Estimating Reaction Functions for Norges Bank’s Key Policy Rate

Anders Falla Aas

Master of Philosophy in Economics

Department of Economics

University of Oslo

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Preface

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Anders Falla Aas
Abstract

This master’s thesis estimates forward-looking reaction functions for Norges Bank’s key policy rate, using the theoretical framework from Clarida et al. (1998) and Clarida et al. (2000). The primary estimator used throughout the thesis is 2SLS, but GMM is used for a robustness test, and OLS is used to investigate misspecification. The main objective for the thesis is to derive a well-specified model for the key policy rate, so that reliable inference can be drawn. Emphasis is therefore placed on investigating potential sources of misspecification, and especially the prospect of invalid instruments and autocorrelation.
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1. Introduction

On March 29th 2001 Norges Bank officially adopted inflation targeting as its new monetary policy regime. This meant that Norges Bank was required to conduct monetary policy with the aim of keeping inflation low and stable, while also considering the impact that this would have on the real economy. In principle, however, this was not new to the central bank, as it in practice had operated under an inflation targeting framework since Svein Gjedrem was appointed governor at the start of 1999. Upon being appointed governor, Gjedrem communicated a clear focus on keeping inflation low and stable. Therefore, Norges Bank’s inflation targeting regime arguably begun in 1999. All inflation targeters are in practice “flexible inflation targeters”, as the real economy also is considered when conducting monetary policy. One way of balancing such concerns is to follow a Taylor rule. The original Taylor rule was proposed by Taylor (1993), and it suggested that the central bank should set the interest rate based on inflation and the output gap. This rule provided a simple but robust guiding principle for central banks, as it was consistent with some key theoretical insights. However, the original Taylor rule had clear limitations in terms of features of monetary policy that it did not capture; features like forward-looking behavior and interest rate smoothing. Therefore, generalized Taylor rules were developed to provide a more accurate description of how central banks conducted monetary policy. Such rules provide a potentially informative way of studying monetary policy, as they can be estimated using econometric procedures.

In this thesis I use a generalized Taylor rule, inspired by Clarida et al. (1998) and Clarida et al. (2000), to estimate reaction functions for Norges Bank’s key policy rate. The main reaction functions in the thesis are estimated with 2SLS, using OxMetrics 7. For the GMM robustness test EViews 9.5 is used. The main objective of this thesis is to derive a well-specified model, so that reliable inference can be drawn.

For the baseline estimation period (1999-2008) we find evidence for Norges Bank having targeted inflation, as the inflation coefficient is found to be significantly greater than unity. This indicates that Norges Bank has adjusted the key policy rate in accordance with the Taylor principle. The output gap coefficient is found to be insignificant, which indicates that Norges Bank was not directly concern with the output gap when the key policy rate was determined. There is also considerable evidence for interest rate smoothing on part of Norges Bank. The main model for this estimation period is found to be fairly robust to: alternative measures of the output gap, adding extra explanatory variables and estimating the reaction
The model does not, however, appear to be robust to an extension of the estimation sample, as using the full sample (1999-2015) yields point estimates that are not consistent with theory. The full sample model, yields significantly different point estimates from the baseline model, even when the financial crisis is attempted controlled for by dummies. The large discrepancy between the baseline model and the full sample model could indicate that Norges Bank has changed their reaction pattern.

The rest of the thesis is organized as follows. In chapter 2, the concept of inflation targeting is introduced. In chapter 3, the transmission mechanism of monetary policy is explained. In chapter 4, I briefly summarize the history of monetary policy in Norway and review the current monetary policy regime of Norges Bank. Chapter 5 presents the generalized Taylor rule that is estimated in the empirical analysis, and reviews the econometric framework that is used to estimate it. Chapter 6 describes the data used in the empirical analysis. In chapter 7, I report the results from the empirical analysis. Chapter 8 concludes.

2. Inflation Targeting

In this chapter I introduce the concept of inflation targeting. First, the defining traits of inflation targeting are summarized. Second, the theoretical insights that gave rise to it are reviewed. Finally, the current standing of inflation targeting is briefly summarized

2.1 What is Inflation Targeting?

Inflation targeting is, as defined by Bernanke and Mishkin (1997), a framework for conducting monetary policy which is rooted in the aim of keeping inflation low and stable. This is achieved primarily by announcing an explicit inflation target and conducting monetary policy with a view to keep inflation close to that target, but also through being transparent about how monetary policy is conducted. For the sake of central banks’ credibility they are usually given a great deal of independence under inflation targeting; this in turn means that accountability is important if the monetary policy is questioned. According to Svensson (2008) these, and the use of forecasts as the operational target when conducting monetary policy, are the main features of inflation targeting. All nations that have adopted inflation
targeting have so far considered the effects on the real economy when conducting monetary policy (Svensson, 2009); this is formally known as “flexible inflation targeting” and was coined by Svensson (1997a). The traditional choice of instrument within an inflation targeting framework is short-term nominal interest rates.

2.2 The Rise of Inflation Targeting

The first country to adopt inflation targeting as its official monetary policy regime was New Zealand, through the Reserve Bank of New Zealand Act of 1989 (the RBZN Act). New Zealand had like most OECD countries experienced high and volatile inflation in the 1970s and early 1980s, but had managed to stabilize inflation at a lower level by tightening monetary policy (Svensson, 2010). The government sought to cement the successful policy of the late 1980’s, and the RBZN Act was the result. It was decided that in order for the monetary policy regime to be credible the central bank had to conduct monetary policy independently of the government, but to maintain accountability an inflation target would be provided so that the governor could be held responsible for any deviations from the inflation target (Goodhart, 2010). The inflation target was set as a range of 0-2 percent annual inflation, and the central bank adopted a 6-12 month horizon for stabilizing inflation. The Act came into force in February 1990. In the following years several countries followed suit and implemented inflation targeting as their monetary policy regime. The reason for the change varies between countries, but two main reasons can be identified: the failings of the alternative monetary policy regimes, and a better theoretical understanding of monetary policy.

2.2.1 Theoretical Foundations

An important part of the economic theory that motivated inflation targeting was the rejection of the notion that there was a permanent trade-off between inflation and unemployment. This notion became popularized through the Phillips curve (Phillips, 1958). The Phillips curve shows an empirical relationship between inflation and unemployment, where a high rate of inflation is associated with a low rate of unemployment. This relationship suggested that if policymakers were willing to tolerate a high enough rate of inflation, they could theoretically push the unemployment rate close to zero. Friedman (1968) understood however, that only nominal variables could be affected by monetary policy in the long run, and that the trade-off

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1 An inflation target is specified as a point, a range, or a point with a tolerance band. See Hammond (2012) for a short summary of pros and cons.

2 There was an understanding that there would be some friction in the labor market.
between unemployment and inflation therefore couldn’t be permanent.\(^3\) Friedman then basically argued that the long-run Phillips curve had to be vertical, because what he called the “natural” rate of unemployment could not be affected by monetary policy. Any attempt to keep unemployment below this level would therefore lead to an ever-accelerating rate of inflation. The reason for this became well understood after Robert Lucas popularized the concept of rational expectations in the 1970s.\(^4\) The central bank might be able to surprise private agents by raising inflation initially and thus lower the unemployment rate, but the agents would adjust their expectations, so unless the central bank continually was able to surprise the agents by raising inflation, unemployment would converge to its natural level.

The rejection of the traditional Phillips curve gained empirical support in the 1970s as stagflation broke the Phillips curve pattern; this helped spread the view that monetary policy should have as its main focus to target variables it could control in the long run, namely nominal ones.

This however, did not mean that the real economy should be completely disregarded. Monetary policy still had the potential to stabilize real variables around their natural level, which would be beneficial for the economy.\(^5\) A potential stumbling block for such stabilization was the presence of time-inconsistencies. Barro and Gordon (1983) pointed out that a central bank under discretion might be tempted to push real variables to unrealistic levels for a short term gain, which in the long-run would lead to a sub-optimal outcome. This could, however, in theory be remedied by a credible commitment from the central bank to follow a monetary policy rule. An absolute commitment to a formulaic rule would clearly be practically infeasible given the rigidity of such a rule. A more practical commitment would be to announce a target for monetary policy. By announcing a target the central bank could make itself accountable for its mistakes, and signal its intent to minimize them. Thus the central bank could reap the benefits of a commitment, while retaining some discretion; operating under what Bernanke and Mishkin (1997) would call “constrained discretion”. This would only be possible though if the agents in the economy found the commitment to be credible. Without credibility the central bank would be unable to convince the agents of its good intentions.

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\(^3\) The view that the Phillips curve was accepted knowledge in the 1960s and that Friedman (1968) was among the first to reject it has recently become contested. Forder (2016) argues that this view is false.

\(^4\) see Lucas (1972), Lucas (1973) and Lucas (1976).

\(^5\) Svensson (1997b) shows that even if society only cares about inflation deviations from target, it will be optimal to put some weight on the real economy, because the real economy is an important determinant of inflation.
Due to well-documented pressure from politicians to affect monetary policy, an essential part of gaining credibility for a central bank is to be independent of the government. This enables the central bank to conduct monetary policy with a clear aim to reach its target even if the policy is not politically popular. By conducting monetary policy this way, the central bank can demonstrate its commitment to reaching its target and increase credibility. Another important way to attain credibility is to be transparent about how monetary policy is conducted. Transparency is seen as such an important part of inflation targeting that Mishkin (2000) refers to it as “the key to the success of inflation targeting”. One of the factors that make credibility and transparency so important is the prospect of anchoring inflation expectations; that is making private agents believe that the inflation target will be reached in the medium-run. As shown by Clarida et al. (1999) this can improve the short-term trade-off between inflation and the output gap, contributing to increased welfare in the economy. The trade-off exists in the presence of cost-push shocks. Since cost-push shocks only directly affect inflation, any attempt to stabilize inflation will lead to a destabilization of the output gap. This creates a trade-off between the variability of inflation and the variability of the output gap, which is illustrated in figure 2.1. A central bank with a preference for keeping both inflation and the output gap stable will therefore find it optimal to rely on a “lean against the wind” policy where the central bank responds to a cost-push shock by “leaning” on the output gap to stabilize inflation (Clarida et al., 1999). If inflation expectations are anchored, the central bank won’t have to “lean” as much on the output gap to have a given effect on inflation, because a given adjustment of the output gap will have a greater impact on inflation. This should in theory lead to greater stability of inflation around the target.

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6 I am paraphrasing, the original quote is: “The key to success of inflation targeting is its’ stress on transparency and communication with the public”.

7 The output gap is defined as the difference between actual and potential output, where potential output is the highest level of output that will not contribute to an accelerating rate of inflation. The output gap represents the real economy.

8 In the graph SIT refers to strict inflation targeting; FIT to flexible inflation targeting; and SOT to strict output targeting.
The focus on keeping inflation low and stable is a fairly recent economic development, one that is demonstrative of the growing consensus that inflation leads to significant costs in the economy. As mentioned by Bernanke and Mishkin (1997), the costs of inflation have only been attributed substantial weight in the last few decades, but these costs have become more apparent as the volume of research has grown. Froyen and Waud (1987) for example finds (using time-series data) that high and volatile inflation leads to inflation uncertainty. Al-Marhubi (1998) (using cross section data), and Judson and Orphanides (1999) (using panel data) finds that uncertainty and volatility leads to lower economic growth. There are also costs associated with inflation being low, like a less efficient labor market (Akerlof et al., 1997).

