticity. From the Portmanteau test, we get a p-value of 0,05. Thus, we reject the null of white noise. In other words, we might have problems with autocorrelation. Combined with the fact that we have a small sample size suggest that we should be careful when interpreting these results. The model starts in 2005q4 since we needed to use some years prior to estimate the forecasting model.

The results can be seen in the figure 6 below. The actual rate is above the Taylor rate we get from the forward-looking model between 2006 and 2009. From 2009 and onwards we see that the opposite is true. Note that the backward and the forward-looking model look quite similar. Accordingly, it doesn’t seem that financial stability has been a serious concern in the conduct of monetary policy after 2011. We will challenge these results when we improve the model.

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[16] Four quarters is also in line with what Stock & Watson (2001) uses. Bayes information criterion supports two lags while Akaikes information criterion supports five lags, hence four lags seems reasonable here. It also deals with potential seasonality issues. For a broader discussion on this topic, we recommend Bjørnland & Thorsrud (2015) page 2015-2016.

[17] If the model is mean reverting, it means that the effect of a shock will eventually die out. We can check for stability by looking at the inverse roots of the characteristic AR polynomial (Bjørnland & Thorsrud, 2015). If all the roots have modules that are less than one and they all lie inside the unit circle, we can say that our estimated VAR is stationary. This is the case here, hence, we can say that the model is stationary.

[18] The adjustment is used when estimating the error variance-covariance matrix. This means that 1 / (T - average number of parameters) is used instead of 1/T which is the large-scale divisor. The average number of parameters are taken from the functional form of y_t over the equations.

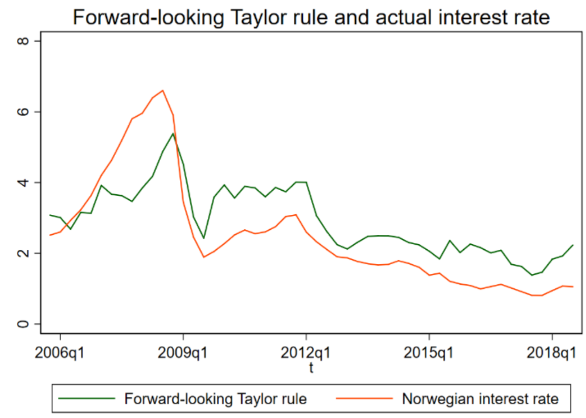

Figure 6. Actual short-term interest rate and predicted interest rate from å model with $\mathrm{i}_t - 0{,}5(\pi_{t+4} - \pi^*) - 0{,}5(x_{t+1})$ as the dependent variable and four lags of i_t, π, x plus a constant as the independent variables. Sample period 1999q1-2018q3. Recursive forecasts of inflation and output gap estimated for the period 2006q1-2018q3.

6.1.3 Error term analysis

We extend the Taylor rule by conducting a simple error term analysis. Results from this give us an indication whether other variables explain the error term from the original models featured above. We test, especially, for financial variables, because we know that the central bank stress their importance. We follow Stock & Watson (1999) and add one variable at a time to both the backward-looking and the forward-looking model.

Table 4: Regressions on residuals from Taylor rule with forecasted inflation and output gap

	Backward-looking model	Forward-looking model
Exchange rate	-0.0125*	-0.0008
	(-2.37)	(-0.12)
Euro Area interest rate	0.0164	0.019
	(0.59)	(0.63)
Change in housing price to income ratio	0.0015	0.0003
	(0.27)	(0.04)
Change in credit-to-GDP ratio	-0.0008	-0.0068
	(-0.07)	(-0.38)
Change in wholesale funding ratio	-0.008	0.0003
	(-1.18)	(0.05)
Change in equity return	0.0006	0.002
	(0.5)	(1.31)
N	75	52

Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Regressions on the residuals from a backward-looking Taylor rule and a forward-looking Taylor rule. The six variables are tested one by one in both the models.

These results yield very few significant coefficients. In fact, the only statistically significant variable is the exchange rate, but the effect is small. The coefficient is also negative, which indicates that a depreciation of the Norwegian krone would lead to a decrease in the nominal interest rate. Typically, one would expect a positive coefficient. Still, a negative coefficient is in line with other previous estimates which find this “exchange rate puzzle” (Bjørnland & Thorsrud, 2015, s. 241). Norges Bank has moved away from targeting the exchange rate directly, but it is still reasonable to expect a significant variable. The relationship will be further discussed later. At this point we don’t find any indications that other variables explain the interest rate, neither in the backward-looking model, nor in the forward-looking model.[19]

6.1.4 Forecasts from VAR models

So far, except for a small exchange rate effect, it doesn’t seem that any of the included variables can predict the error terms from the original Taylor rule. We proceed with a different approach. Specifically, forecasting exercises by our own VAR-model. The three series from the VAR model are seen in figure 7 below. We see that our model follows the three variables almost perfectly. The model is adjusted for a significant outlier, namely the forth-quarter of 2008. We deal with this potential issue by including a dummy as an exogenous variable.[20] It is reasonable to control for the financial crisis, because we want to estimate Norges Banks normal reaction pattern. Residuals with and without the observation is presented in appendix D. We also adjust for a small sample.

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[19] We also split the sample in two; pre and post 2011. The split separates the sample into the two periods with different governors of Norges Bank. These results did not change our conclusion; hence they are not presented here. We do a similar exercise in the GMM section.

[20] After the financial crisis, the Central Bank drastically reduced the interest rate. The key policy rate was initially 5,25 on October 15. 2008. On October 29, it was reduced to 4,75. Then, it was reduced to 3 percent on December 17.

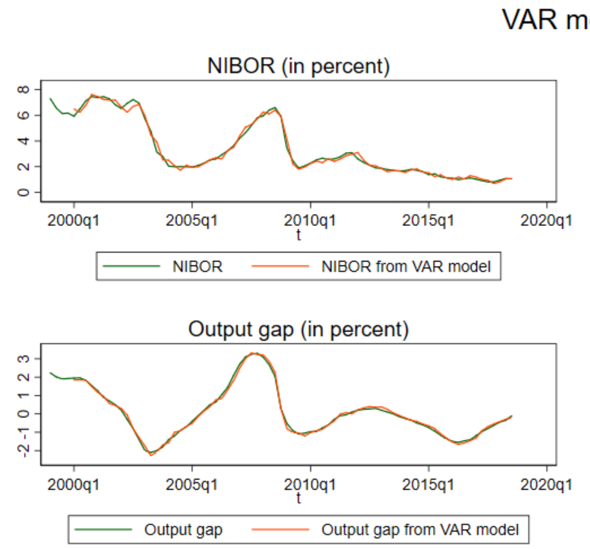

Figure 7 The fitted VAR model with NIBOR, inflation and output gap as endogenous variables. Four lags are added to the models. A dummy for the fourth quarter of 2008 is added as an exogenous variable.

The goal of the forecasting exercises is to see whether adding financial variables improve our forecasts of the interest rate. We forecast, in-sample, the last three years using our model from 1999q1 to 2015q3. When the sample is reduced, or whenever variables are added, we need to check if the model remains covariance-stationary. We test this by checking whether the eigenvalues of the companion form matrix are less than one. If they are, the effect of the shocks eventually dies out and, thus, the model is considered stationary (Bjørnland and Thorsrud, 2015). This is the case for all the models we present. In figure 8, we compare forecasts where different variables are added to the VAR model.

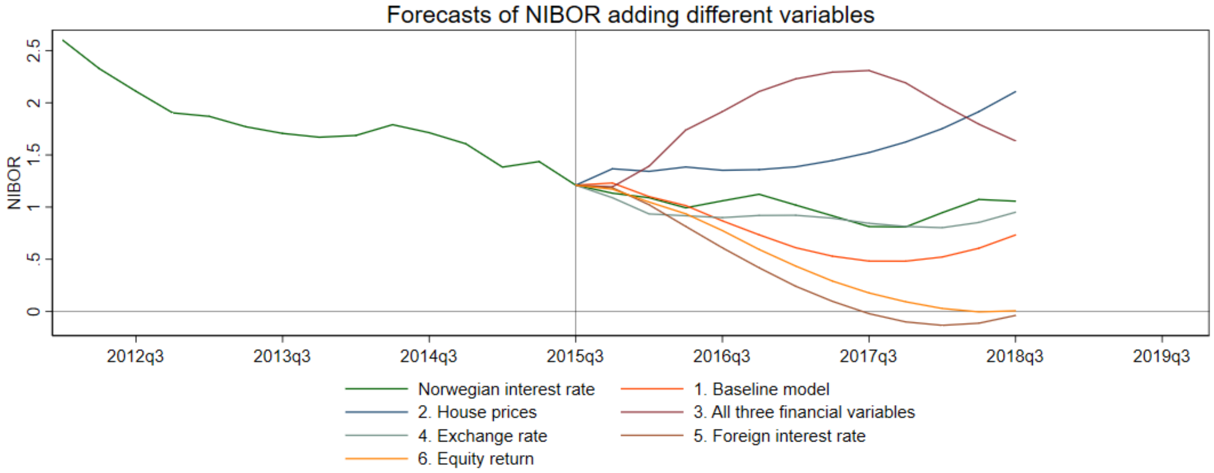

Figure 8 Forecasts from models based on the period 1999q1-2015q2. Forecasts from 2015q3 to 2018q3

Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Output gap Inflation NIBOR	Output gap Inflation NIBOR Housing prices	Output gap Inflation Housing prices Wholesale funding Credit NIBOR	Output gap Inflation NIBOR Exchange rate	Output gap Inflation NIBOR Foreign interest rate	Output gap Inflation NIBOR Equity return

Table 5 The variables used in the six different forecasting models presented in figure 8

The range between the different forecasts are quite large. One way to compare the forecasts is to look at the root mean square errors.[21] A lower score means a better forecast.

	1	2	3	4	5	6
RMSE	0,282	0,544	0,896	0,106	0,68	0,547

Table 6 Root means square error of the six three-year forecasts from figure 8

The differences between the forecasts are substantial. Both the RMSE and figure 8 indicate that the best model is the one where we add the exchange rate (model 4).[22] This line follows the actual interest rate closely, see figure 8. Drawing on earlier estimations we remember that the exchange rate was the only significant variable. The second-best model is the baseline model (model 1), with no extra variables added from the original Taylor rule. The RMSE from adding house prices (model 2) and equity prices (model 6) are about the same, but the predictions head in different directions. It is reasonable to believe that adding housing prices would predict a higher interest rate. The worst model is the one where the three financial variables are added (model 3). In this model we add four lags of the housing prices to income ratio, the credit-to-GDP ratio and the banks' wholesale funding ratio. If we believe this model, we see that Norges Bank is far from the interest rate path that would suggest a monetary policy with a financial stability concern.