Having inflation at a low level also means that negative cost push shocks are more likely to lead to deflation, which is widely recognized as being more harmful to the economy than inflation. In addition, low inflation may also weaken the ability of central banks to respond to deflationary shocks, as reductions in nominal interest rates become less effective the lower the rates are (Olsen, 2015). Furthermore, official inflation estimates tend to overstate the actual rate of inflation (Boskin et al., 1996). The realization that a stable and low but positive rate of inflation seemed to be an important precondition for economic growth meant that inflation to an increasing extent was considered a viable target on its own, and that it could be used as a nominal anchor. A nominal anchor is a variable the central bank aims to keep stable so as to...
ensure stability in the economy and facilitate economic growth. Inflation’s seemingly direct importance for these goals made it an ideal candidate.

One weakness inherent in the concept of targeting inflation, though, is the fact that there are long lags between monetary policy actions and their impact on inflation. This means that the central bank will have to use forecasts to determine the best course of monetary policy. In practice this use of forecasts means that inflation targeters, are doing what Svensson (2005) termed “forecast targeting”. Forecast targeting is to set the monetary policy instrument such that the forecasts show the target variables converging to target within the stated policy horizon. The policy horizon is the timeline in which a central bank aims to stabilize inflation around the target; it is usually communicated to the public for the sake of transparency. The use of forecasts to conduct monetary policy represents a potential source of inaccuracy, as it is difficult to predict future inflation (Cecchetti, 1995).

2.2.2 The Failure of Alternative Monetary Policy Systems

The two main alternatives to inflation targeting, exchange rate targeting and monetary targeting, both showed flaws in the 1980s and early 1990s. Monetary targeting it was argued (most notably by Friedman (1968)) could achieve stable economic growth by targeting steady growth in a monetary aggregate. This however necessitated a stable relationship between the demand for the targeted monetary aggregate and the target variables. Starting in the 1970s, several industrialized nations attempted to target money growth, but mainly due to new financial innovations the relationship between the monetary aggregate and the goal variables quickly deteriorated, which led governments to gradually deprioritize the use of monetary aggregates (Mishkin, 2000).

Exchange rate targeting, as opposed to monetary targeting, is still widespread today, but its status was reduced during the early 1990s as speculative attacks on European currencies highlighted some of its key weaknesses. Stabilization of the exchange rate is associated with costs, both through interventions in the foreign exchange market and through the use of the interest rate. When the interest rate is used to defend an exchange rate target it can have pro-cyclical effects, as has been the case in Norway (Steigum, 1998). Pro-cyclical effects can also be created through interventions in the foreign exchange market if the interventions aren’t sterilized. Sterilization, however, usually comes with a cost as well. The speculative attacks

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9Intermediate targets are also an alternative, but as Svensson (1997b) argues, there is no better intermediate target than a forecast of the medium-run target.

10To sterilize a foreign exchange market intervention means to neutralize the impact on the money supply.
on the British pound in 1992 highlighted how expensive it can be to defend an exchange rate target against speculators. The Bank of England exhausted almost all of its foreign exchange reserves, and raised the interest rate to 12 percent while promising to raise it to further to 15 percent before it gave up and let the pound float. This however was not the first time a country had found it difficult to keep an exchange rate peg; the Smithsonian Agreement collapsed under similar circumstances (IMF, 1973). A devaluation or a more flexible exchange rate target could have remedied some problems, but an increased focus on inflation also served as an argument for a change. To target inflation it is essential to be able to conduct stabilizing monetary policy, however when a country has free capital flows, the central bank must choose whether they prefer to keep a fixed exchange rate or the ability to conduct stabilizing monetary policy. This was another argument in favor of inflation targeting.

2.3 Inflation Targeting Today

Since its inception in 1990 inflation targeting has gathered a large following. In 1991 Canada became the second nation to adopt inflation targeting, and a trio of countries forced to leave the European Exchange Rate Mechanism soon followed. Early inflation targeters achieved positive results, and built up empirical support for the advantages of inflation targeting. In turn, this strengthened the reputation of inflation targeting and contributed to its increasing popularity. Countries have since continued to adopt inflation targeting, and at the beginning of 2012 27 nations were recognized as having officially adopted it (Hammond, 2012). In addition, many countries that aren’t officially recognized as inflation targeters employ some of its key principles. Japan and the United States for example both have inflation targets, but haven’t officially implemented inflation targeting. As Svensson (2010) notes, inflation targeting is widely regarded as a success. Studies find that inflation expectations are better anchored under inflation targeting (Levin et al. (2004) and Gürkaynak et al. (2006)), that inflation targeting has lowered the volatility of inflation (Vega and Winkelried, 2004), and that it has led to lower inflation (Hyvonen, 2004). A good indicator that countries seem to have been satisfied with the performance of inflation targeting is that no country so far has abandoned inflation targeting, except to adopt the Euro (Svensson, 2010).

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11 Rasmussen (2002) points out that having a low cost of reneging on an exchange rate target can lead to multiple equilibria and thus a volatile exchange rate. Devaluing the pound would have been indicative of a low cost of reneging on the exchange rate target; thus there is a possible cost associated with a devaluation to.

12 This is known as the impossible trinity.
3. The Transmission Mechanism of Monetary Policy

In this chapter I review how monetary policy can affect the economy through adjusting short term nominal interest rates. First, the effect on market rates is considered. Second, the individual channels that interest rate adjustments can affect the economy through are examined. Finally, the transmission lag in these processes is considered.

3.1 Monetary Policy Instruments

The transmission mechanism of monetary policy describes how monetary policy affects the economy, something which is highly dependent upon what kind of instrument the central bank employs. In the case of deregulated, liberalized, credit markets, the traditional choice of monetary policy instrument has been some form of a short-term nominal interest rate, usually the rate associated with a loan from, or a deposit to the central bank. Conventionally there has been a view that such rates have a zero lower bound, however, negative rates have in recent years become a reality. Still, negative interest rates are treated with caution, as there are doubts over how effective they are, and there is a recognition that banks may be negatively affected by them (Olsen, 2015). This is why the more common solution to the zero lower bound has been the non-traditional instrument of quantitative easing; that is buying up bonds to increase the money supply and lower the effective interest rate. This is also a relatively recent invention, and is considered an unconventional instrument. Another instrument the central bank has at its disposal, and which is especially relevant for inflation targeters, is so called forward guidance. The theory is that by communicating its expectations, the central bank can affect long-term interest rates. Since the standard main instrument of inflation targeters is a short-term nominal interest rate, and that Norges Bank relies on this as their main instrument, this chapter will focus on the transmission mechanism of monetary policy for adjustments in a short-term nominal interest rate.

3.2 From the Key Policy Rate to Market Rates

The main goals for inflation targeters are to keep inflation low and stable, and ensure stability in the real economy, therefore it is vital that the chosen instrument affects these variables. For this to happen the central bank needs to affect the interest rates that are important to enterprises and households, the ones offered by private banks (market rates). To achieve this,

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13 The most common alternative to this has been to use the money supply as the instrument for monetary policy, but this is not very common anymore. As Clarida et al. (1999) shows, it is an inferior instrument in the presence of unobservable money demand shocks.
central banks aim to control the overnight interest rate in the interbank market for central bank reserves (Woodford, 2005). The standard procedure is to supply the monetary base demanded by the private agents for a given key policy rate (Ireland, 2008). By controlling the monetary base the central bank can ensure that the overnight interbank interest rate stays close to the key policy rate. A change in the overnight interbank interest rate by itself however, probably will not affect the market rates noticeably, as these depend mainly on the expected future path of the overnight interbank interest rate. Therefore successful monetary policy hinges on the ability of the central bank to affect market expectations, and convince private agents that adjustments in the key policy rate are indicative of the future path of the overnight interbank interest rate. If the central bank can accomplish this, we would expect market rates to move in the same direction as an initial shift in the key policy rate. A lower expected path for the overnight interbank interest rate should for example give banks an incentive to lend to private agents rather than other banks, and lead to an increased supply of loans, which should drive down the market rates. Given well-functioning capital markets a reduction in the key policy rate usually lowers the market rates relatively fast (Olsen, 2015). This channel can run into problems in times like the collapse of Lehman Brothers in 2008, but throughout this chapter the functionality of this channel will be taken for granted. In other words, a lower key policy rate will be synonymous with lower market rates.

3.3 The Channels of the Transmission Mechanism

Through its effect on the market rates, the key policy rate can affect nominal and real variables through several channels. The three most important ones are: the interest rate channel; the exchange rate channel; and the expectations channel. Figure 3.1 gives a basic overview of the three channels, where the interest rate channel is represented by blue arrows; the exchange rate channel by green; and the expectations channel by red. There are other channels as well, such as the asset-price channel and the credit channel, but I only go through the three main ones since these are given the most weight in the literature.

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14 I refer to the short-term nominal interest rate used as the central bank’s main instrument as its key policy rate.
15 Like in Olsen (2015), where excess reserves are removed from the market to keep the overnight interbank interest rate close to the key policy rate.
16 Banks take deposit on a short-term basis, and lend on a long-term basis, therefore their profit margins are sensitive to changes in the interest rate, which means that they must consider the long-term interest rates.
3.3.1 The Interest Rate Channel

The interest rate channel is also referred to as the demand channel; it captures the effect that a change in the key policy rate has on aggregate demand through its impact on the real cost of capital, and how changes in aggregate demand affects inflation. The key policy rate can affect aggregate demand because there are nominal rigidities in the economy, which makes prices and wages adjust slowly. This means that inflation will be slow to adjust as well, and in turn inflation expectations, since private agents with rational expectations should recognize the consequences of nominal rigidities. Private agents are unlikely to have rational expectations, but as long as they learn at a positive rate, they should eventually recognize how inflation responds to changes in the key policy rate. The key policy rate can therefore have a temporary impact on the real interest rate, and by extension real economic variables. The real interest rate is the difference between the nominal interest rate and expected inflation. A change in the real interest rate represents a change in the cost of capital, which will affect aggregate demand in the economy. If for example a central bank wants to stimulate the economy, it can lower the key policy rate, which should lower the real interest rate. A lower real interest rate means that there will be a lower real return on deposits, and a lower real cost of borrowing. The lower cost of borrowing will make more investments profitable and encourage more consumption, which should increase the aggregate demand in the economy. Higher aggregate demand will create inflationary pressure, as firms will respond to the increased demand by increasing production, contributing to a higher output gap. To increase production firms will hire more workers, leading to a lower unemployment rate, which means that higher wages
will be needed to attract workers. Higher wages and a lower unemployment rate will increase aggregate demand further. Higher aggregate demand enables the firms to increase the prices, which leads to higher inflation.