6.1.5 Different forecast horizons

So far, forecasting comparisons have only been done for one particular year. Changing the year might make a difference and we control for this next. Still, we are most interested in financial variables. For this purpose, we will only compare the original model with a model

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[21] RMSE of the forecasts is calculated as $\sqrt{E[(e_{T+h})^2]} = \sqrt{E[(y_{T+h} - \hat{y}_{T+h})^2]}$. We divide by the number of forecasted observations which is 12.

[22] We get the same result when we compare the models using a Diebold-Mariano (West) test where we compare the accuracy of the different forecasts. For a discussion of this test see (Diebold, 2013)

including Norges Bank’s three key financial indicators. Hence, we will not try to find a “preferred model”, but rather investigate whether adding financial variables can improve the in-sample forecast.

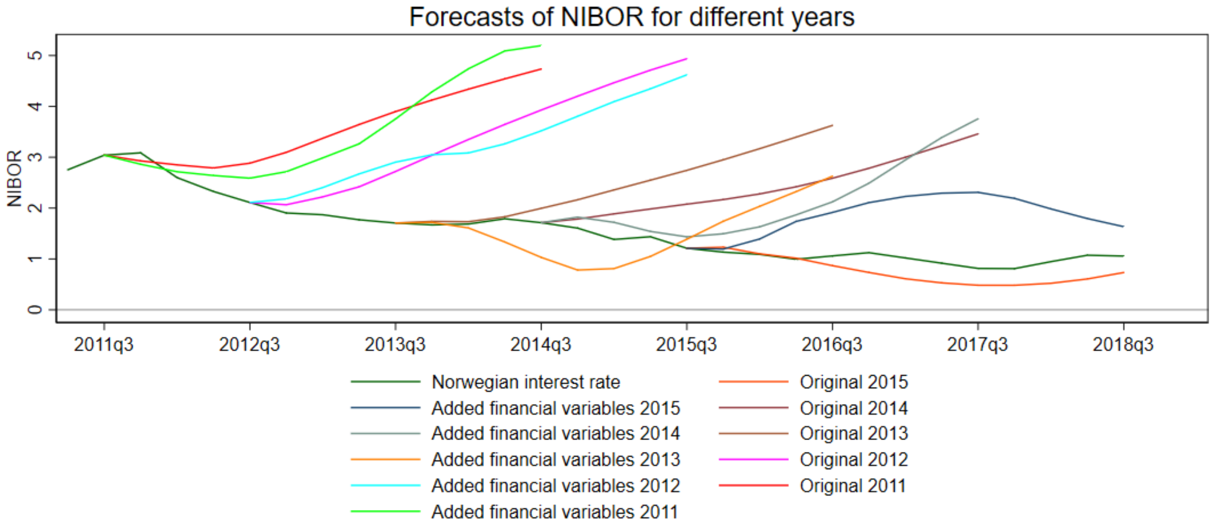

Figure 9 Three-year dynamic forecasts for the years 2011-2015. The original three-variable VAR is compared to the six-variable VAR where three financial indicators are added to the system

Noteably, different years yield quiet different results. The projections suggest an increased interest rate for most years. Interestingly, as time pases the predicted paths converge, somewhat, towards the actual interest rate path. 2011 and 2012 feature by far the highest RMSE, while 2015 feature much lower values. One possible explanation for a low prediction, and thereby a low RMSE in 2015, might be related to lower activety levels in the Norwegian economy due to the drop in oil price in 2014. Inflation also declined in 2016. Combined, this would suggest a lower predicted Taylor rate. The complete RMSE table can be seen in table 7, below.We see that the projections by the original model are weak in the years before 2015. Furthermore, the model with the three financial variables outperforms the original model for all years; except for 2015. However, the differences most years aren’t substantial and it is difficult to draw clear conclusions.[23] We also have to remember that this is a fairly simple model, hence there can be many reasons for mispecification. A decreasing interest rate is an

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[23] Forecasted values of the interest rate from models that ends in 2016, 2017 and 2018 with forecast until 2021 can be found in appendix E. We compare the original model, with the three key financial variables model, but we also add the exchange rate model. According to these models, the interest rate will reach the long-term equilibrium interest rate of 2,5 percent in 2021. The long-term equilibrium interest rate is the target inflation (2 percent) plus the long-term real interest rate (0,5 percent).

international phenomenon, and by excluding international variables (to aviod too heavy parametricized models) we believe that there is an omitted variable problem.

	2015	2014	2013	2012	2011
Three original variables	0,282	1,322	1,123	1,829	1,607
Add financial variables	0,896	1,035	0,64	1,673	1,588

Table 7 The three original variables are output gap, inflation and the interest rate. The three financial variables are changes in housing prices to income ratio, changes in credit-to-GDP ratio and changes in wholesale funding ratio

6.1.6 Impulse response functions and forecast error variance decomposition

The last thing we do with the VAR framework is to create and study the orthogonalized impulse response functions and to do a forecast error variance decomposition. In order to do so, we need to make the VAR model recursive. Thus, we identify the model by Cholesky decomposition.[24] To be able to identify the system we must add short-term restrictions. We can, consequently, add contemporaneous effects to the model. Our endogenous variables are ordered recursively in the following way for the two models:

Baseline model	Add financial variables
Output gap	Output gap
Inflation	Inflation
NIBOR	Housing prices
	Credit
	Wholesale funding
	NIBOR

Table 8 Variables included in the baseline model and the extended model containing financial variables. The variable at the top is ranked the most exogenous variable and the variable at the bottom is ranked the least exogenous variable is the Cholesky identification.

By ranking the interest rate at the bottom, we allow it to respond contemporaneously to changes in all the other variables. This type of ranking is in line with previous estimations using a structural VAR approach, see for example Bjørnland & Jacobsen (2009) or Robstad (2014). The variable at the top is only allowed to react to lags of the other variables. Importantly, all results are in line with a Granger causality test. See appendix C for test values.

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[24] For a broader discussion on this identification method, see Lutkepohl ch. 3 (2005) or Bjørnland & Thorsrud (2015) page 2015-2016.

When interpreting we must, however, be aware of a drawback to the Cholesky decomposition. Specifically, only one variable is allowed to react to all other variables contemporaneously. For example, if we think there is a simultaneity issue between the interest rate and the housing prices, only one of them can respond to the other in the same period, thus, the responses that we estimate to the shocks will be biased.[25] Featured in figure 10 are the orthogonalized impulse response functions, and the forecast error variance decomposition for both models. First, we analyse the baseline model. Second, the model with financial variables. The impulse response functions illustrate how the NIBOR responds to a one standard deviation shock, both to itself, and the other variables over a period of three years. The grey area represents the bootstrapped 95 percent confidence interval using 1000 repetitions.[26]

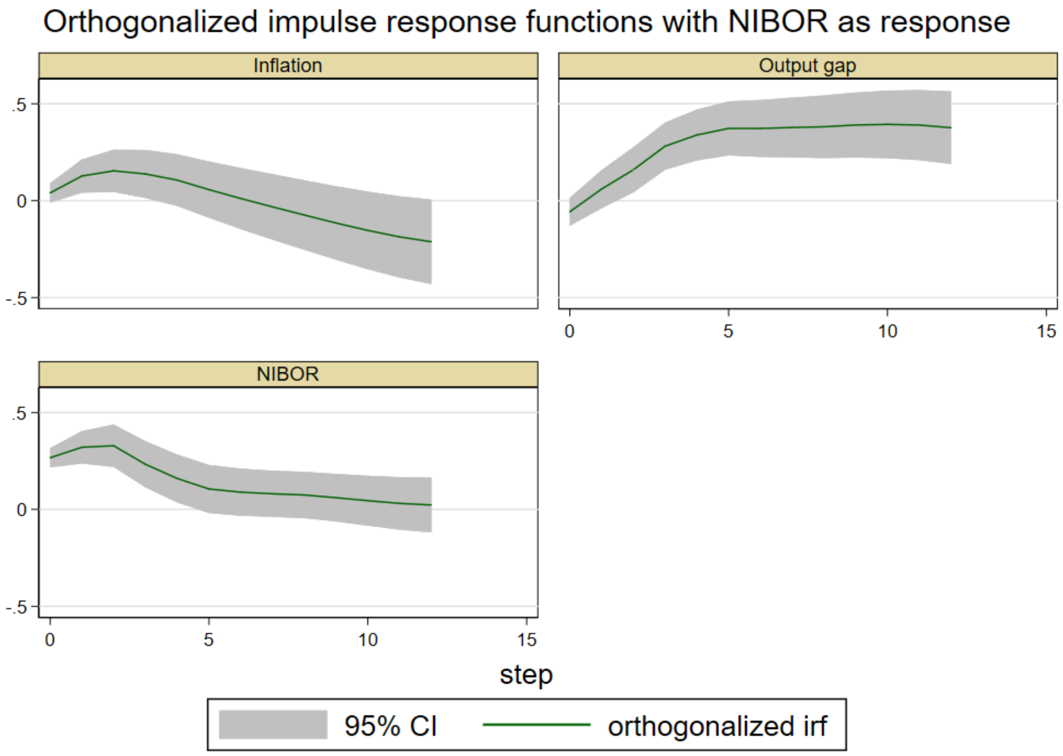

Figure 10 Orthogonalized impulse response functions for the baseline VAR model containing output gap, inflation and the interest rate. The figures show the response in NIBOR to a one standard deviation shock to each of the three variables in the system

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[25] In the literature, this problem has been solved by for example, adding a combination of sign restrictions and short run restrictions (Bjørnland & Jacobsen, 2009), or a combination of short-run and long-run restrictions. However, there are also shortcomings with this procedure, see Bjørnland and Thorsrud (2015) page

[26] The method of bootstrapping is described in section 6.3.3 in *Bootstrap Methods and Their Application* by Davidson & Hinckley (Bootstrap Methods and their Application, 1997). We use bootstrapped confidence intervals to account for the possibility of heteroskedasticity in the error terms.

Figure 10 shows the impulse responses in NIBOR after a one standard deviation shock to each of the variables in the system, over a period of three years. Observably, a rise in inflation leads to an increase in the interest in the short run, before eventually declining. The increase is significant for the first three quarters with a peak increase of 15 basis points after two quarters. The increase is in line with the Taylor principle. Further, a shock to the output gap significantly increases the interest rate. The increase peaks after ten quarters with an increase of 39 basis points in the interest rate.[27]

The long-term reaction path of the interest rate to an inflation shock still looks a bit disconnected from standard theory. Again, we underline that this is a simple model, thus results like the “price puzzle” might be hard to avoid. As earlier mentioned, however, if we instead use a combination of long and short-term restrictions, or sign and short-run restrictions, this problem might be solved (Bjørnland & Jacobsen, 2009).