3.3.2 The Exchange Rate Channel

The exchange rate channel, which is especially important for small open economies, captures the impact a change in the key policy rate will have on aggregate demand and inflation, through its impact on the exchange rate. A change in the key policy rate usually leads to a change in the nominal exchange rate, because it alters the return on domestic investments relative to foreign investments. If for example the key policy rate is reduced, there will be a lower nominal return on domestic investments, which should lead to a lower demand of the domestic currency relative to foreign currency. The nominal exchange rate will therefore appreciate, leading to import goods being more expensive in terms of the domestic currency, because they are originally denominated in a foreign currency. In practice this means that the price of imported goods has increased, which leads to increased inflation. This is called imported inflation.

It is however not only the nominal exchange rate that will appreciate after a reduction in the key policy rate. As already mentioned there exists nominal rigidities which make prices and wages slow to adjust. This means that the real exchange rate also will be affected. An appreciation of the nominal exchange rate will lead to a temporary appreciation of the real exchange rate, making domestic goods relatively cheaper than foreign goods. This will increase the demand for domestic export goods and domestic import competing goods, contributing to higher aggregate demand in the economy. The higher aggregate demand will through the mechanism presented in the section about the interest rate channel lead to higher inflation.

3.3.3 The Expectations Channel

The expectations channel captures the impact a change in the key policy rate has on aggregate demand and inflation, through its effect on inflation expectations. In isolation a lower key

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17 The nominal exchange rate is here defined as the number of units of the domestic currency needed to purchase one unit of a foreign currency. Note that if the relative return on investments determines the nominal exchange rate, then the foreign interest rate will be as important as the domestic.

18 Similarly to the nominal exchange rate, the real exchange rate is here defined as the number of units of the domestic good that must be given up to get one unit of the foreign good. The formula for the real exchange rate is: \( \frac{P^*}{P} E \). Where \( P^* \) represents the foreign price level, \( P \) is the domestic price level, and \( E \) is the nominal exchange rate.
policy rate should lead to increased inflation through mechanisms like the ones described in
the interest rate channel and the exchange rate channel, which means that inflation
expectations should increase following a reduction in the key policy rate. Increased inflation
expectations will have a direct effect on inflation, but it will also have an impact through the
interest rate channel and the exchange rate channel. The direct effect is a consequence of the
fact that inflation expectations are important for price setting; the higher inflation expectations
are, the greater the price increase is possible without becoming more expensive relative to
competitors. Inflation expectations also influence wage setting, as workers will need a greater
raise to maintain their real wage for a higher rate of inflation. This effect and the
intertemporal substitution of consumption will work through the interest rate channel.
Intertemporal substitution of consumption means that consumers prefer to consume more in
the periods in which goods are the cheapest. This means that higher inflation expectations
can be expected to lead to higher demand in the present, which in turn will lead to higher
inflation. Inflation expectations are regarded as an important indicator of future exchange
rates, and can therefore affect the economy through the exchange rate channel.

3.4 Transmission Lag

An adjustment of the key policy rate can impact economic variables through all of the
channels described above, but it will normally do so with a considerable lag. Although certain
mechanisms work pretty instantaneously, such as the formation of inflation expectations and
the reaction of nominal exchange rates to changes in the key policy rate, the variables that
inflation targeters target are only affected after a significant lag. Svensson (2001) for example
suggests a lag of “about one year” for imported inflation. He also suggests that aggregate
demand will be affected after about one year, and that this effect will carry over to inflation
after another year. This is roughly consistent with the results from Cristiano et al. (2005),
which find that the effect on inflation should peak after approximately two years, and that the
effect on the output gap should peak after about one and a half years. These estimates
however are at best rough rules of thumb. As Svensson (2001) points out, the effects will be
spread out over several quarters and will depend upon external factors such as the pass-
through of changes in the nominal exchange rate. In addition the economy is subject to a
continuous process of shocks that are hard to identify, which can distort estimates. This
underlines the fact that the control monetary policy exerts over the economy can be
unpredictable.
4. Monetary Policy in Norway

In this chapter I briefly review how monetary policy has been conducted in Norway, and why for all intents and purposes inflation targeting was adopted by Norges Bank in 1999. Further, the current mandate of monetary policy in Norway is summarized. Finally, the manner in which Norges Bank operates monetary policy is considered.

4.1 A Brief Summary of Monetary Policy in Norway

The current monetary policy regime of inflation targeting was officially implemented by Norges Bank March 29th 2001 (Ministry of Finance, 2001). This represented a break with the long held tradition in Norway of aiming to keep the Norwegian krone fixed to some foreign currency or a weighted basket of them, a tradition only broken two times since the Second World War by short periods of letting the exchange rate float in between monetary policy regimes, cf. Norges Bank (2004a).

The first monetary policy regime Norway opted for after WW-2 was the Bretton Woods system. It was created in 1944 and Norway joined in 1946. It worked by tying the currencies of all participating countries to the dollar, which was fixed to the price of gold. This was done with the aim of ending the competitive devaluations that had characterized the 1930’s, as well as ensuring exchange rate stability and encouraging economic growth. The Bretton Woods system came to an end in 1971 as large deficits for the US made it difficult to maintain the gold peg. The solution was to abolish the gold peg and thus effectively put an end to the monetary union (Bordo, 1993, pp.27-37 and 74-80). After the collapse of the Bretton Woods system Norway decided to let the NOK float until a suitable replacement could be found. It only took four months before the short-lived Smithsonian Agreement of 1971 was chosen as the heir to the Bretton Woods system. Norway also joined the European “Currency Snake” in 1972, whose short coexistence with the Smithsonian Agreement was dubbed the “Snake in The Tunnel” due to their different adjustment margins. After leaving the Smithsonian Agreement in 1973 Norway was left with the European “Currency Snake”, which meant that the NOK was to keep a stable exchange rate against other European currencies. Strong appreciation of the Deutsche Mark however led to a real appreciation of the NOK against key currencies such as the Japanese yen and the American dollar. This contributed to a loss of international competitiveness for Norwegian industry, and the problems and discontent that this created eventually led to Norway leaving the “Currency Snake” in 1978.
Norway instead opted to keep the NOK stable in relation to a trade-weighted currency basket. Advantages such as a greater separation from the appreciating Deutsche Mark, and the increased flexibility of a currency basket were cited as key reasons for choosing this exchange rate target. Only a year after adopting this new policy the trend in the exchange rate between the mark and the dollar had become reversed. This meant an even lower competitiveness for Norwegian industry, as the appreciating dollar made the NOK appreciate relative to European currencies. In addition, inflation during the 70’s and 80’s was high compared to inflation among Norway’s trading partners, which further contributed to the falling competitiveness. To increase competitiveness, a real depreciation of the NOK was seen as necessary. The new exchange rate target made it easier for the government to devaluate the NOK, and even though the first devaluation of what has come to be known as the “devaluation decade” happened within the “Currency Snake” in 1976, the change of monetary policy regime enabled this to continue. Frequent devaluations made in the name of increasing competitiveness were made, but the government was unsuccessful in controlling inflation. This meant that despite numerous devaluations in 1976-1986 Norway actually ended up less competitive.

To regain competitiveness it was determined that a more independent central bank than established through the central bank law of 1985 was needed.\textsuperscript{19} This meant that in 1986 Norges Bank was given the authority to use the interest rate to keep the exchange rate fixed. This resulted in Norges Bank making what is arguably its first independent interest rate adjustment in modern times on December 2\textsuperscript{nd}, 1986. To combat the high inflation from the “devaluation decade” the government employed contractive fiscal policy, this worked and inflation was brought down and stabilized. An unfortunate consequence of this policy was that unemployment increased, and it was this problem that led Norway to aim for a fixed exchange rate against the ECU.\textsuperscript{20} This policy was adopted in 1990. In 1992 the NOK came under significant downward pressure, as a series of speculative attacks on European currencies spread to Norway. Norges Bank attempted to stabilize the NOK by intervening in the foreign exchange market and by raising the interest rate, bringing the key policy rate up to 25 percent at the highest.\textsuperscript{21} Still the short selling of the NOK continued, and on December 10\textsuperscript{th}...

\textsuperscript{19} Cf. “Lov om Norges Bank og pengevesenet mv. (sentralbankloven).”
\textsuperscript{20} The European Currency Unit; it was a weighted basket of currencies that included the currencies of all the countries in the European Community.
\textsuperscript{21} This was the overnight lending rate (D-loan); it was used as the key policy rate from March 1986 until May 1993. Since May 1993 the sight deposit rate has been used as the key policy rate.
1992 the peg to the ECU was abandoned. The strain placed upon the economy by the high interest rate was seen as unsustainable; this led to the adoption of a temporary floating exchange rate until currency markets calmed down.

Continued turmoil in the European currency markets led policymakers to let the NOK float for almost two years before deciding on a new monetary policy regime. In 1994 a “flexible fixed exchange rate regime” was introduced. Even though this formally meant a return towards targeting the exchange rate, it also brought with it an unprecedented amount of flexibility for Norges Bank, as is apparent in the wording of the new guidelines.

“Substantial changes in the exchange rate shall be met with a response in the instruments with a view to bring the exchange rate back to the target range in due time.”

The Target range was defined as the rate the NOK had been trading at while floating, however, no margins of error or timeframe was specified. Thus Norges Bank was given some freedom to decide when intervention was needed. In practice, this allowed for a gradual implementation of inflation targeting. An example of the increasing importance of inflation in monetary policy came in 1998. The interest rate had been raised several times that year in response to downward pressure on the NOK, but despite continued pressure Norges Bank announced on August 24th that further increases were unlikely. Norges Bank expected the current interest rate to bring the exchange rate back in the target range “in due time”. Kjell Storvik (the governor at the time) defended this decision by stating how the current interest rate would stabilize inflation expectations and in turn the exchange rate (Norges Bank, 1999, P.11-12). Norges Bank was aiming to stabilize the exchange rate on a longer time horizon than before; this was made possible by the vague formulations in the mandate from 1994, and allowed a greater focus on inflation.

When Svein Gjedrem was appointed governor in 1999 he was explicit about how monetary policy would be conducted. He maintained that the main focus of monetary policy would be to keep the NOK stable in relation to European currencies, but he also highlighted that this would be done on a long term basis, and that the best way to do this would be to target inflation.

“There are two fundamental conditions necessary for achieving stability against European currencies. First, price and cost inflation must fall to the level aimed at by euro countries. A

22 St.meld. Nr.2. Revidert Nasjonalbudsjett 1994. P.43. My translation, the original quote is: “Ved vesentlige endringer i kursen skal virkemidlene inrettes med sikte på at valutakursen etter hvert bringes tilbake til utgangsleiet.”
high rise in prices and costs will in itself fuel depreciation expectations. Monetary policy must therefore be oriented with a view to bringing price and cost inflation in Norway down to the inflation target in Europe.” – Gjedrem (1999)

Gjedrem thus set out to keep inflation stable around ECBs inflation target (below, but close to, 2%) using the interest rate as the primary instrument, while securing a stable NOK long term. Inflation targeting wouldn’t be officially adopted until over two years later, but the strong resemblance between the outline presented by Gjedrem and inflation targeting has led many to believe that the inflation targeting regime of Norges Bank started when Gjedrem was appointed as governor in 1999.23 This view is strengthened by the fact that the document which lays down the guidelines for monetary policy under inflation targeting extensively quotes official Norges Bank documents and speeches made by Gjedrem (Ministry of Finance, 2001).