Variance decomposition of change in NIBOR

		Variance decomposition (percentage points)		
Forecast Horizon	Forecast Standard Error	Output gap	Inflation	NIBOR
1	0,13	4	2	94
4	0,32	22	12	66
8	0,31	58	7	35
12	0,28	69	9	22

Table 9 Forecast error variance decomposition of the change in the interest rate

Interestingly, after about two years (eight quarters), the output gap becomes the most significant variable in predicting the interest rate. By that time as much as 58 percent of the interest variance can be explained by the shocks in the output gap. These results indicate that Norges Bank has been more concerned about reacting to changes in output gap than to changes in the inflation. In section 2.1.4 we discussed how responding stronger to changes in the output gap can be a way to deal with financial imbalances. This also falls in line with the undershooting of the inflation target that has been present in Norway for many years. On a cautionary note, inflation has been low for most of the sample period.[28] Therefore, if Norges

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[27] The effects on NIBOR from the shocks to inflation and output gap eventually dies out. NIBOR is back to zero after about six years after both shocks.

[28] The only periods inflation has been above the target since 2002 is in 2008-2009 and in 2015-2016.

Bank typically only responds to “large” deviations in the inflation rate, then our interpretation might be wrong, just based on the fact that there hasn’t been any need to react to changes in inflation over the sample period. We must keep this in mind throughout the rest of the analysis. In the following we change to the model where the three financial variables are added.

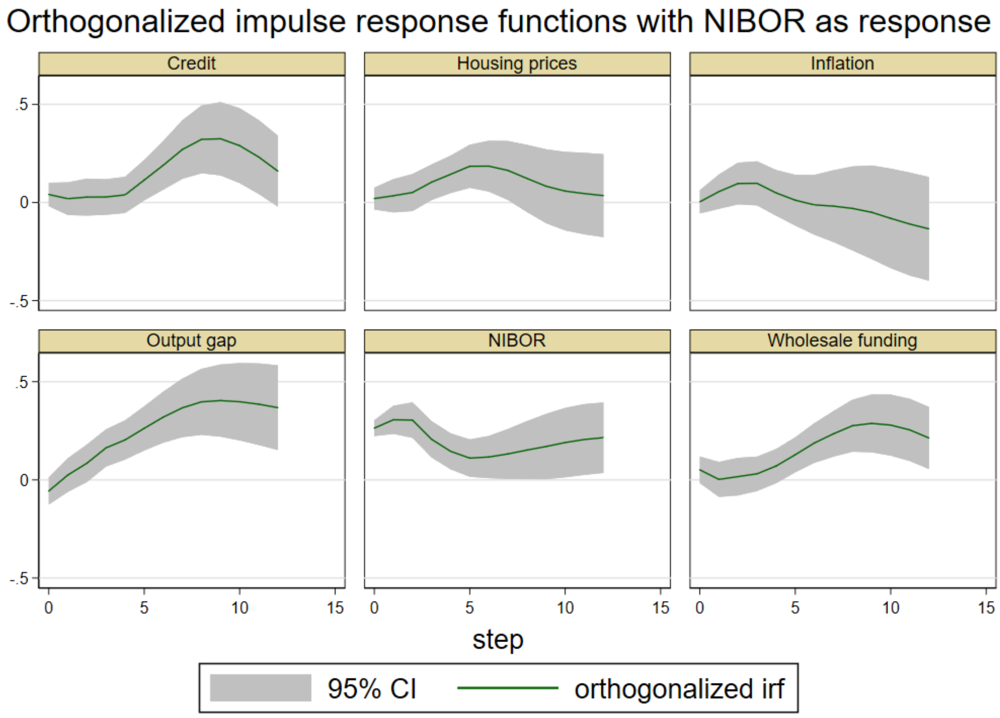

Figure 11 Orthogonalized impulse response functions when financial variables are added. Each graph shows the response over three years in NIBOR to a one standard deviation shock in the variable that is naked in the header of each graph

The effect from a one standard deviation shock to output gap on the interest rate is about the same as before. Furthermore, the effect on NIBOR from a one standard deviation shock to the three financial variables are all significant at some point in time. The effect on NIBOR of a housing price to income ratio shock peaks at 19 basis points after six quarters. The effect is significant at a five percent level between quarter three and quarter seven. The effect of a credit-to-GDP shock peaks after nine quarters with an effect of 33 basis points. This effect is significant between quarter five and eleven. Lastly, after a wholesale funding shock, the effect on NIBOR peaks with an increase of 29 basis point after nine quarters. The effect is significant from the fifth quarter and onwards.

The interest rate’s reaction path after a shock to the financial variables are met with an increased interest rate. This indicate that Norges Bank react to financial variables, but sluggishly and with a lag of about 1,5 years. However, these results depend on the ordering of the variables. A weakness is that the financial variables are not allowed to respond contemporaneously to changes in the interest rate as we discuss in subsection 6.1.7.

From the decomposition of the forecast error in table 10, we see that shocks to the financial variables explain only some of the interest rate variation; amounting to almost nothing in the short run. On the other hand, after three years, the three variables explain 53 percent of the forecast error variance. Thus, the results correspond with the impulse response functions. In other words, financial variables can help explain the interest rate movements, but only in the medium to long-term. The output gap is still the most significant explanatory variable in the long run. Inflation has a low score in both models, hence it has not been important in explaining the forecast error variance in the sample period.

Variance decomposition of change in NIBOR							
		Variance decomposition (percentage points)					
Forecast Horizon	Forecast Standard Error	Output gap	Inflation	Housing prices	Credit	Wholesale funding	NIBOR
1	0,32	4	0	1	2	3	90
4	0,44	10	6	4	1	1	78
8	0,5	34	2	11	11	10	32
12	0,55	39	2	6	18	16	19

Table 10 Forecast error variance decomposition of changes in the interest rate when the three financial variables are added to the VAR model

6.1.7 **Limitations of VAR models**

There are many problems with VAR models, as discussed in Stock and Watson (2001) and Bjørnland & Thorsrud (2015). First, omitted variables become a part of the error term. This means that estimating effects of shocks to the variables in the system will be biased, as these omitted variables become a part of the assumed independent shock. Further, adding more variables to a VAR-model can cause many problems, especially when the sample is small. Hence, we like to keep the models small as well. While adding lags gets rid of serial correlation, it also consumes degrees of freedom. This trade-off is something to bear in mind.

We need to be careful when drawing conclusions from the VAR analysis. There can be many potential reasons for model misspecification. We could have included the exchange rate, the Euro Area interest rate, or both in the VAR model. Nevertheless, we chose to concentrate the model on the original variables plus the three financial indicators. We did this to avoid getting a too heavy parameterized model. However, creating the best possible forecasting model, would probably demand the use of both short and long run restrictions, or a combination of sign and short run restrictions. We have discussed these identification difficulties in the analysis. The problem has to do with simultaneity among variables. In the analysis, we could also have ordered the variables in many different ways. However, since we focus on the responses to the interest rate, we found it reasonable to make it the least exogenous variables. Further, we could have paid more attention to the economic relationships between the variables and made a structural VAR model. However, the results would not have been different from our recursive VAR model since the model is equally identified. Alternatively, we could have collected many more financial indicators, and used a factor augmented VAR approach. We found this to be unnecessary for our analysis.

Nonetheless, to conclude, we see that financial variables don't seem important for Norges Bank in the short run. In the medium- to long-run, we see that an increase in financial variables is met with a tighter monetary policy After three years, a significant amount of the forecast error variance can, in fact, be explained by the financial variables. Furthermore, our in-sample forecasts improve most of the years when financial variables were added.

6.2 GMM estimations

This part attempts to build the model that fits the Norwegian data best. To do so, we add variables, such as the exchange rate, the Euro Area interest rate, the housing prices, the credit level and the wholesale funding ratio. We add variables either as instruments or as both instruments and regressors. Furthermore, we also do a structural break analysis that aims at answering whether there has been a change, around the year 2011, in how Norges Bank conduct their monetary policy. The goal is to test whether our results are robust to changes in forecast horizons. Lastly, we compare VAR and GMM results. Why we prefer GMM have been discussed in section 4.2.

We use a heteroskedasticity and autocorrelation consistent (HAC) weighting matrix for our estimations. HAC demand that we specify the maximum order of any significant autocorrelation that may be present in the disturbance process. In other words, we need to specify the maximum lag length. We decided to use three lags. One reason is that this follows the rule of thumb where the lag length is based on the formula: $L = \sqrt[4]{N}$. Previous results on Norwegian data like Skumsnes (2013) and Helseth (2015) also use three lags. Using three lags is the same as using a bandwidth of four. Our estimations are done in both Stata and in

Eviews.[29] Eviews allowed us to compare our results to previous master theses.[30] Since we use four lags, and four quarter lead on inflation, the sample is from 2000q1 to 2017q3.

6.2.1 Baseline results and results from adding instruments

The original model regressors are inflation, output gap, a smoothing parameter and the constant term. Inflation is set four quarters ahead and output gap one quarter ahead. Why we use forecasted values and smoothing have been discussed in section 3.2. The model contains instruments as well. Namely, we include four lags of inflation, output gap, and the interest rate. Finally, we control for the financial crisis, which is represented as a big outlier is the first quarter of 2009. To control for this, we include a dummy to the model. There is a noticeable difference in the residuals when this quarter is included, compared to when it is not. More information on the financial crisis dummy can be read in appendix D. The first results can be seen in column (1) in table 11. The estimated model is $i_t = (1-\rho_1)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q}) + \rho_1 i_{t-1} + \epsilon_{1t}$. Primarily, we want to evaluate how the baseline results change when we add different instruments to the model.

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[29] For a further discussion on the specifications see Stata's user's guide (2017) chapter 26.21 and Eviews User's Guide (2017).

[30] We were able to replicate the results from Skumsnes (2013) and Helseth (2015), which are the most recent GMM estimations we could find for Norway.

Table 11. Results adding instruments

	(1) Original model	(2) Add second lag of NOBIR	(3) Spread and world inflation	(4) Euro Area interest rate	(5) The exchange rate	(6) Housing price	(7) I44, Euro rate and house price	(8) Financial variables
p1								
	0.961^{***}	1.33^{***}	1.30^{***}	1.30^{***}	1.31^{***}	1.29^{***}	1.30^{***}	1.30^{***}
	(43.75)	(0.05)	(0.03)	(0.02)	(0.03)	(0.02)	(0.02)	(0.02)
p2								
		-0.38^{***}	-0.34^{***}	-0.35^{***}	-0.36^{***}	-0.34^{***}	-0.35^{***}	-0.34^{***}
		(0.05)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
a								
	-3.807	0.96	1.65	2.00^{**}	1.85^{**}	2.04^{**}	2.37^{***}	1.82^{***}
	(-0.63)	(2.23)	(1.36)	(1.02)	(0.87)	(0.95)	(0.51)	(0.64)
b								
	3.955	1.23	0.79	0.59	0.72	0.55	0.40	0.67^{**}
	(1.20)	(1.19)	(0.78)	(0.59)	(0.49)	(0.54)	(0.30)	(0.33)
g								
	3.543^{*}	2.32^{***}	2.82^{***}	2.82^{***}	2.86^{***}	2.81^{***}	2.83^{***}	2.84^{***}
	(2.05)	(0.78)	(0.67)	(0.59)	(0.50)	(0.50)	(0.33)	(0.38)
f								
	-2.804^{***}	-2.25^{***}	-1.95^{***}	-1.94^{***}	-1.93^{***}	-1.94^{***}	-1.86^{***}	-1.95^{***}
	(-4.66)	(0.28)	(0.11)	(0.09)	(0.10)	(0.10)	(0.08)	(0.07)
N	71	71	71	71	71	71	71	71
J	5.6	6.17	11.90	12.43	14.46	13.02	15.33	15.29
P-value	0.69	0.52	0.69	0.87	0.76	0.84	0.97	0.97

Standard errors in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Sample period 2000Q1 to 2017Q3. Estimated model (2)-(8): $i_t = (1-(\rho_1+\rho_2))(\alpha+\beta\pi_{t,k}+\gamma x_{t,q})+\rho_1 i_{t-1}+\rho_2 i_{t-2}+\epsilon_{1t}$. Four lags of inflation, output gap and NIBOR in (1) as well as a dummy to capture the financial crisis. Second lag of NIBOR added to the model in (2). Added lags of spread and world inflation in (3). The extension from model (3) are kept in the rest of the models. (4) adds four lags of the Euro Area interest rate and (5) adds four lags of the exchange rate. (6) adds four lags of housing prices. (7) combines the three Euro Are, I44 and housing prices. Lastly, (8) adds four lags of change in housing prices, change in credit-to-GDP ratio and change in wholesale funding ratio.

The original model results don't seem reasonable. Firsts, the inflation coefficient of 3,955 is large with a big standard error of 1,2. The coefficient explains the estimated percentage point change in the interest rate after a one percentage point increase in inflation. Second, when we test for autocorrelation in the residuals, we reject the null from the Portmanteau test for white noise.[31] The Portmanteau test statistic (Q) for the baseline model is 54,9 with a p-value of 0,02. Hence, we have autocorrelated residuals. Appropriately, we would want to change our model to a second order partial adjustment model. Generally, it means that we add a second lag of the interest rate. Clarida, Gali & Gertler (1998) also finds that this type of model fits the data better. Adding the second lag is sufficient to eliminate any serial correlation in the error term.

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[31] The null hypothesis in the Portmanteau test is that the variables follow a white noise process. A p-value below 0,05 means that we reject the null and conclude that the variables are not white noise. In other words, that autocorrelation is not a problem in the model.

The Q statistic for model (2) is 26,6 with a p-value of 0,81. Moreover, the model is known to capture a higher order of interest rate smoothing dynamics. It implies that we must interpret the smoothing coefficient as the sum of the two coefficients; p1 and p2.

Model (3) adds lags of the world commodity price inflation and the spread between 10-year government bonds and NIBOR, as well as the second lag of NIBOR. The instrument choice reflects that of Clarida, Gali & Gertler (2000). It is reasonable to believe that these added instruments don't correlate with the error term, which, in turn, means that they are exogenous and can be considered good instruments. The model (3) J-statistic almost doubles compared to our initial model. More on the -J-statistic later. In the following we refer to model (3) as our new baseline.

The inflation coefficient is positive, but insignificant with a standard error of 0,78. A one percentage point increase in inflation leads, all else equal, to a 0,79-percentage point increase in the interest rate. The inflation coefficient is below *one* for most of our model specifications. Theory suggests that the Taylor principle should hold, see subsection 3.1. Thus, the interest rate should increase more than the inflation, in order to avoid an increased inflation. Norges Bank has, however, not reached the inflation target for most periods after the financial crisis. This means that inflation has been undershooting the target value. Low inflation can imply a weakened relationship between inflation and the interest rate. To illustrate, the correlation between inflation and NIBOR is 0,29 for the whole sample. When we split the sample at point of the leadership rotation, we find a correlation of 0,71 before 2011, and minus 0,28 after.

Further, the coefficient for the output gap (g) is high and significant at a one percent level. We get a much higher coefficient than what was presented in the original Taylor rule. From model (3): a one percentage point increase in the output gap leads, all else equal, to a 2,82-percentage point increase in the interest rate. The NIBOR and the output gap follow each other closely throughout the sample period. Both series declined for many years after 2010. The output gap started to recover in 2016, and the interest rate increased in the third quarter of 2018. From figure 1 in section 5.2, we see that the output gap is leading the interest rate. A simple correlation exercise (as we did for the inflation) yields further insight. The full- sample correlation between the output gap and NIBOR is 0,59. It is 0,5 before 2011, and as high as 0,68 after. This indicates that Norges Bank has put more weight on the output gap, compared to the inflation gap in recent years. Bearing in mind the discussion from 2.1.4, we note that these results fall in line with our expectations.

The smoothing parameter is highly significant, and close to one for all the model specifications. This suggest that the central bank reacts slowly to changes in inflation and the output gap. From model (3), If the inflation increases with one percentage point, the central bank will only change the interest rate by 0,0395 (0,79*0,05) percentage points. 0,05 is the difference between one and the sum of ρ_1 and ρ_2, and inflation is represented by coefficient b. Gradual changes in the interest rate is something we expect.

The long run equilibrium nominal rate is measured from the constant term: $\alpha = (i^* - 2{,}5\beta)$. Inserting our estimated coefficients from model (3) we get: $1{,}65 = (i^* - 2{,}5 * 0{,}79)$. Thus, $i*$ = 3,625. The resulting interest rate is close to the sample period average, which is 3,4. The long run real equilibrium rate, on the other hand, is $3{,}625 - 2{,}5 = 1{,}125$. Recall, that Taylor (1993) originally suggested this to be equal to two. In fact, Norges Bank estimate that today's rate has come down to about 0,5 percent. Before 2009, the estimate was 2,5. Our result, which lies somewhere in between, seems reasonable. Detailed calculations, as featured here, will not be done for all the upcoming models.

We must also check if the overidentification restrictions are valid or not, since we have more instruments than coefficient, see section 4.3 for more details. This is done by a J-test (Clarida, Gail & Gertler, 1998). A further description of the J-test can also be found in appendix F. The test results will establish whether the instruments are weak or not. Weak instruments mean that they are weakly correlated with the endogenous variables. If so, they violate the orthogonality condition. Under the null, the J-test has a χ^2_{15} distribution. The reason is that we have six parameters and 21 instruments in model (3). The J-test results concludes that we cannot reject the null for any of our models. Hence, the instruments only correlate with the leaded variables and not with the error.

In model (3)-(8) we add the Euro Area interest rate, the exchange rate and the three financial variables as instruments. We see that the J-statistic from model (4)-(8) increases, compared to model (3), but not by much. Further, the coefficients are about the same for all the model specifications. However, the standard errors decrease whenever more instruments are added. In model (8), inflation is significant at a ten percent level, but the coefficient is low. Again, the results are in line with the undershooting of the inflation target. The predicted interest rate from model (3) compared with the actual interest rate are pictured in figure 12, below. Model (3) follows the interest rate closely for the whole sample. Compared to the original Taylor rule parameters from earlier, we conclude that this model has a far better fit.

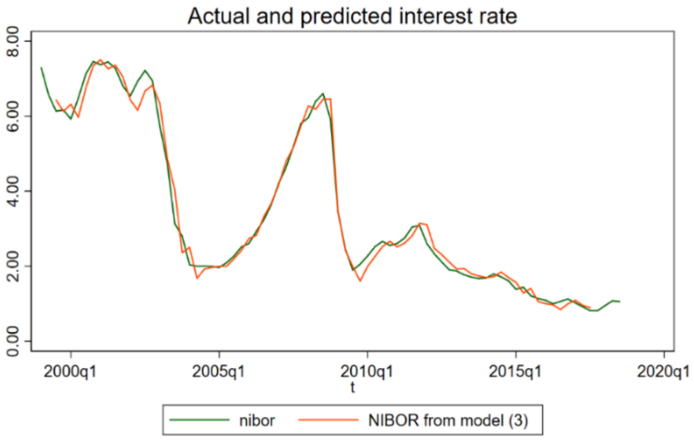

Figure 12 Actual interest rate and predicted interest rate from GMM model (3). Four lags of inflation, output gap, NIBOR, spread and world inflation is used as instruments in the model.

So far, we have only added variable lags as model instruments. By adding instruments, we believe that these variables can do better predictions of the future inflation and the future output gap. Interestingly, Norge Bank has stated that they have increased the weight on the output gap. The fact that we get a high output gap coefficient in this analysis, can work as an indication that this has been the case. In other words, Norges Bank seems to be more willing to respond to changes in the output gap, rather than to changes in inflation. When we include financial variables as instruments, the coefficients don't change by a lot. These preliminary results make it difficult to see the real difference between models where financial variables are added to the instrument set, compared to models where they are not.

6.2.2 **Add one regressor**

Financial variables can, alternatively, be added as model regressors. When adding regressors, we test whether Norges Bank acts directly to changes to financial variables. The difference between adding a variable as an instrument, as a regressor or both, has clear economic consequences. It is, therefore, interesting to explore the difference. There has been a literary debate regarding this separation. Clarida, Gali & Gertler (1998) only add instruments when regressors also are added. Siklos, Werner and Bohl (2004), who did estimations for France, Germany and Italy argues that the model is better when variables are added as instruments and not as regressors. Again, this means that they find that variables only help forecast inflation and the output gap. Next, we add regressors to the model and compare the results. Whenever we add one regressor, we also add four lags of that variable to the instrument set.

Table 12. Estimated results adding one variable

	(3) Baseline model	(9) Add Euro Area interest rate	(10) Add exchange rate	(11) Add housing price	(12) Add credit	(13) Add wholesale funding
p1	1.30^{***}	1.29^{***}	1.24^{***}	1.28^{***}	1.30^{***}	1.27^{***}
	(0.03)	(0.05)	(0.04)	(0.03)	(0.03)	(0.04)
p2	-0.34^{***}	-0.34^{***}	-0.31^{***}	-0.32^{***}	-0.34^{***}	-0.31^{***}
	(0.03)	(0.05)	(0.03)	(0.03)	(0.03)	(0.04)
a	1.65	1.95^{*}	0.35	-0.60	1.40	2.17^{*}
	(1.36)	(1.04)	(0.89)	(1.81)	(1.68)	(1.28)
b	0.79	0.62	1.68^{***}	1.65^{*}	0.98	1.10
	(0.78)	(0.59)	(0.56)	(0.89)	(1.04)	(0.80)
g	2.82^{***}	2.79^{***}	2.06^{***}	2.77^{***}	3.24^{***}	4.04^{***}
	(0.67)	(0.58)	(0.54)	(0.73)	(1.04)	(1.15)
f	-1.95^{***}	-1.94^{***}	-1.86^{***}	-1.82^{***}	-1.99^{***}	-1.85^{***}
	(0.11)	(0.10)	(0.10)	(0.11)	(0.11)	(0.11)
n		0.09	-0.22^{***}	0.41^{**}	-0.07	-0.48^{*}
		(0.53)	(0.07)	(0.19)	(0.26)	(0.27)
N	71	71	71	71	71	71
J	11.90	12.29	14.31	14.19	11.88	12.62
P-value	0.69	0.83	0.76	0.72	0.85	0.81

Standard errors in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Sample period 2000Q1 to 2017Q3. Estimated model: $i_t = (1-\rho_1-\rho_2)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q} + \eta h_t) + \rho i_{t-1} + \rho i_{t-2} + \epsilon_{2t}$. Four lags of inflation, output gap, NIBOR, spread and world commodity inflation are added to all the models. When a regressor is added, four lags of that variable are added.