4.2 The Current Monetary Policy Regime

The current objective for monetary policy in Norway was outlined in a mandate issued to Norges Bank by the government in 2001.24 It states that monetary policy should be conducted with a view to keep inflation, measured by a consumer price index, low and stable, and that the operational goal of monetary policy should be to keep annual inflation close to 2.5% over time.25 Norges Bank should aim to accomplish this while also taking into account the impact on the real economy, as stability in employment and output is a priority. Later, and in particular after the financial crisis, Norges Bank has stated that the build-up of financial imbalances will be considered when monetary policy decisions are made (Norges Bank, 2015). The concern for real variables is visible through the stipulation that changes to the rate of inflation brought about by changes in interest rates, excise duties, taxes and extraordinary temporary disturbances, should not be taken into account. For this reason, Norges Bank focuses on measures of core inflation, which excludes some of the most volatile prices. The main measure of core inflation for Norges Bank, is the measure derived from the CPI-ATE index, which excludes the effects from taxes and energy products. The CPI-ATE index is produced by Statistics Norway. This focus on core inflation enables Norges Bank to allow short term inflation deviations from target in order to keep real variables stable, which is

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25 This inflation target is consistent with the international consensus that optimal annual inflation lies somewhere between 1% and 3% (all industrialized inflation targeters have inflation targets between 1% and 3% (Hammond (2012))).
consistent with the medium term horizon Norges Bank communicates (Norges Bank, 2015). The formulation of the horizon is purposefully vague, as it provides flexibility for Norges Bank, and because it will depend on disturbances and the transmission mechanism of monetary policy. The lag in the transmission mechanism means that forecasts are used to conduct monetary policy. In combination with the communicated horizon this means that Norges Bank reacts with its main instrument, the key policy rate, when forecasts show a divergence of inflation from the target in the medium term, and that the central bank will adjust the key policy rate with a view to take inflation back towards the target. However, Norges Bank should not compensate for previous deviations.

For Norges Bank the key policy rate is the interest rate private banks receive on deposits in the central bank up to a certain quota; this interest rate is known as the sight deposit rate. For deposits over the quota banks receive the reserve rate, which is one percentage point lower than the key policy rate. The D-loan rate, which is the interest rate private banks pay on loans from the central bank, is one percentage point higher than the key policy rate. Together, these interest rates make up an interest rate corridor, where the key policy rate is placed in the middle. When conducting monetary policy Norges Bank aims to keep the overnight interbank interest rate (NOWA) close to the key policy rate, which is achieved by limiting the supply of central bank reserves (Olsen, 2015). According to the theory of inflation targeting, changes in the key policy rate is expected to affect the economy through the mechanisms described in chapter 3.

Internationally, interest rates have been observed to exhibit a strong degree of autocorrelation; this means that previous values are good indicators of its present value. This observation is usually attributed to interest rate smoothing on part of the central bank. Interest rate smoothing means that the interest rate is adjusted gradually in response to changes in the economy. Norges Bank have communicated a preference for interest rate smoothing for example in Norges Bank (2012) as part of a proposed loss function. Other reasons to smooth interest rates include: concern for disturbing financial markets (Goodfriend, 1991), and it

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26 Norges Bank has previously communicated horizons of 2 years and 1-3 years, but has since Norges Bank (2007) described the horizon as “the medium term”. A medium term horizon is the standard for inflation targeters according to Hammond (2012), who defines it as a horizon of 2 years or more.

27 There are other sources of autocorrelation, though. Rudebusch (2006) divides the inertia of interest rates into two causes: intrinsic inertia and extrinsic inertia. Intrinsic inertia is due to interest rate smoothing by the central bank, while extrinsic inertia is due to slow movement in macroeconomic variables. Rudebusch finds that extrinsic inertia is the most important factor.
being an efficient method of affecting long term interest rates while keeping the key policy rate stable (Woodford, 1999).

Decisions about whether to change the key policy rate are made at monetary policy meetings, of which there are six each year, by the executive board. The executive board consists of central bankers from Norges Bank and representatives from the private sector and academia. When the key policy rate is adjusted, it is done in increments of 25 basis points. Norges Bank, however, isn’t restricted to use an interest rate as its main instrument, as it has instrument independence, which means that it is free to choose its instruments based on what it thinks will best achieve the monetary policy goals. The distinction between instrument independence and goal independence was made by Debelle and Fischer (1994), who argued that goals should be delegated to central banks (that they should be goal dependent), but that central banks should be free to determine how to achieve them, which is consistent with the current practice of Norges Bank. The freedom to operate monetary policy independently, however, makes it vital that there are accountability mechanisms for the central bank, as monetary policy actions have large effects on the economy. Furthermore, it is a matter of principle in democratic societies that agents of the government are held accountable for their actions. For Norges Bank this is dealt with by mechanisms like supervision by the Supervisory Council and an annual external review known as Norges Bank Watch. For external reviews like the Watch Report to be able to accurately assess monetary policy, the central bank needs to have a considerable focus on transparency, as deviations from the inflation target can be due to many different reasons: bad policy, bad forecasts, or completely unexpected shocks that the central bank cannot be expected to anticipate. Therefore, proper accountability is dependent on the central bank providing the reasoning behind its actions, and specifying what data those are based on.

Norges Bank’s main method of communicating this information to the public is through the Executive Board’s Assessment, which is released in conjunction with each monetary policy meeting, and through the quarterly release of a Monetary Policy Report. In the Executive Board’s Assessment the governor motivates the interest rate decision, while the Monetary Policy Report provides a more comprehensive review and analysis of the economy. Through the Monetary Policy Report Norges Bank communicates: the monetary policy targets, the

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28 Other accountability mechanisms include: An open hearing for the governor before the Standing Committee on Finance and Economic Affairs (Norges Bank (2015), and that Norges Bank should give a thorough explanation for substantial deviations from the inflation target in the Annual Report (Ministry of Finance, 2001).
considerations that are made when the interest rate is set, analyses of both the domestic and the international economy, and forecasts of key variables. Norges Bank is one of only a few central banks that publishes forecasts of its key policy rate (Svensson, 2010). Besides enabling a greater degree of accountability for the central bank, transparency can also make monetary policy more efficient. By communicating clearly with the public the central bank can reduce uncertainty in the economy, and make it easier for private agents to anticipate changes to the key policy rate, which should yield a stronger and faster response in long term rates in response to an adjustment of the key policy rate. To achieve this Norges Bank aims to be a transparent central bank, which is visible not only through published forecasts, but also through its openness regarding the considerations that are made when the key policy rate is determined.

To inform the key policy rate decisions Norges Bank relies on several different economic models. One of these is the Norwegian Economic Model (NEMO), which is the central bank’s main macroeconomic model. In it the appropriate interest rate is determined by a loss function which the central bank argues can represent a simplified version of the assessments that are made when the key policy rate is determined. An example of such a loss function is provided by the central bank in Norges Bank (2012):

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

Here the first argument refers to the inflation deviation from target, the second to the output gap, the third to interest rate smoothing and the fourth to the deviation of the interest rate from the normal interest rate.\(^{29}\) \(\lambda, \gamma\) and \(\tau\) refer to how much weight each argument is given relative to the inflation deviation.\(^{30}\) Note that each deviation is squared, so that the sign of the deviation does not matter, and that large deviations will yield more than proportional losses compared to small deviations. In a loss function like this the interest rate is set to minimize the total “loss” imposed upon the economy. This is of course a simplification, as there are many other variables that may be relevant for the key policy rate, and in addition a fair amount of discretion is used when the Executive Board makes their decision. One of the elements that are especially difficult to model, and where models often are augmented by discretion, is robustness. Robustness means that we can expect the interest rate to yield a

\(^{29}\) The normal interest rate is here defined as the interest rate that is consistent with an inflation and output gap equal to zero over the medium term. This term is used interchangeably with the neutral interest rate throughout the thesis.

\(^{30}\) Norges Bank is the only central bank that has communicated the values it uses for these coefficients to the public (Svensson, 2010). In Norges Bank (2012) they were reported to be: \(\lambda = 0.75; \gamma = 0.25; \tau = 0.05\).
favorable outcome for different assumptions about the economy. Simple interest rules are often used as cross-checks to achieve robustness, as they exhibit considerable independence with respect to the assumptions made about the economy. Interest rate rules prescribe a reaction pattern based on values of economic variables; the most famous is known as the Taylor-Rule.

5. The Theoretical Framework

In this chapter I review the theoretical framework that will be used in the empirical analysis. First the Taylor rule and the Taylor principle are introduced. Second, the former is generalized so that it can capture forward looking behavior and interest rate smoothing. Finally, the econometric framework and the main estimation methods used in the thesis are introduced.

5.1 Taylor Rules

5.1.1 The Original Taylor Rule

The Taylor rule was proposed by Taylor (1993) as a way for central banks to capture gains from commitment, either by letting the rule inform interest rate decisions quantitatively or by following its basic theory, without setting the interest rate mechanically. It was understood that formal rules could not capture all the considerations that needed to be made when setting the interest rate in practice, and that formal rules therefore should only reflect essential theoretical insights. A rule could then be thought of as capturing what the central bank should do in “normal times”, given values of the most important economic variables, while discretion could be exercised by policymakers to respond to other concerns.

Simplicity was therefore an important part the Taylor rule, since it only was meant to capture the most important features of operational monetary policy. In addition, it would be essential for policymakers seeking to supplement an interest rate setting rule with their judgement to know what factors the rule captured and which ones it did not. In line with this simplicity concern the Taylor rule proposed that the interest rate should be positively dependent on two variables: inflation and the output gap. Since the original Taylor rule was a backward-looking model, lags of these variables would be used. Using the original values that Taylor (1993) proposed for the US, which provided a good fit for the federal funds rate between 1987 and 1992, the original Taylor rule can be rewritten to:

\( r = 4 + 1.5(p - 2) + 0.5y \)
Here, $r$ denotes the federal funds rate, $p$ inflation over the previous four quarters and $y$ the output gap expressed as the percentage deviation of real GDP from a target. The inflation target is set equal to 2 percent. When both inflation and the output gap are equal to their respective targets the federal funds rate is equal to 4 percent, or 2 percent in real terms. These rates are referred to as long-run equilibrium interest rates. The original coefficients for inflation and the output gap suggest that the federal funds rate should increase by 1.5 percentage points for a 1 percentage point increase in inflation, and by 0.5 percentage points for a 1 percentage point increase in the output gap. These coefficients are consistent with an important principle of monetary policy that has become associated with the Taylor rule; namely, the Taylor principle. It states that for monetary policy to have a stabilizing effect on the economy, the central bank has to react more than one-for-one with the nominal interest rate to changes in inflation. This is because the nominal interest rate is expected to affect the economy through its impact on the real interest rate (as covered in chapter 3), and for the real interest rate to increase after an increase in inflation the nominal interest rate has to respond more than one-for-one to inflation. This principle can be reduced to the requirement that the inflation coefficient must be greater than one. For the output gap to be stabilized as well, the output gap coefficient needs to be greater than zero. In the original Taylor rule such coefficient requirements are equivalent to responding to changes in the economy with full force immediately, which to interest rate smoothing central banks might seem extreme. A more realistic alternative is that central banks may aim to follow such principles over time.