The inflation coefficient increases, in most of the models, when one regressor is added. Adding the exchange rate or adding housing prices make the inflation coefficient significant as well. These results are more in line with our expectations. The preferred model from table 12 is the one where the exchange rate is added. It yields both the highest J-statistic and has the most significant inflation coefficient. Recall, the exchange rate model was also preferred in the VAR analysis. Once again, however, the exchange rate coefficient is negative. This implies that a depreciation of the krone would reduce the interest rate. The correlation between the exchange rate and NIBOR is -0,35 for the full-sample, and this might explain why we get a negative coefficient. We have previously discussed the possibility of a “exchange rate puzzle”, see section 6.1. Furthermore, the output gap coefficient is still high and significant. The difference between the output gap coefficient in table 11, were only lags are added, and table 12, when one regressor is added, is small. The output gap coefficient is higher, nonetheless, for two of the models. First, when the change in credit-to-GDP ratio is added, and second, when the change in the wholesale funding ratio is added.

Regarding the financial variables, we get significant coefficients for housing prices and the wholesale funding ratio. The housing price coefficient is positive and significant at a five percent level. The interpretation is that a one percentage point increase in the yearly change of housing prices lead to a 0,41-percentage point increase in the interest rate. The coefficient for the change in the wholesale funding ratio is negative. We expect the coefficient to be positive, as an increase in this ratio is associated with increased risk. The same is true for credit growth. These results suggest, nevertheless, that Norges Bank has been reacting to, at least, changes in the housing prices in the sample period. Not only do forecasts improve when we add variables to the original Taylor rule, but it also allows for better interest rate predictions. With counteracts of financial imbalances in mind we would except *positive* coefficients for all key financial variables. Chances are still, however, that much of the financial imbalance concerns are "baked" into the output gap coefficient, see discussion in 2.1.4 and in 6.1. Therefore, the concern for financial stability might still be captured, implicit, through this large, and highly significant, output gap coefficient.

6.2.3 **Add two regressors**

In the following subsection we add two regressors. Thus far, we have seen that adding one variable can improve the model. Now we combine different financial variables and compare how the coefficients change. Lags of the included variables are added to the instrument set in each estimation. Every model share the baseline incluson of four lags of interst rate, inflation, output gap, the spread between long-term bonds and short-term bills and the world commodity price inflation.

Table 13. Estimations adding two regressors

	(14) I44 and Euro Area rate	(15) I44 and Housing prices	(16) I44 and wholesale	(17) Euro Area rate and credit	(18) Credit and housing prices	(19) Wholesale and housing prices
p1	1.10***	1.23***	1.23***	1.28***	1.28***	1.25***
	(0.07)	(0.03)	(0.04)	(0.05)	(0.03)	(0.04)
p2	-0.16**	-0.28***	-0.29***	-0.33***	-0.32***	-0.28***
	(0.07)	(0.03)	(0.03)	(0.05)	(0.03)	(0.04)
a	-0.16	-1.02	-0.07	2.07*	-0.87	-0.68
	(0.77)	(1.30)	(0.89)	(1.12)	(1.71)	(2.48)
b	1.97***	1.98***	2.06***	0.59	1.84*	2.27
	(0.48)	(0.66)	(0.50)	(0.74)	(0.95)	(1.43)
g	1.62***	2.17***	2.09***	3.04***	2.77***	4.66**
	(0.35)	(0.62)	(0.75)	(0.76)	(0.74)	(1.88)
n1	-0.30***	-0.26***	-0.25***	0.22	-0.04	-0.69
	(0.07)	(0.08)	(0.09)	(0.54)	(0.22)	(0.43)
n2	1.33*	0.31**	-0.09	-0.08	0.43**	0.43*
	(0.78)	(0.14)	(0.16)	(0.25)	(0.17)	(0.25)
f	-1.76***	-1.66***	-1.89***	-1.90***	-1.83***	-1.73***
	(0.12)	(0.10)	(0.08)	(0.09)	(0.09)	(0.11)
N	71	71	71	71	71	71
J	12.88	15.37	14.75	12.66	14.65	15.11
P-value	0.91	0.81	0.84	0.93	0.88	0.82

Standard errors in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Sample period 2000Q1 to 2017Q3. Estimated model: $i_t = (1 - \rho_1 - \rho_2)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q} + \eta_1 h_{1t} + \eta_2 h_{2t}) + \rho i_{t-1} + \rho i_{t-2} + \epsilon_{3t}$. Four lags of inflation, output gap, NIBOR, spread and world commodity inflation are added to all the models. When a regressor is added, four lags of that variable are added.

Our baseline model coefficients increase for most specifications when adding more variables. The inflation coefficient is now significant and positive for model (14)-(16) and (18). Compared to previous results, the inflation coefficient is higher. At the same time the constant term is lower. We still define the constant term as: $\alpha = (i^* - 2{,}5\beta)$. Inserting our estimated coefficients from model (15) yield: $-1{,}02 = (i^* - 2{,}5 * 1{,}98)$. Thus, $i*$ = 3,93. The resulting interest rate is close to what we got earlier (3,625). The long run real equilibrium rate is now $3{,}93 - 2{,}5 = 1{,}43$. This is approximately 0,3 percentage points higher than our previous result (1,125). The output gap coefficient is still high and significant. It reaches an all-time high, compared to all our previous estimations, when both housing prices to income and the wholesale funding ratio are added.

We add the exchange rate to model (14)-(16) and study how this affects the coefficients in a two regressor models. The choice of testing the exchange rate on different financial variables is based on the fact that it was our preferred variable in a one regressor model. Furthermore, we believe that Norges Bank follows it closely, as Norway is a small, open economy. The exchange rate stays negative and significant at a one percent level. It is interesting, however, that the Euro Area interest rate becomes significant at a ten percent level when added with the exchange rate. In contact with Svein Gjedrem, the former governor of Norges Bank, he told us that the difference between the interest rate in Norway and other countries is the most important variable to add. However, the exchange rate and the Euro Area interest rate are closely linked. In one way, adding the exchange rate could capture the effect of changes in foreign interest rates. We see, among other things, that adding the exchange rate makes the coefficient for the Euro Area interest rate higher, but the standard error also increases. We talk more about these variables in the structural break analysis.

Additionally, we see that the housing prices to income ratio is the only key financial variables that is significant. The coefficients for credit-to-GDP ratio and the wholesale funding ratio are still negative, and insignificant. The result adds further evidence that Norges Bank reacts directly to changes in housing prices, but not to other key financial variables. The J-statistic remains high when more regressors are added, which means that we don't have problems with weak instruments. In fact, we can't reject the test for overidentification in any of these models. Looking at the predicted values for the interest rate compared to the actual interest rate yield further insights.

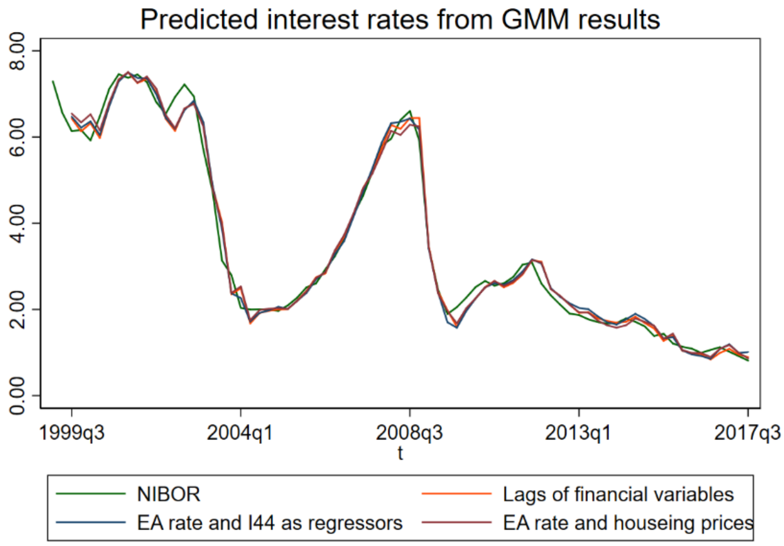

Figure 13 Actual interest rate and predicted interest from three different GMM estimated models.

Here we compare actual NIBOR with three models. The first model adds lags of the three financial variables as instruments; second model adds the Euro Area interest rate and the exchange rate as regressors; and the third model adds Euro Area interest rate and the housing prices-to-disposable income ratio as regressors. The differences between the models are microscopic. To make anything of this, particular, analysis we compare the models by looking at the standard errors of these regressions.[32] The first model has a standard error of 0,28, and the second has a standard error of 0,26. Finally, the third model has a standard error of 0,27. These differences are negligible. The fact that some models yield significant variables, and others do not is difficult to see either from the figure 13 or by comparing the standard errors in table 13. In fact, the standard error is 0,28 for our initial baseline model in figure 13. An implication is that the added value from including financial variables are rather small.

6.2.4 **Structural break**

Next, we do a structural break analysis. The breaking point is set when Norges Bank assigned a new governor in 2011, see discussion 2.3.4. If Norges Bank's monetary policy has mitigated the risk of build-up of financial imbalances increasingly after the leadership rotation, then we should be able to see signs of this in the data. Put differently, we want to test if Norges Bank has targeted key financial indicators when setting the interest rate to a higher degree in the years following 2011. We have discussed earlier that this typically either will show up as an increased output gap coefficient, or as more significant financial variables (when we add them as regressors). To proceed, we split the sample in two. Model (20)-(23) are set between 1999q1-2010q4, while model (24)-(27) are from 2011q1-2018q2. Model (20) includes lags of the three financial variables, while the three other models include two regressors.

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[32] Standard errors of the regressions are calculated as: $\sqrt{\sum \frac{(Y-Y')^2}{N-k}}$ where Y is actual NIBOR; Y' is predicted NIBOR. N is the number of observations and k is the number of parameters

Table 14. Results before and after 2011

	Before 2011				After 2011			
	(20) Financial variables	(21) EA19 rate and I44	(22) EA19 and housing prices	(23) EA19 and credit	(24) Financial variables	(25) EA19 rate and I44	(26) EA19 and Housing prices	(27) EA19 and credit
p1								
	1.30^{***}	1.03^{***}	1.33^{***}	1.28^{***}	1.32^{***}	0.75^{***}	0.83^{***}	0.89^{***}
	(0.01)	(0.03)	(0.05)	(0.03)	(0.02)	(0.04)	(0.02)	(0.06)
p2								
	-0.40^{***}	-0.15^{***}	-0.40^{***}	-0.37^{***}	-0.36^{***}	0.18^{***}	0.05^{***}	0.05
	(0.01)	(0.03)	(0.05)	(0.04)	(0.03)	(0.03)	(0.02)	(0.04)
a								
	0.12	-0.08	-0.95	0.60	1.96^{***}	0.09	1.75^{***}	1.86^{***}
	(0.26)	(0.19)	(0.71)	(0.38)	(0.28)	(0.70)	(0.06)	(0.27)
b								
	2.74^{***}	2.60^{***}	2.86^{***}	2.76^{***}	-0.52^{**}	0.87^{***}	0.10^{***}	0.18
	(0.13)	(0.12)	(0.43)	(0.32)	(0.26)	(0.31)	(0.03)	(0.14)
g								
	0.25^{**}	0.28^{*}	0.81	0.60	0.24	0.03	0.84^{***}	0.10
	(0.11)	(0.15)	(0.55)	(0.45)	(0.18)	(0.16)	(0.03)	(0.26)
f								
	-2.09^{***}	-1.73^{***}	-1.91^{***}	-2.03^{***}				
	(0.02)	(0.04)	(0.06)	(0.07)				
n1								
		0.63^{***}	-0.52	0.20		3.62^{***}	1.93^{***}	3.15^{***}
		(0.19)	(0.35)	(0.22)		(0.84)	(0.16)	(0.96)
n2								
		-0.30^{***}	0.27^{***}	-0.18^{**}		-0.21^{***}	0.05^{***}	-0.79^{***}
		(0.03)	(0.08)	(0.09)		(0.05)	(0.01)	(0.29)
N	44	45	45	44	27	27	27	27
J	11.13	10.63	10.56	10.92	7.41	7.02	7.03	7.25
P-value	0.99	0.97	0.97	0.96	0.99	0.99	0.99	0.99

Standard errors in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Sample period 2000Q1 to 2010Q4 for model (1)-(4) and 2011Q1-2017Q3 for model (5)-(8). Estimated model in (20) and (24) $i_t = (1 - \rho_1 - \rho_2)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q} + \eta_1 h_{1t} + \eta_2 h_{2t}) + \rho i_{t-1} + \rho i_{t-2} + \epsilon_{4t}$. Estimated model in (21)-(23) and (25)-(27): $i_t = (1 - \rho_1 - \rho_2)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q} + \eta_1 h_{1t} + \eta_2 h_{2t}) + \rho i_{t-1} + \rho i_{t-2} + \epsilon_{4t}$. Four lags of inflation, output gap, NIBOR, spread and world commodity inflation are added to all the models. When a regressor is added, four lags of that variable are added.

We compare the first four models to the last four. The first thing we notice is the reduced coefficient for inflation. The inflation coefficient reduces from about 2,7 before 2011, and ends up between -0,52 and 0,87 after the change in leadership. Variations after 2011, however, are large. One reason can be that we only have 27 observations. The model is, therefore, likely to be misspecified. Thus, we have to be careful when interpreting the results. Additionally, the J-statistic reduces from around eleven to around seven. Suddenly, the output gap coefficient doesn’t show any signs of an increase. Put in other terms, it doesn’t seem that financial stability concerns have been accounted for through additional weighting of the output gap coefficient. This contradicts earlier findings.

The most interesting change is the Euro Area interest rate, featured as n1 in the table. The coefficient is 0,63 in model (21), while 3,62 in model (25). From model (25), a one percentage point increase in the yearly change in the Euro Area interest rate, thus, increases the NIBOR with 3,62 percentage points. An illustration of the close relationship between the two variables can be seen in a simple correlation analysis. For the whole sample, the correlation between NIBOR and the Euro Area interest rate is 0,89. Before 2011 it was 0,79, while it is as high as 0,98 after 2011. This helps to describe why the coefficient is high and significant. Svein Gjedrem emphasizes the importance of foreign interest rates, and here it appears to explain a lot more than both the output gap and the key financial indicators.

Results from comparing the change in housing price to income and change in credit-to-GDP are less clear. Credit is significant for the first time, but it has a negative sign. If Norges Bank really reacts to changes in the credit level, we would expect this relationship to be positive. To dampen credit growth the interest rate must be raised, not lowered. However, in the period after 2011 both the interest rate and the growth in credit levels has come down. This might explain the negative coefficient. Again, the correlation is a good illustration of the relationship. Before 2011 the correlation is 0,5, while after it is minus 0,34. For the change in housing prices to income, the correlation is -0,08 before 2011 and 0,15 after 2011. In summary, Norges Bank has not been able to react to changes in the credit-to-GDP ratio or wholesale funding ratio over the sample. In fact, none of the results from the structural break analysis indicate a heightened in focus of counteracts of a financial imbalance build-up after 2011.

6.2.5 Different horizons

In the last robustness test we change the horizon for inflation and output gap. Norges Bank use a “medium term” horizon for their own forecasts, which means 1-3 years. We have used a one-year horizon for all the models in our main analysis. In the following we concentrate on the model that includes lags of the three financial variables and the model that adds the Euro Area interest rate and housing prices. The results are as follows:

Table 15. Results with different horizons for inflation and output gap

	(28) Fin. var inflation +8	(29) EA19 and housing, inflation +8	(30) Fin. Var, inflation +12	(31) EA19 and housing, inflation +12	(32) Fin. Var, inflation +8, output gap +2	(33) EA19 and housing, inflation +8, output gap +2
p1						
	1.30^{***}	1.28^{***}	1.29^{***}	1.28^{***}	1.36^{***}	1.34^{***}
	(0.02)	(0.06)	(0.02)	(0.05)	(0.02)	(0.06)
p2						
	-0.37^{***}	-0.34^{***}	-0.38^{***}	-0.34^{***}	-0.41^{***}	-0.38^{***}
	(0.02)	(0.06)	(0.02)	(0.06)	(0.02)	(0.06)
a						
	6.42^{***}	5.51^{***}	6.03^{***}	4.69^{***}	6.60^{***}	4.02^{*}
	(0.56)	(1.10)	(0.32)	(0.63)	(0.84)	(2.30)
b						
	-1.93^{***}	-1.63^{***}	-1.63^{***}	-1.24^{***}	-2.02^{***}	-0.89
	(0.30)	(0.58)	(0.15)	(0.32)	(0.46)	(1.23)
g						
	2.63^{***}	2.48^{***}	1.78^{***}	2.52^{***}	3.19^{***}	3.09^{***}
	(0.24)	(0.34)	(0.24)	(0.46)	(0.40)	(0.61)
f						
	-1.88^{***}	-1.65^{***}	-1.75^{***}	-1.69^{***}	-1.89^{***}	-1.63^{***}
	(0.07)	(0.11)	(0.08)	(0.14)	(0.06)	(0.14)
n1						
		0.15		-0.24		-0.06
		(0.31)		(0.37)		(0.52)
n2						
		0.16^{*}		0.24^{***}		0.30
		(0.09)		(0.09)		(0.19)
N	67	67	63	63	67	67
J	15.85	13.86	12.90	11.71	15.88	13.99
P-value	0.96	0.88	0.99	0.95	0.96	0.87

Standard errors in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Sample period for model (28) - (29) and (32)-(33) is 2000q1 to 2016q3. For model (30) and (31) it is 2000q1 to 2015q3. Estimated model for (28), (30) and (32) $i_t = (1-\rho_1-\rho_2)(\alpha+\beta\pi_{t,k}+\gamma x_{t,q})+\rho i_{t-1}+\rho i_{t-2}+\epsilon_{2t}$. Estimated model for (29), (31) and (33): $i_t = (1-\rho_1-\rho_2)(\alpha+\beta\pi_{t,k}+\gamma x_{t,q}+\eta_1 h_{1t}+\eta_2 h_{2t})+\rho i_{t-1}+\rho i_{t-2}+\epsilon_{4t}$ where n1 is yearly change in Euro Area interest rate and n2 is yearly changes in housing prices to income ratio.

Model (28) and (29) changes the forecast horizon for inflation from one year to two years, while model (30) and (31) uses a three years horizon. Model (32) and (33) use a one-year inflation target but changes the output gap target from one quarter to two quarters. Compared to our initial analysis we see that the inflation coefficient is negative for all the models, and highly significant for all except model (33). The results are in line with the undershooting of the inflation target. Basically, it means that Norges Bank, aren't very determined to bring inflation back to the target when they look even further into the future. It makes sense, as high inflation has not been a big worry for Norges Bank in recent years. Inflation has been below the target for most of the sample period. The output gap coefficient, on the other hand, remains high and significant. It increases when the horizon changes from one quarter to two quarters.

6.2.6 Comparison of results

Lastly, we want to compare the results from the VAR analysis with the results from the GMM analysis, and also to compare with previous estimations done by Skumsnes. Static forecasts from 2014 to 2017q3 can be seen in figure 14, below. We include the VAR model where the exchange rate is added, since this was our preferred model from the VAR analysis (represented by the orange line). From the GMM results we include the model with lags of exchange rate, Euro Area interest rate and housing prices and the model with exchange rate and housing prices added as regressors. The former is represented by the blue line, and the latter by the burgundy line.

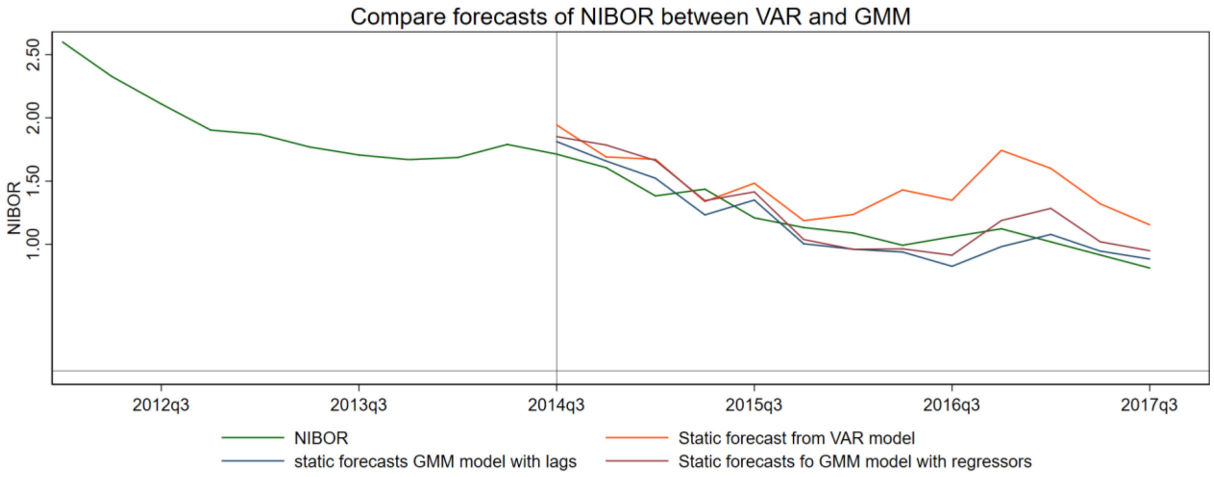

Figure 14 Comparison of results from VAR and GMM estimations.