In summary, the Taylor rule provides a robust simplification of policy behavior while being consistent with some key theoretical insights. These features have led to it being used as a guiding principle for monetary policy, which is visible through central banks using variations of the Taylor rule to cross-check proposed interest rate paths. Despite the popularity and influence of Taylor rules, however, the original formulation has some clear limitations, which could prevent it from capturing important features of monetary policy.

### 5.1.2 A Forward-Looking Taylor Rule

One of the clearest inconsistencies between the Taylor rule and the way inflation targeting central banks claim to conduct monetary policy is that the original Taylor rule is backward-looking.

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31 A long-run equilibrium interest rate can be thought of as a long-run version of a normal/neutral interest rate.
32 As pointed out by Taylor (1993) the lag of inflation is used as a proxy for expected inflation in the original Taylor rule when it is formulated in terms of the real interest rate.
33 This is stated explicitly by for example Norges Bank in Norges Bank (2014) p. 19.
looking, whereas central banks seek to target forecasts. A backward-looking rule either disregards the lag in the transmission mechanism, or uses the lag of a variable as an indicator of its future value. The use of a forecast ought to be a superior alternative, as it means recognizing the lag in the transmission mechanism while allowing the predicted future value of a variable to be based on a wide array of information. To allow for the possibility of targeting forecasts a generalized Taylor rule, inspired by Clarida et al. (1998) and Clarida et al. (2000), is introduced:

\[
i_t^* = i^* + \beta (E[\pi_{t,k} | \Omega_t] - \pi^*) + \gamma E[\gamma_{t,q} | \Omega_t]
\]

Here, \(i_t^*\) is the prescribed nominal interest rate, \(\beta\) the inflation coefficient, \(\gamma\) the output gap coefficient and \(i^*\) the long-run equilibrium nominal interest rate. Given well-anchored inflation expectations \(i^*\) can be written as the sum of the inflation target \((\pi^*)\) and the long-run equilibrium real interest rate \((r^*)\), so that \(i^* = \pi^* + r^*\). \(\Omega_t\) is the information set available to the policymaker in period \(t\), which will include all information from period \(t-1\) and earlier. This means that variables from period \(t\) (contemporaneous variables) and later will be viewed as the central bank’s forecasts. \(\pi_{t,k}\) is the Y/Y inflation between period \(t+k-4\) and period \(t+k\), while \(\gamma_{t,q}\) is the average output gap between the beginning of period \(t\) and the beginning of period \(t+q\). Note that a genuine forecast will be used for inflation if \(k\) takes a non-negative value, and that an expected value then will be used (the same logic applies to \(q\) values greater than zero and the output gap). With this setup the Taylor principle remains the same, except that the central bank should react to changes in expected inflation instead of changes to a lag of inflation. Adding extra explanatory variables to this rule is trivial, as it simply means introducing a new argument consisting of the expected value of the new variable and its associated coefficient. The generalized rule used here nests backward-looking models that rely on lags of inflation and the output gap. This can be seen by setting \(k\) and \(q\) equal to -1, which should yield a reasonably close approximation of the original Taylor rule.

5.1.3 A Forward-Looking Taylor Rule with Interest Rate Smoothing

Another potentially important feature of monetary policy that is missing from the original Taylor rule is interest rate smoothing. Central banks may not want to adjust the interest rate to

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34 One notable difference between inflation and the output gap here, is that inflation will be a forecast when \(k\) is set equal to zero, while the output gap will disappear when \(q\) is equal to zero. This discrepancy is present for forward-looking models, but disappears for backward-looking models.

35 Taylor (1993) never explicitly addresses how long the lag is for the output gap; here it is assumed that the most recent lag is used.
the one suggested by the Forward-Looking Taylor rule immediately, but rather do so gradually. To capture central banks’ preference for gradual adjustments the procedure of Clarida et al. (1998) and Clarida et al. (2000) is followed and a partial adjustment rule is adopted:

\[ i_t = (1 - \rho)i_t^* + \rho i_{t-1} \]

Here, \( i_{t-1} \) is the nominal interest rate from the previous period and \( i_t^* \) the nominal interest rate recommended by the Forward-Looking Taylor rule. \( i_t^* \) can be thought of as the target rate for the central bank, as it is the interest rate that is seen as optimal when interest rate smoothing is not considered. By giving \( i_{t-1} \) and \( i_t^* \) weights of \( \rho \) and \( (1-\rho) \), respectively, and requiring \( \rho \) to take values in the interval \([0,1]\), \( \rho \) can be interpreted as a smoothing coefficient. If for example \( \rho \) is equal to 0.5 the central bank will adjust the interest rate halfway towards the target in each period. If \( \rho \) is equal to 0 this rule will be reduced to the Forward-Looking Taylor rule. If the Forward-Looking Taylor rule in equation (5.2) is inserted for the interest rate target in equation (5.3), the partial adjustment rule looks like:

\[ i_t = (1 - \rho)i_t^* + \rho i_{t-1} + (1 - \rho)\beta E[\pi_t | \Omega_t] + (1 - \rho)\gamma E[\pi_t | \Omega_t] \]

To simplify the expression, the expected deviation of inflation from target (the expected inflation gap) has been defined as \( \pi_t \). The inflation coefficient is \( (1-\rho)\beta \), because only a \( (1-\rho) \) share of the distance to the target rate will be covered in each period. Over time; however, the interest rate will approach the target, which means that the total response to a change in expected inflation will be equal to \( \beta \). Placed into this framework the Taylor principle therefore does not require that the inflation coefficient is greater than one, but rather that the coefficient \( \beta \) is. In the language of time series econometrics \( \beta \) is the long-run derivative of the interest rate with respect to inflation. Compared to the static formulation above, the Taylor principle now implies that the interest rate should be increased more than one-for-one with respect to permanent inflation changes, not temporary changes. This important distinction cannot be made in the original static Taylor rule.

5.1.4 Taylor Rules and Empirical Analysis

Estimating Taylor rules represents a popular way of studying monetary policy. The theoretical consistency and robustness associated with these rules imply that estimates of its coefficients can have relevance for how central banks conduct monetary policy. Generalized Taylor rules

\[ E[\pi_{t,k} | \Omega_t] = E[\pi_{t,k} | \Omega_t] - \pi^* \]
in particular, such as the one presented in equation (5.4), capture many important features of operational monetary policy while at the same time nesting simpler rules. In addition, rules of this form can be derived as an optimal rule for central banks if monetary policy is based on a quadratic loss function, like the one communicated in Norges Bank (2012) (Svensson, 1997a). It is unlikely that any central bank would follow a rule derived from such a loss function slavishly, but it is possible, given how well generalized Taylor rules capture the concerns communicated by inflation targeting central banks, that it could provide a broad approximation of how monetary policy is conducted. Its flexibility along with its direct connection to loss functions makes the rule in equation (5.4) a good candidate for studying monetary policy.

5.2 The Econometric Framework

5.2.1 Choice of Estimators

The original backward-looking Taylor rule can be estimated with Ordinary Least Squares (OLS), as it is based on predetermined variables of inflation and the output gap. Predetermined explanatory variables lead to a bias, but with white-noise disturbance this bias is small, even for relatively short samples, and is asymptotically equal to zero.

More precisely, as long as the associated disturbance covariance matrix is proportional to an identity matrix,37 OLS will provide consistent estimates of the parameters, and efficient estimates of the variance. Generalizations of the Taylor rule, however, can pose problems for OLS also under the classical assumptions about the disturbances. First, the introduction of interest rate smoothing makes the rule nonlinear in parameters, and secondly, a forward looking rule will introduce expectations, which introduces endogenous explanatory variables. Both of these features are present in the generalized rule from equation (5.4), which for the purpose of estimation can be formulated as:

\[
i_t = (1 - \rho)/\gamma + \rho i_{t-1} + (1 - \rho)\beta (E[\tilde{\pi}_{t,k}|\Omega_t]) + (1 - \rho)\gamma (E[\tilde{y}_{t,q}|\Omega_t]) + \nu_t
\]

In this equation, \( \nu_t \) denotes the error term, which captures the interest rate movements that are left unexplained after controlling for the explanatory variables; this is best thought of as a zero mean exogenous interest rate shock. The tilde over \( \pi \) and \( y \) is used to represent that the variables are measured as the deviation from their respective targets, so that \( \tilde{\pi} \) is the inflation gap, and \( \tilde{y} \) the output gap. Since \( \pi^* \) is part of the explanatory variable \( \tilde{\pi} \), a value will have to

37 This is equivalent to having homoscedastic and non-serially correlated error terms.
be imposed upon \( \pi^* \) before estimation, otherwise the equation must be reparametrized. Equation (5.5) is clearly nonlinear in parameters, which means that linear estimators such as OLS and Two-Stage Least Squares (2SLS) will not be able to estimate all the coefficients of interest directly. However, nonlinearity is in this case not a big issue, since equation (5.5) allows for the non-linear parameters of interest to be “backed out” after linear estimation. This is seen by expressing equation (5.5) as a linear-in-parameters equation:

\[
(5.6)\quad i_t = a_0 + a_1 i_{t-1} + a_2 (E[\pi_{t,k} | \Omega_t]) + a_3 (E[\gamma_{t,q} | \Omega_t]) + v_t
\]

With reference to equation (5.5), the parameters in equation (5.6) should be self-explanatory. Note that \( a_1 \) is a direct estimate of \( \rho \) and thus allows for estimates of \( i^* \), \( \beta \) and \( \gamma \) to be calculated from estimates of \( a_0 \), \( a_2 \) and \( a_3 \), respectively. Rewriting the expressions for \( a_0 \), \( a_2 \) and \( a_3 \) to get expressions for \( i^* \), \( \beta \) and \( \gamma \) makes the relationships between the parameters explicit:

\[
(5.7)\quad i^* = \frac{a_0}{1-a_1} \quad \beta = \frac{a_2}{1-a_1} \quad \text{and} \quad \gamma = \frac{a_3}{1-a_1}
\]

By inserting for \( i^* = r^* + \pi^* \), equation (5.7) allows for estimates of \( r^* \) to be calculated as well, given a value of \( \pi^* \). Hence, the estimate of \( r^* \) will depend upon the value that is exogenously determined for \( \pi^* \). Since Norges Bank has had an official inflation target of 2.5% annual inflation since 2001, and an unofficial target of around 2% from 1999 to 2001, \( \pi^* \) will be exogenously set as 2.5% in the empirical analysis.\(^{38}\)

To obtain the variance of a nonlinear parameter that has been “backed out”, the delta method can be applied. The delta method relies on a Taylor approximation to give a linear approximation of the nonlinear parameter of interest. After a linear approximation has been derived, the standard formula for variance can be used to derive an estimate of the nonlinear parameter’s variance. As an example, the variance of \( \beta \) can be estimated by utilizing a first order Taylor approximation, which is given by:\(^{39}\)

\[
(5.8)\quad g(x_1, \ldots, x_k) \approx g_\mu + \sum_{i=1}^{k} \left( \frac{\partial g}{\partial x_i} \right) \bigg|_{x_i = \mu} (x_i - \mu_{x_i})
\]

In this equation \( k \) is the number of linear parameters that the nonlinear parameter of interest \( g(x_1, \ldots, x_k) \) consists of, and \( \mu \) is the average value of a parameter. Using estimated

\(^{38}\) See chapter 4 for references on Norges Bank’s inflation targets.