We use the root mean square error to compare the in-sample forecasts. For the VAR model the RMSE is 0,352. The GMM model with lags has a RMSE of 0,13. This is much lower than the VAR model. The GMM model with added regressors has an RMSE of 0,163. Based on this simple analysis we can see that the GMM model results outperform the VAR model results. However, the GMM results “cheat” and use the actual values of the future inflation and output gap when forecasting. To do so, we need to assume that differences between forecasted and actual values are random, or in other words just white noise. It is easier, naturally, to make good predictions when you know the future. Thus, we do not put too much weight on this comparison. Also, the difference between the two GMM models are small. Therefore, we can’t find any significant difference between adding instruments or regressors to the models.

Next, we compare our results to Skumsnes’ (2013) results on the Norwegian economy. Interestingly, our output gap coefficient, for the full-sample estimation, is significantly higher than what he found. Putting more weight on the output gap is one way to deal with financial imbalances. Thus, this is evidence towards a monetary policy with financial stability concerns. It is, however, easy to grasp why the full effect of the policy change back in 2011 would not show in Skumsnes' research, since his research was concluded in 2012. At the same time, our inflation coefficient is significantly lower compared to Skumsnes. This goes for all the model specifications. The implication is that inflation has been less important and output gap has been more important in the time after 2011. This can of course be a result of the undershooting of the inflation target. Another possibility why Norges Bank has not reacted to changes in inflation, could be because inflation has been low throughout the sample period. Note, that the output gap coefficient changed a lot when we conducted the structural break analysis. After 2011 the output gap coefficient is low, and it seems that the most important determinant of the Norwegian interest rate has been the Euro Area interest rate.

7. Conclusion

This thesis has investigated the movements in the short-term interest rate by using a Taylor rule. Our sample period stretches from 1999 to 2018. We have studied whether Norges Bank target financial variables when setting the interest rate. We focused especially on how adding the three key financial indicators (as defined by Norges Bank) changed both our models and forecasts. Furthermore, we conduct a structural break analysis for the year of the governor change in Norges bank. This attempts to test whether Norges Bank's monetary policy has counteracted the build-up of financial imbalances increasingly after the leadership rotation in 2011.

In the VAR analysis we focused on differences in forecasts between the original Taylor rule and a model where financial indicators were added. When we added the three key financial indicators to our three-year forecasting model and compared it to the original Taylor rule, we found that the original Taylor rule was outperformed for most years between 2011-2015. Further, from the orthogonalized impulse response functions we saw that Norges Bank reacts sluggishly to changes in all financial indicators. Put differently, it reacts with a lag of about 1,5 years. We found that the peak response to the interest rate from a one standard deviation shock to credit-to-GDP ratio, was 33 basis points. After a house prices to income ratio shock, the peak response to NIBOR was 19 basis points. The peak responses was after nice quarters and six quarters, respectively. From the forecast error variance decomposition, we saw that 52 percent of the forecast error variance could be explained by shocks to the three financial variables; after about three years. However, we have discussed the limitations of these results due to potential misspecification and identification issues. VAR results also rely on very strong assumptions.

In the GMM analysis, on the other hand, we found that the coefficients for the inflation and output gap are robust to changes in the model. Interestingly, the coefficient for output gap is much higher than expected; ranging from 1,62 to 4,66. The best model, based on a low standard error and a high J-statistic, is the one where exchange rate and the housing prices to income ratio is added as regressors. Thus, we focus on the interpretation from this model in the following. First, we get that a one percentage point increase in the output gap, is followed by a 2,17 percentage points increase in NIBOR. The coefficient for inflation, on the other hand, is 1,98. The interpretation follow the same jargon as for the output gap. Both are statistically significant at a one percent level.

Helseth (2015) found that the parameters of the Taylor rule are weakly identified for Norway. Presumably, his conclusion is based on the high degree of policy inertia that we also have spotted in our GMM analysis. Recall, we found a smoothing parameter of 95 percent. Consequently, we get almost equally good fits between models even when the parameter values differ. It has, therefore, proven difficult to outperform our baseline model, no matter which (or how many) instruments or regressors we add. Nevertheless, adding the key financial indicators improve our models to some extent. Changes in housing prices to income ratio is statistically significant and has a positive coefficient of 0,31 in our preferred model. Conversely, the structural break analysis doesn't give any indications that neither the weight on output gap, nor the weight on the key financial indicators has increased after 2011.

Although the results on the key financial indicators are somewhat inconclusive, we must retrace the possibility that a financial stability concern might be "baked in" the output gap coefficient, see subsection 2.1.4. In the first few (full sample) GMM analyses we receive clear signs that Norges Bank have shifted pursuit, from focusing on inflation targeting, towards a monetary policy that adds more weight to the output gap coefficient. However, we expected to get even stronger evidence towards this shift in our structural break analysis. This was not the case; hence we cannot conclude that Norges Bank has increased its focus on counteracting the build-up of financial imbalances. Nonetheless, we must not forget that Norges Bank also have macroprudential policies (the countercyclical capital buffer) that aims at counteracting financial imbalances. When more forces work towards the same goal, we expect that each part contributes a respective share.

The most interesting result from the structural break analysis is the large increase in the Euro Area interest rate coefficient. The Norwegian interest rate experienced in 2018 the first increase after a seven-year decline, and we see similar trends in the interest rate paths of Norway's key trading partners. Importantly, the correlation between NIBOR and the Euro Area interest rate has been as high as 98 percent since 2011. This points to the fact that concerns about interest rate developments abroad has been more important than tackling the build-up of financial imbalances in Norway.

Helseth (2015), as mentioned, concluded that the Taylor rule parameters are weakly identified. We, on the other hand, can't reject the J-test for overidentifying restrictions for any of our models. Arguable, since we find coefficients that matches (more or less) with the communication from Norges Bank, and that the coefficients seem quite robust to changes give us reason to trust them. That being said, the inflation coefficient is not robust to changes in the forecasting horizons. When changing the horizon from one to two-years, the inflation coefficient becomes significantly negative. A lower coefficient would not be surprising when the horizon increases, but a negative coefficient is unaligned with economic theory. Also, the NIBOR is not stationary, and this may cause problems to the estimation.

In conclusion, we find it reasonable to state that Norges Bank attempts to respond to changes in the financial indicators. However, many of our findings support Svenssons views, in which financial stability concerns are easily side-lined; because there are so many other considerations that come before. Our collective evidence points towards the fact that decreasing interest rates internationally, exchange rate concerns and stabilizing output have outweighed Norges Bank’s wish to counteract the build-up of financial imbalances. Norway has therefore also instated a countercyclical capital buffer as a macroprudential policy. Above all, while financial stability concerns point in the direction of an interest rate increase, other concerns (international interest rates, exchange rates, oil-price shocks) point in the opposite direction. To conclude, Norges Bank has not *really* been responding to financial variables; at least not purposefully since 2011.

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9. Appendix

Appendix A List of variables and transformations

Inflation: Four quarter log difference of the CPI-ATE. Available from Statbank, SSB from 2003. Before that available in reports from SSB. The first year is estimated numbers from Norges Bank.

Output gap: Series from Norges Bank. Measures the percentage deviation between mainland GDP and estimated potential mainland GDP. Available on request from Norges Bank.

Interest rate: The Norwegian interbank offered rate expressed in yearly percentages. From OECD database.

Change in foreign interest rate: Four quarter percentage difference of the Euro Area interbank rate. From OECD database.

Change in exchange rate: Four quarter log difference of the Import-weighted krone exchange rate (I44). From Norges Bank

Change in ratio of house prices to disposable income: Four quarter log difference of the house prices relative to disposable income. Collected from Norges Bank.

Change in credit-to-GDP ratio: Four quarter log difference of the total credit mainland Norway as a share of mainland GDP.

Change in banks' wholesale funding ratio: Year-on-year difference in the Banks' wholesale funding ratio.

> The three financial variables are downloaded from Norges Bank: https://www.norges-bank.no/en/Liquidity-and-markets/Advice-on-the-countercyclical-capital-buffer/Key-indicators/

Change in equity return: Four quarter log difference of the OSEBX. From OECD database.

Spread: Difference between the Norwegian 10-year government bonds and the NIBOR. From OECD database.

World commodity inflation: Four quarter log difference of the world commodity price index. From IMF database

Appendix B Stationarity test results

We have checked all the variables in our model for stationarity using an augmented Dickey-Fuller test below. The variables that naturally should include a constant has that. No tests are added a trend. The null hypothesis is that the series is a random walk and the alternative hypothesis is that the series is stationary (Bjørnland & Thorsrud, 2015, chapter 4). Different lag lengths are added to make sure that autocorrelation is not creating biased standard errors.[33] We can reject the null from the Dickey-Fuller test for all variables, except the interest rate. The results are fairly robust to changes in the lag length. This means that all our variables are stationary, except the interest rate. NIBOR is the only variable that is kept in levels. The other variables are measured in changes; hence they are already differenced (I(1)). From an economic perspective, we would believe that the interest rate is stationary in the long run, which means that it will move towards the long-term equilibrium interest rate. However, it is not mean reverting in our sample period.