\(^{39}\) The formula is taken from Bårdsen and Nymoen (2011) p. 72
parameters from equation (5.6) to derive the approximate variance of $\hat{\beta}$ should yield (see the appendix for calculation):\textsuperscript{40}

\begin{equation}
(5.9) \quad Var(\hat{\beta}) = Var \left( \frac{\sigma_2}{1-\beta_1} \right) \approx \left( \frac{1}{1-\beta_1} \right)^2 \left[ \sigma_a^2 + 2 \left( \frac{\beta a_2}{1-\beta_1} \right) \sigma_{a_2,a_1} + \left( \frac{\beta a_2}{1-\beta_1} \right)^2 \sigma_{a_1}^2 \right]
\end{equation}

Note that when the inflation target is exogenously set, then this equation can estimate the approximate variance of all the nonlinear parameters in equation (5.5) by replacing $a_2$ and $a_1$ with the relevant parameters. Thus, in this case, interest rate smoothing does not pose a problem for linear estimators like OLS and 2SLS. Therefore, linear estimators will be preferred for the empirical analysis.\textsuperscript{41}

A factor that does imply problems for OLS is the presence of endogenous explanatory variables. The generalized Taylor rule in equation (5.4) allows for forward-looking behavior on part of the central bank, which means targeting forecasts. The standard way to derive the forecasts of the central bank, is to rely on the rational expectations assumption; an assumption that I also will use. The realized future values of inflation and the output gap are likely to be endogenous, though, as it is not realistic that the $\Omega_t$ information set available to the central bank would allow perfect forecasts. This means that the variables will be correlated with the error term, which makes OLS an inconsistent estimator. To deal with the endogenous explanatory variables, an instrumental variables estimator will be used, and to avoid limiting the number additional instruments that can be used, the estimator will be one capable of dealing with over-identification, which means having more additional instruments than endogenous explanatory variables. The main instrumental variable estimators that allow for this are: Generalized Method of Moments (GMM) and Two-Stage Least Squares (2SLS).\textsuperscript{42}

In the literature, the standard choice of estimator for estimating forward looking Taylor rules with interest rate smoothing is GMM.\textsuperscript{43} The advantage of using GMM over 2SLS, is that GMM is more robust with respect to the assumptions made about the covariance matrix. For 2SLS to be an efficient estimator the covariance matrix has to be proportional to an identity

\textsuperscript{40} The “hat” over a character denotes that it is an estimator.

\textsuperscript{41} Unless linear estimators perform badly, it is in general preferable to avoid nonlinear estimators, as they tend to be less robust. This is because nonlinear estimators rely on initial guesses of the parameter values that should be estimated, and imprecise initial values could lead to poor estimates.

\textsuperscript{42} 2SLS yields identical results to Generalized Instrumental Variable Estimator (GIVE), so the choice between 2SLS and GIVE is in practice irrelevant.

\textsuperscript{43} In fact, it is nonlinear GMM, but given the established preference for linear estimators here, this section will focus on the pros and cons of linear GMM and 2SLS. GMM has been used by: Clarida et al. (1998), Clarida et al. (2000) among others.
matrix, while GMM is asymptotically efficient even when there is heteroscedasticity and/or autocorrelation. There can, however, be drawbacks to this increased robustness. If the main research purpose is to derive “the true” estimate of the parameters in equation (5.4), then all relevant explanatory variables should be controlled for. The presence of autocorrelation could signal that there are omitted variables; thereby removing the autocorrelation by using GMM could be counterproductive, because it could prevent omitted variables from being detected. Therefore, it may be beneficial to rely on a less robust estimator, at least initially, to improve the model. If the model can be improved, the estimates will be better, and if it cannot then GMM can still be used instead. 2SLS is therefore chosen as the main estimator in the empirical analysis, while GMM is used as a robustness test. 2SLS is explained intuitively in the next section. For information about GMM, see for example Davidson and MacKinnon (2009) Ch. 9.

5.2.2 Estimating the Generalized Taylor Rule with 2SLS

Since 2SLS is a linear estimator, the estimable equation has to be linear in parameters, like equation (5.6). Using equation (5.6) as a starting point, the rational expectations assumption first has to be implemented, which means replacing the unobservable expected values by the actual values. To achieve this, the following error term is defined:

\[
\epsilon_t = u_t - a_2(\tilde{\pi}_{t,k} - E_t[\tilde{\pi}_{t,k} | \Omega_t]) - a_3(\tilde{y}_{t,q} - E[\tilde{y}_{t,q} | \Omega_t])
\]

Here, \(u_t\) is the zero mean exogenous interest rate shock from before, while the other arguments are the forecasting errors of inflation and the output gap. As pointed out by Clarida et al. (2000) these forecasting errors can lead to the error term having a moving average structure. This means that there will be autocorrelation in the model even if it is correctly specified. Using 2SLS to estimate the model initially still has value, though, as there are other potential sources of autocorrelation, such as omitted variables, that can be controlled for. This allows the model to be improved by isolating the inherent autocorrelation as the only source, while relying on GMM as a robustness test to test whether any autocorrelation that might remain leads to poor estimates. Solving for \(u_t\) and inserting into equation (5.6) yields:

\[
i_t = a_0 + a_1i_{t-1} + a_2\tilde{\pi}_{t,k} + a_3\tilde{y}_{t,q} + \epsilon_t
\]

This is the policy reaction function; it is linear in parameters and consistent with the rational expectations assumption. It will, however, as explained earlier, have explanatory variables that are correlated with the error term. Therefore, 2SLS will be used to deal with the endogenous explanatory variables.
As suggested by its name, the 2SLS estimator consists of two stages. In the first stage the endogenous explanatory variables are regressed on a set of instruments, using OLS, to determine what part of the variation in the endogenous explanatory variables that can be explained by the $\Omega_t$ information set. Given valid additional instruments, these regressions should yield the linear combinations of instruments that maximize the correlation to the endogenous explanatory variables, while remaining independent of the error term in the original equation. The set of instruments should include all the predetermined and exogenous explanatory variables from the original regression, as well as additional instruments. In the second stage, the original equation is estimated by OLS, using the predicted values from the first stage regressions to instrument for the endogenous explanatory variables. The estimates from this second stage regression are the 2SLS estimates.

5.2.3 Instrument validity

In order for the additional instruments to be valid they have to be correlated to the endogenous explanatory variables and be independent of the error term in the original equation. If the additional instruments are only weakly correlated to the endogenous explanatory variables, the instrument set is said to be weak. This can be problematic because the variance of the 2SLS estimates, relative to the OLS estimates, is directly tied to the strength of the instrument set; the weaker the instrument set is, the higher will the variance of the 2SLS estimates be relative to the OLS estimates. In addition, weak instruments can lead to severely biased estimates. If the independence condition is violated the 2SLS estimator will yield inconsistent estimates.

The possibility of weak instruments will be addressed by examining the first stage regressions from the 2SLS estimation. The F-statistics from these regressions, testing whether the additional instruments have explanatory power over the endogenous explanatory variables, will be reported with the 2SLS estimation results. The rule of thumb for structural equations with a single endogenous explanatory variable is that this F-statistic should be greater than 10 (Staiger and Stock, 1997). This rule does not generalize to the case with multiple endogenous variables in that it does not provide precise statistical inference, however, high F-statistics are still indicative of instrument relevance. Therefore, F-statistics comfortably greater than 10 will be interpreted as evidence of sufficient instrument relevance.

---

44 By referring to a variable as independent of the error term, I mean that the variable is independent of the contemporaneous error term i.e. that the predeterminedness condition holds.
In order to test whether the independence condition is satisfied in 2SLS estimations, the Sargan test and the J-test are reported. These tests have the same interpretation and both rely upon homoscedastic standard errors and the absence of autocorrelation to provide precise inference. The Sargan test is computed directly in OxMetrics 7 (see Doornik and Hendry, 2013), while the J-test is calculated from estimation output in accordance with the definition from Davidson and MacKinnon (2009) Ch. 8.6 and Bårdsen and Nymoen (2014) Ch. 3.1.7. The J-test can also be calculated for GMM, which means that it provides a practical way of comparing instrument validity between models estimated with 2SLS and GMM. When the J-test is reported for GMM estimations, it is computed directly in EViews 9.5 (see EViews 9 User’s Guide II, 2016). Since GMM is robust to autocorrelation and heteroscedasticity, the associated J-test inherits these traits.

The Sargan test and the J-test are known as over-identification tests, because they test whether the over-identifying restrictions imposed upon the structural model by the additional instruments are valid. These restrictions state that the over-identifying instruments should be independent of the error term. The null hypothesis of these tests is that the restrictions are valid, which means that insignificant test results will be indicative of valid additional instruments. Significant tests, however, have two possible interpretations. First, some instruments may simply be invalid, which mean that they should be dropped and replaced by valid instruments. Second, some instruments may have explanatory power over the residuals because they are omitted variables from the original equation, or because they are correlated to omitted variables. The presence of omitted variables would mean that the original equation is misspecified and should be reconsidered. The two interpretations have very different implications for how to proceed with estimation/modelling, and therefore the interpretation of a significant over-identification test should not be taken lightly.

5.2.4 Misspecification tests

Since the efficiency of the 2SLS estimator depends upon the structure of the residual term, a battery of misspecification tests will be reported alongside the 2SLS estimation results. These tests are included to test whether the residual term violates any of the conditions it has to fulfill in order for 2SLS to provide consistent point estimates and reliable inference. These misspecification tests are all calculated in OxMetrics 7, and will now be summarized briefly.

45 Specifically, the J-test is calculated by running an auxiliary regression, regressing the residual from the 2SLS estimation on the instrument set. The explained sum of squares from this auxiliary regression, which should be equal to the minimized IV criterion function for the 2SLS estimation (Davidson and Mackinnon, 2009. p. 334), is then divided by the estimated regression variance from the 2SLS estimation.
For more detailed information about these tests and how they are calculated, see Doornik and Hendry (2013)

The “Normality” test can be used to test whether the residuals deviates significantly from a normal distribution. If this test alone is found to be significant, exact inference based on t-statistics cannot be used. In that case an asymptotic normal distribution must be relied on. As pointed out by Anderson and Sawa (1979), however, the speed at which the asymptotic distribution approaches normality can be quite slow. Therefore, a failed normality test should be considered when drawing inference based asymptotic normality.

The “Hetero” test statistic tests whether the variance of the residual term is heteroskedastic. More specifically, it tests whether the variance is dependent upon the value of the regressors or the squares of the regressors. Since the 2SLS estimator relies upon homoscedastic variance in order to calculate the variance correctly a significant test will lead to inaccurate estimates of the variance, which can lead to unreliable inference.

The “ARCH(1-x)” test also tests whether the variance of the residual term deviates from homoscedasticity. The difference from the “Hetero” test is that variance here is modelled as an autoregressive process of order x. A significant test means that the homoscedasticity condition is violated, and that the reported variance thus will be inaccurately calculated, which can lead to misleading inference.