Augmented Dickey-Fuller (ADF) tests for unit root

Lags	0	1	2	3	4	Constant
Variable:						
NIBOR	-1,485	-1,949	-1,857	-1,697	-1,594	Yes
Output gap	-1,715	-3,535***	-3,580***	-3,479***	-3,216***	No
Inflation	-1,879	-2,540	-3,247**	-3,905***	-2,141	Yes
Change in Exchange rate	-3,231***	-4,412***	-4,768***	-4,941***	-2,453**	No
Change in Euro Area interest rate	-2,308**	-5,577***	-4,748***	-3,651***	-3,015***	No
Change in Housing prices to income ratio	-2,245**	-5,432***	-4,421***	-3,526***	-2,529**	No
Change in Credit-to-GDP ratio	-1,952**	-1,863*	-1,909*	-2,226**	-1,548	No
Change in Wholesale funding ratio	-3,559***	-2.757***	-2,340**	-3,775***	-2,389**	No
Change in Equity return	-2,606**	-3,591***	-3,358***	-3,665***	-2,217**	No
World commodity inflation	-2,884*	-5.412***	-4,355***	-3,742***	-2,693*	Yes
Short-long spread	-2,570**	-3,519***	-2,953***	-2,939***	-2,269**	No

Table 16 Augmented Dickey-Fuller tests for the main variables. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Test statistics (z(t) are presented in table

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[33] We have also used a modified Dickey-Fuller test (dfgls) to help the decision about lag length. A Kwiatkowski-Phillips-Schmidt-Shin test for stationarity (kpss) has been performed as well to see whether we get the same results.

Appendix C Granger-Causality tests

Granger-Causality test for the baseline model with output gap, inflation and the Norwegian short-term interest rate. These results indicate that the preferred ordering of the variables is 1) Output gap, 2) Inflation, 3) interest rate. There is no clear statistical way to decide the ordering of the coefficients, hence different orderings are tried to see whether results are robust to the ordering. P-values from the Granger-causality test (F-tests) are presented below. Rejection means that lags of the other variables can help explain the dependent variable in the regression. For example, with a p-value of 0,01 we can say that inflation systematically respond to the output gap. This is also reasonable from theory. For a further discussion on the test, see Stock & Watson (2001).

Granger-causality test for baseline model

	Dependent variable in regression		
Regressor	Output gap	Inflation	Interest rate
Output gap	0.00	0.01	0.00
Inflation	0.12	0.00	0.04
Interest rate	0.05	0.13	0.00

Table 17 Granger-Causality tests including output gap, inflation and NIBOR

Granger-Causality test from the model with the same three variables as above plus the three key financial indicators housing price to income ratio, credit-to-GDP ratio and banks' wholesale funding ratio.

Granger-causality test for model with financial variables

	Dependent variable in regression					
Regressor	Output gap	Inflation	Interest rate	Housing	Credit	Wholesale
Output gap	0.00	0.00	0.00	0.31	0.35	0.07
Inflation	0.02	0.00	0.24	0.57	0.64	0.49
Interest rate	0.00	0.16	0.00	0.83	0.63	0.01
Housing	0.14	0.77	0.56	0.00	0.01	0.02
Credit	0.17	0.06	0.63	0.17	0.00	0.00
Wholesale	0.18	0.15	0.34	0.24	0.10	0.00

Table 18 Granger-Causality test including output gap, inflation, interest rate, housing prices to income ratio, credit-to-GDP ratio and wholesale funding ratio

Appendix D Detection of outliers

From the VAR model we find that extracting the fourth quarter of 2008 is reasonable. This can be seen from the output gap estimation below. The reason for extracting it has been discussed in the paper.

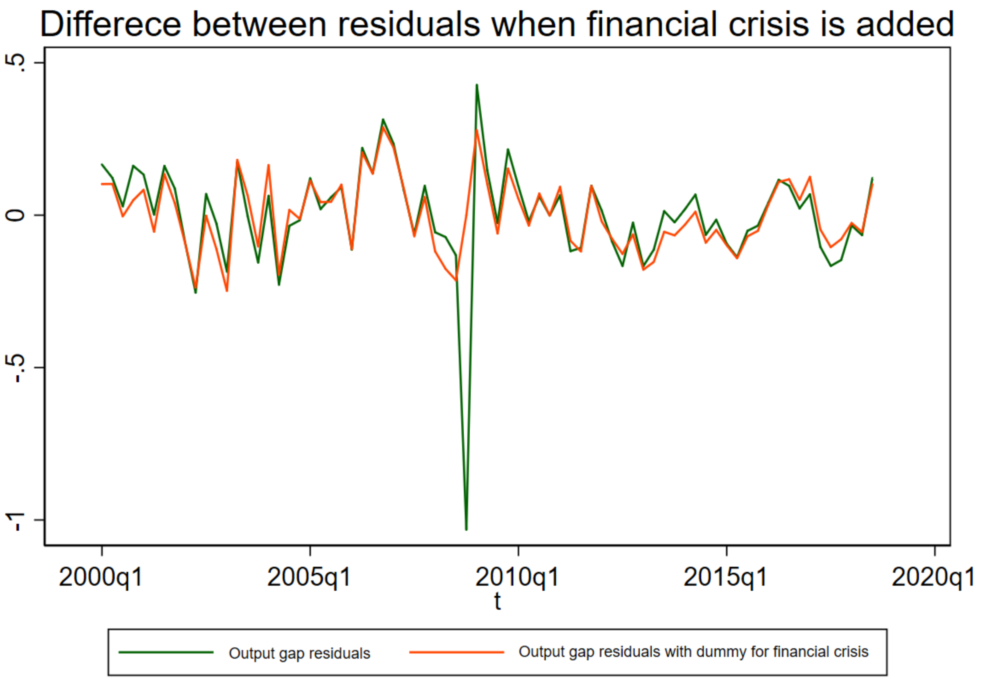

Figure 15 Output gap residuals from VAR model containing output gap, inflation and NIBOR and residuals where 2008q3 is controlled for with a dummy

In the GMM section, 2009q1 is the outlier observation. This can be seen in figure 16. Here are the residuals from the Taylor rule estimation.

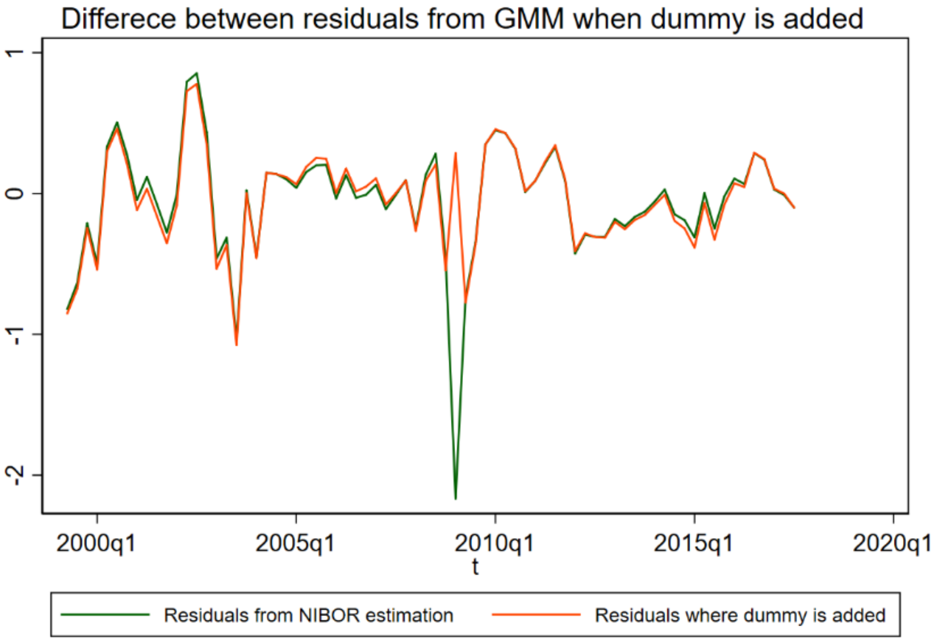

Figure 16 Residuals from the GMM model with and without controlling for the financial crisis. The outlier here is 2009q1.

Appendix E Forecasts from VAR model 2018-2021

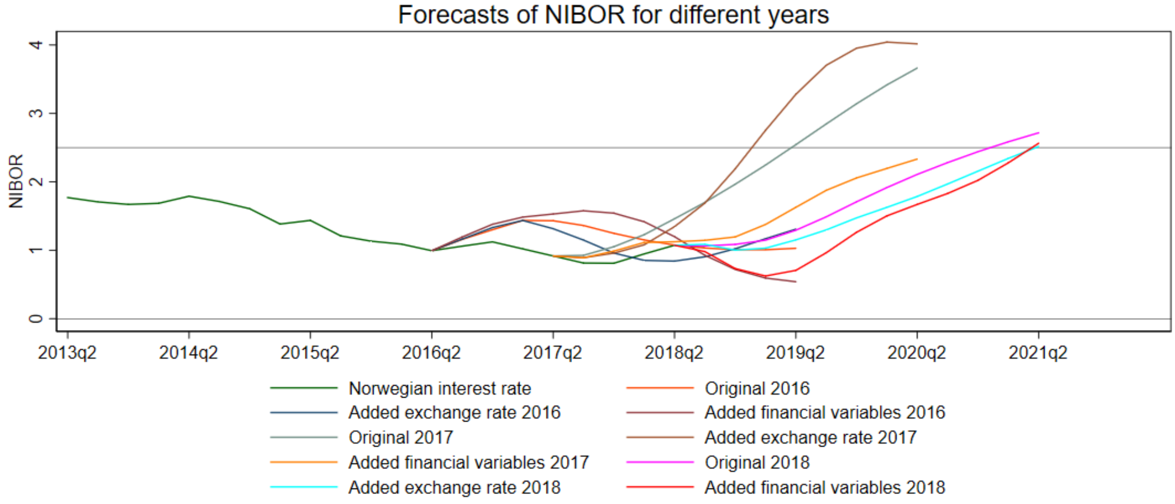

Figure 17 Three year forecasts from VAR models..Forecasts stsrt from 2016q2, 2017q2 and 2018q2.

From 2017 we can see that the model with exchange rate performs the worst and the best is the one where the financial variables are added. Onwards from 2018, all three estimates that we will reach the equilibrium nominal interest rate of 2,5 percent in 2021. The estimates by Norges Bank is that we will have an interest rate of around two percent at that time according to the latest monetary policy reports; hence, our models agree with the projections by the central bank.

Appendix F The J-test

The Sargan-Hansen J-test is something that we want to use whenever the number of orthogonality conditions exceeds the number of parameters. Perhaps, it is better known as the test for overidentifying restrictions. From the definition of the GMM estimator in a general model, we had: $\overline{m}(\theta) = \frac{1}{T}\Sigma_{t=1}^{t} m(y_t, x_t, \theta)$. Now, what we want is to choose an estimator of θ that brings $m(y_t, x_t, z_t, \theta)$ as close to the value of zero as possible. In other words, we want to check whether the model's moment conditions match our data well or poorly. Under the null hypothesis of the J-test we have:

$m(y_t, x_t, z_t, \theta) = 0$

The alternative hypothesis is:

$m(y_t, x_t, z_t, \theta) \neq 0$

If $m(y_t, x_t, z_t, \theta)$ is close to zero, then the null hypothesis cannot be rejected. We say that the model fits our data well. On the other hand, if $m(y_t, x_t, z_t, \theta)$ takes a value far away from zero, then we have evidence that support the alternative hypothesis.