The “AR(1-y)” statistic tests whether the residual term is correlated with the first y lags of itself. A significant test means that the calculated variance will be inaccurate and that inference based on these estimates therefore can be unreliable. In addition, the presence of predetermined explanatory variables means that a significant test also renders 2SLS an inconsistent estimator.

6. Data and Estimation Period

In this chapter I introduce the data used in empirical analysis. First, three key variables are presented. Second, the estimation period is outlined. Finally, the possibility of structural breaks is considered.

6.1 Data

The dataset used in the empirical analysis consists of ex-post time-series data with quarterly frequency. Quarterly is the most common frequency to use for estimating monetary policy
reaction functions. The alternative would be to use monthly data, which technically might provide a better correspondence with the frequency of monetary policy meetings. However, the use of monthly data does not necessarily improve econometric estimates; Islam (2011) finds that Taylor rules perform equally well for quarterly and monthly data. In order for the data to be compatible with the econometric approach from chapter 5, the interest rate and inflation must constitute stationary time-series. Following Clarida et al. (1998) and Clarida et al. (2000) this is assumed.

6.1.1 The Key Policy Rate

As explained in chapter 4.2, Norges Bank uses the sight deposit rate as their key policy rate. This rate is determined by Norges Bank, and represents the interest rate private banks receive on deposits up to a certain quota. Adjustments are made at Norges Bank’s monetary policy meetings, and the rate is changed in increments of 25 basis points. Since the key policy rate can be changed within quarters, the quarterly average will be used to represent the rate that affects the economy. The original data on the key policy rate is given in daily frequency, so an arithmetic mean is used to obtain the quarterly average. The quarterly average of the key policy rate is illustrated in figure 6.1.

Figure 6.1: Norges Bank’s key policy rate for 1999Q1 – 2016Q2.

46 All averages are arithmetic means unless otherwise noted.
6.1.2 Inflation

To construct a measure of inflation the CPI-ATE index, produced by Statistics Norway, will be used. This is also the index that is used to calculate Norges Bank’s operational definition of Norwegian inflation. The CPI-ATE index excludes price effects from taxes and energy goods, which makes it relevant as a measure of core inflation. With reference to the monetary policy mandate, which states that price effects from (among other factors) taxes and extraordinary temporary disturbances should not be taken into account, these exclusions seem reasonable.

Taxes are mentioned specifically, and the exclusion of energy products is understandable given the volatility of energy prices and the direct reference to temporary shocks in the mandate. The CPI-ATE index is released on a monthly basis, so a quarterly average is taken. From the resulting quarterly index the Y/Y inflation is calculated. This measure of inflation represents a natural way to control for seasonal variation, and therefore the unadjusted CPI-ATE index is used. The quarterly Y/Y CPI-ATE inflation over the estimation period is depicted in figure 6.2. For illustrative purposes, and because the inflation deviation from target will be used as an explanatory variable in the empirical analysis, Norges Bank’s inflation target of 2.5% is also shown in the graph. The average inflation in the estimation period is roughly 1.75%, meaning that inflation on average has been 0.75 percentage points below target.

![CPI-ATE Inflation Y/Y for 1999Q1-2016Q2. Inflation target of 2.5% included for comparison.](image)

\[47\text{ To be specific: } \left( \frac{\text{CPI}_{t-1} - \text{CPIATE}_{t-4}}{\text{CPIATE}_{t-4}} \right) \times 100\]
6.1.3 The Output Gap

The output gap is an unobservable variable, defined as the difference between actual and potential output, where potential output is the highest level of output that will not contribute to an accelerating rate of inflation. The Seasonally adjusted gross domestic product (GDP) for Mainland-Norway will be used to construct a measure of the output gap. Seasonally adjusted data is used because the GDP for Mainland-Norway exhibits a large degree seasonal variation, which causes the data to be volatile. This seasonal variation is easily observable, and we would certainly expect that Norges Bank does not let it interfere with policy decisions. To derive a measure of the output gap from a single variable a Hodrick-Prescott filter (HP filter) is used. An HP filter extracts a trend from a data-series by minimizing a loss function like the one in equation (6.1). \(^48\)

\[
(6.1) \quad \min \{ y_t^* \}_{t=1}^T \left[ \sum_{t=1}^T (y_t - y_t^*)^2 + \lambda \sum_{t=1}^T [(y_t^* - y_{t-1}^*) - (y_{t-1}^* - y_{t-2}^*)]^2 \right]
\]

In this equation \( y_t^* \) is the trend value in period \( t \), while \( y_t \) is the actual value. The first argument inside the parenthesis represents the loss imposed by letting the actual value deviate from the trend, while the second represents the loss imposed by changing the trend between periods. \( \lambda \) is the weight placed on the second argument relative to the first, which means that a higher \( \lambda \) will yield a more persistent trend. Hodrick and Prescott (1997) proposed using \( \lambda = 1600 \) for quarterly data, which has become the international standard even though it was clearly chosen to fit the US data. In any case experience has shown that trends in the Norwegian economy seem to be better captured by using a higher \( \lambda \). I use \( \lambda = 40000 \) as my standard choice of \( \lambda \), as this is the value Statistics Norway use in their analyses of the Norwegian economy (Statistics Norway, 2014). \( \lambda = 1600 \) will be used as a robustness test. When GDP data is used in the HP filter, the trend value can be interpreted as potential output. Thus, by following the standard practice of taking the log of GDP before extracting a trend, the percentage deviation of output from potential output is estimated by subtracting \( y_t^* \) from \( y_t \), and then multiplying by 100. The estimated output gap for the estimation period, constructed in OxMetrics 7, is shown in figure 6.3.

\(^48\) This equation is taken from Frøyland and Nymoen (2000).
The HP filter has two major drawbacks. First, it is a two-sided filter, which means that it uses past and future information about the output to determine the trend value in a given time period. This means that the output gap is calculated using information not yet available to the central bank, which means that the variable might be endogenous for us as econometricians, even when a lag is used. Second, the HP filter suffers from an endpoint problem, which means that estimates of the trend are sensitive to changes near the endpoints. To avoid an endpoint problem near the start of the estimation period, data for 1978Q1–2016Q2 is used to estimate the output gap in figure 6.3. To avoid an endpoint problem at the end of the estimation period, it is possible to augment the data series with forecasts.

6.2 Estimation Period and Potential Structural Breaks

The estimation period in the empirical analysis is chosen to capture Norges Bank’s inflation targeting regime, and is therefore chosen to be 1999Q1 – 2016Q2. With reference to chapter 4.1, 1999Q1 is chosen as the starting point because the consensus seems to be that Norges Bank became a de-facto inflation targeter after Svein Gjedrem was appointed as governor. Since the current monetary policy mandate states that inflation should be targeted, and Norges Bank describes the current monetary policy regime as “a flexible inflation targeting regime” (Norges Bank (2015)), the most recent data available is used as the endpoint (2016Q2). If Norges Bank have maintained the same criteria for conducting monetary policy throughout this estimation period, and weighted them roughly equal, estimating a well-specified reaction
function should yield stable coefficients. This estimation period, however, includes several events which could constitute structural breaks for the way Norges Bank have conducted monetary policy.

The potential structural break that will be focused on in the empirical analysis, is the financial crisis of 2008. The financial crisis can be dated back to the fall of 2007, but it was only after Lehman Brothers applied for bankruptcy on September 15, 2008 that the majority of economists started to grasp the full ramifications of the crisis (Mishkin, 2011). For this reason, September 15, 2008 seems like a reasonable start date for the financial crisis. However, since September 15 is near the end of the third quarter it is unlikely that the quarterly average of the key policy rate was substantially affected. Therefore, the start of the financial crisis will here be defined as 2008Q4. The financial crisis caused worldwide disruptions in financial markets, and may have led central banks to deviate from their usual reaction patterns. Such deviations could represent temporary responses to the crisis, or more permanent adjustments of the criteria used to determine an appropriate interest rate. In the first monetary policy report of 2012 (Norges Bank, 2012), Norges Bank communicated a change to the weighting of the arguments in their loss function. It was stated that changes had been made to the loss function used in this report, compared to previous reports, in order to “enable the Bank’s model-based analyses to better capture the monetary policy response pattern since the financial crisis in autumn 2008”. This is suggestive of some kind of break occurring due to the financial crisis. Other events that could constitute structural breaks for Norges Bank include: The official implementation of inflation targeting in 2001Q2; changes in the communicated horizon in 2004Q3 and 2007Q2; and the appointment of Øystein Olsen as governor in 2011Q1.

7. Empirical Analysis

In this chapter I present estimated models for Norges Bank’s key policy rate, and interpret the results. First, a baseline forward-looking model is estimated and analyzed. Second, the validity of the instruments in the baseline model are assessed. Third, possible explanations for autocorrelation in the baseline model are investigated. Fourth, the robustness of the model is

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49 At least to the extent that it can represent a structural break in the interest rate setting of Norges Bank.
50 Norges Bank were primarily referring to a higher weight placed upon the output gap relative to inflation, but also to changes in the weighting of interest rate deviations from simple interest rate rules.
51 Norges Bank (2004b) and Norges Bank (2007) were the first monetary policy reports where horizons of 1-3 years and the medium term, respectively, were communicated.
considered. Fifth, the analysis is extended to include the financial crisis and subsequent observations. Finally, the results are discussed.

7.1 The Baseline Estimation

The baseline model is estimated by 2SLS and is of the form of the linear equation (5.11), where Norges Bank’s key policy rate is used as the dependent variable. The reported coefficients are the long-run derivatives of the key policy rate with respect to the explanatory variables. These long-run derivatives are obtained by the relationships given in equation (5.7), and their variances estimated by the delta method. Given that Norges Bank communicates a forward-looking reaction pattern, and forward-looking models are thought to provide the most plausible reaction pattern for central banks, the baseline model is forward-looking. Following Clarida et al. (1998) and Clarida et al. (2000) a model with a four quarter horizon for inflation (k=4) and a one quarter horizon for the output gap (q=1) is estimated. This means that forecasts of the output gap in period t and the inflation between period t and period t+4 are used. This choice of horizons for inflation and the output gap implies, under the assumption of the model, an inherent MA(3) structure in the error term. The set of instruments used to estimate the baseline model is based on the instrument set used in Clarida et al. (1998) to estimate reaction functions for the Bank of England and the Bank of France, as a constant and four lags of: inflation ($\pi$), the output gap ($\bar{y}$), world commodity price inflation ($wcpi$), the key policy interest rate ($i$) and the log of the real exchange rate ($lrex$) are used as instruments.

Although the theory underlying the forward-looking models assumes that the future distribution functions are known, it does not seem realistic that monetary policy makers could/were able to calculate conditional forecasts based in correct post-financial crisis probability densities. Hence, it is reasonable to expect a structural break in the interest rate setting equation, around the time the financial crisis of 2008. Therefore, the baseline model was estimated for the period of 1999(1)-2008(3). And as noted I look at the full sample results as part of the robustness-check.

Given the inflation targeting framework of Norges Bank, we expect to estimate coefficient values that serve to stabilize inflation and the output gap. Thus a long-run inflation coefficient greater than one and a long-run output gap coefficient greater than zero are to be expected. I also expect to find a smoothing coefficient with a value between zero and one, and a long-run equilibrium key policy rate that is reasonably close to the average key policy rate over the

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52 Note that the different inflation variable used in Clarida et al. (2000) means that the interpretation of the inflation term here is slightly different, but that the two measures will be identical for $k = 4$. 

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estimation period. The average key policy rate should, over a reasonably long sample with no structural break, be a reliable estimate of the long-run equilibrium of the key policy rate. My sample is not very long, but around 40 observations is enough to at least consider the average rate as an interesting comparison with the estimate from the econometric model. Over the baseline estimation period the key policy rate averaged 4.66 percent, but since there is considerable uncertainty associated with estimating the long-run equilibrium key policy rate even non-negligible deviations would not be surprising. A long-run equilibrium key policy rate of roughly 4.16-5.16 percent would be expected.53 The results from estimating the outlined model with 2SLS in OxMetrics 7 are presented in table 7.1.

Table 7.1: Estimation results for the baseline model – Model 1.

<table>
<thead>
<tr>
<th>i*</th>
<th>ρ</th>
<th>β</th>
<th>γ</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.90***</td>
<td>0.90***</td>
<td>2.67**</td>
<td>0.51</td>
</tr>
<tr>
<td>(1.64)</td>
<td>(0.04)</td>
<td>(1.30)</td>
<td>(0.72)</td>
</tr>
</tbody>
</table>

Estimation method: 2SLS
No. of instruments: 21
Estimation period: 1999(1)-2008(3)
Sigma: 0.4051
Observations: 39
RSS: 5.7450

First stage F-test – inflation gap $F(19,18) = 26.68 [0.000]***$
First stage F-test – output gap $F(19,18) = 17.21 [0.000]***$
Sargan test $\chi^2(17) = 24.42 [0.108]$
J-test $\chi^2(17) = 21.92 [0.187]$
AR(1-3) $F(3,32) = 10.60 [0.000]***$
ARCH(1-3) $F(3,33) = 1.50 [0.230]$
HETERO $F(6,32) = 3.15 [0.015]***$

Normality $\chi^2(2) = 7.54 [0.023]$

Notes:
The coefficients are for: $i_t = (1 - \rho)i^* + \rho i_{t-1} + (1 - \rho)\beta(E[\tilde{\pi}_{t,k} | \Omega_t]) + (1 - \rho)\gamma E[\tilde{y}_{t,d} | \Omega_t] + \epsilon_t$, where the horizon for inflation is set to four quarters ahead ($k=4$) and the horizon for the output gap is set to one quarter ahead ($q=1$). The instrument set includes: $\pi_{t-1}, ..., \pi_{t-4}, \tilde{y}_{t-1}, ..., \tilde{y}_{t-4}, i_{t-1}, ..., i_{t-4}, wcpi_{t-1}, ..., wcpi_{t-4}, blex_{t-1}, ..., blex_{t-4}$ and a constant. */**/*** denotes significance at the 10%/5%/1% level, respectively. Standard errors are reported in parentheses.

Table 7.1 shows that all of the estimated coefficients have the expected signs, but that their significance varies. The inflation coefficient is estimated to be 2.67 with a standard error of 1.30, which makes it significant at the 5% level. The point estimate means that a one percentage point increase in expected annual inflation historically has been accompanied by a

53 Over the baseline estimation period inflation and the output gap averaged roughly 0.75 percentage points below and above their targets, respectively. Since inflation is expected to be given greater weight than the output gap, an argument could be made that the average key policy rate will underestimate the long-run equilibrium key policy rate. This would imply an apparent upward bias for estimates of $i^*$. 
2.67 percentage point increase in the key policy rate. This result suggests that Norges Bank has had a clear focus on targeting inflation. However, the inflation coefficient is not found to be greater than unity at any standard significance level. Therefore, we do not get formal statistical evidence in support of the hypothesis that Norges Bank adjusts the key policy rate in accordance with the Taylor principle. The output gap coefficient is found to be positive, but insignificant at all standard significance levels. The point estimate indicates that an expected one percentage point increase in the output gap has been associated with a 0.51 percentage point increase of the key policy rate. The insignificance of this estimate means that it is uncertain whether the output gap has represented a direct concern when the key policy rate has been determined. An important caveat here is that there may have been a large difference between the real-time output gap that the central bank may have acted upon, and the output gap series that I have constructed, with the use of the latest quarterly national accounts data.

Both the constant term and the smoothing coefficient are found to be significant at the 1% level. The smoothing coefficient is estimated to be 0.90, which indicates that Norges Bank adjusts the key policy rate 10% towards the target rate in each quarter. This is consistent with a strong degree of interest rate smoothing; a finding that is common for estimated Taylor rules with interest rate smoothing. The long-run equilibrium key policy rate is estimated to be 5.90 percent with a standard error of 1.64 percentage points. This implies a deviation of 1.24 percentage points from the average key policy rate, which is insignificant at all standard significance levels. The estimate of the long-run equilibrium real interest rate is found to be 3.71 percent, which is calculated by subtracting the inflation target from the long-run equilibrium key policy rate and accounting for the fact that the real interest rate is measured in terms of market rates.54

Inspection of the first stage F-statistics indicates that weak instruments is unlikely to represent a problem in the baseline estimation. The F-statistics of 26.68 and 17.21 for the inflation gap and the output gap, respectively, comfortably satisfy the rule of thumb that they should be greater than 10. As mentioned earlier this rule does not provide precise inference when there are multiple endogenous explanatory variables, but the high F-statistics should be a good indicator of instrument relevance. Both of the over-identification tests are insignificant at all standard significance levels, indicating that the instrument set is valid. However, the Sargan

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54 The 3-month Norwegian Interbank Offered Rate (NIBOR) is used as a measure of market rates. The average spread between the key policy rate and the NIBOR over the baseline estimation period was 0.31 percentage points, which means that the long-run equilibrium real interest rate is equal to: 5.90 - 2.50 + 0.31 = 3.71 percent.
test is only marginally insignificant at the 10% level, and the presence of autocorrelation and heteroscedasticity mean that inference based on the over-identification tests can lead to questionable conclusions. Therefore, a closer inspection of the instruments used in the baseline model seems warranted. This is done in chapter 7.2.

Out of the four reported misspecification tests, only the test for autoregressive conditional heteroscedasticity is insignificant. The normality test is significant at the five percent level, meaning that asymptotic inference will have to be relied on. The test for heteroscedasticity is also significant at the five percent level, which means that the reported standard errors will be inaccurate. Finally, the test for autocorrelation is significant at the one percent level, strengthening the case for the reported standard errors being unreliable, but also rendering 2SLS an inconsistent estimator. The latter test represents the greatest problem for the 2SLS estimates. Therefore, the source of the autocorrelation will be investigated in chapter 7.3.

In sum, the baseline model yields coefficients that are consistent with Norges Bank’s inflation targeting framework, but they are likely to be biased. This bias should stem from strongly significant autocorrelation, and possibly invalid instruments. In addition, the derived standard errors are likely to be unreliable. The estimates from table 7.1 and any inference drawn from these estimates should therefore be treated with upmost skepticism, as there are many potential sources of misspecification.

7.2 Investigating Instrument Validity

If the over-identifying restrictions from the baseline model are not valid, at least one of the instruments from the baseline model should be correlated with the error term. In order to identify which instruments that might be correlated to the error term, each instrument is controlled for individually. Almost by definition, instruments that are significantly correlated to the error term, are likely to also be significant when used as explanatory variables in the interest rate setting equation. Therefore, the instruments that are most significant when controlled for, are also likely to represent the greatest problems to the validity of the instrument set.

The only instrument that was found to be significant at the 1% level when controlled for, was the second lag of the key policy rate, henceforth $i_{t-2}$. On the assumption that $i_{t-2}$ really is strongly significantly correlated to the error term, it can either be an omitted variable, correlated to omitted variables or an invalid instrument. In the first interpretation, which is in accordance with the specification test interpretation of the J-test (see Davidson and
MacKinnon (2009) Ch. 8.6 and Bårdsen and Nymoen (2014) Ch. 3.1.7,  \( i_{t-2} \) should be controlled for as a pre-determined variable in the model. This would imply that a second order partial adjustment model is the correct model for the key policy rate. In the literature such a model has been motivated with reference to higher order interest rate smoothing dynamics which cannot be captured by controlling for a single lag of the key policy rate. Clarida et al. (1998) and Clarida et al. (2000), among others, have used such a model to model the federal funds rate. A model with a second order autoregression therefore seems to represent an interpretable alternative to the baseline model. Controlling for  \( i_{t-2} \) yields the model estimated in table 7.2.

Table 7.2: The baseline model: controlling for  \( i_{t-2} \).

<table>
<thead>
<tr>
<th>( i^* )</th>
<th>( \rho )</th>
<th>( \beta )</th>
<th>( \gamma )</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.26***</td>
<td>0.85***</td>
<td>3.08***</td>
<td>-0.47</td>
</tr>
<tr>
<td>(0.88)</td>
<td>(0.03)</td>
<td>(0.74)</td>
<td>(0.31)</td>
</tr>
</tbody>
</table>

**Notes:**

The coefficients are for:  
\[
i_t = (1 - \rho)i^* + \rho_1 i_{t-1} + \rho_2 i_{t-2} + (1 - \rho)\beta(\mathbb{E}[\pi_{t,k}|\Omega_t]) + (1 - \rho)\gamma(\mathbb{E}[\gamma_{t,q}|\Omega_t]) + \epsilon_t,
\]

where  \( \rho = \rho_1 + \rho_2 \), and  \( \rho_1 \) and  \( \rho_2 \) are the coefficients for the first and second lag of the key policy rate, respectively. The horizon for inflation is set to four quarters ahead (\( k=4 \)) and the horizon for the output gap is set to one quarter ahead (\( q=1 \)). The instrument set includes:  \( \pi_{t-1}, \ldots, \pi_{t-4}, \gamma_{t-1}, \ldots, \gamma_{t-4}, i_{t-1}, \ldots, i_{t-4}, wcpit_{t-1}, \ldots, wcpi_{t-4}, trex_{t-1}, \ldots, trex_{t-4} \) and a constant. */**/*** denotes significance at the 10%/5%/1% level, respectively. Standard errors are reported in parentheses.

Table 7.2 shows that estimating a model where  \( i_{t-2} \) is included as an explanatory variable, rather than an instrument, yields over-identification tests that are clearly insignificant at all standard significance levels. The first stage F-statistics remain high, indicating that the remaining instrument set has relevance. Apart from a less significant test for autocorrelation, the misspecification tests largely remain unchanged. The point estimates are generally consistent with a priori expectations, with the output gap coefficient being the only exception. The long-run output gap coefficient is found to be significantly negative at the 15% level. While, this does not constitute formal significance, it is in clear violation of both theory and
the reaction pattern communicated by Norges Bank. Since the estimation sample used here is relatively small, I follow Bernhardsen and Bårdsen (2004) and put emphasis on the a priori expectations. Therefore, the second order partial adjustment model is rejected, which implies that $i_{t-2}$ is not an omitted variable.

Again, it is important to note that the output gap coefficient may be affected by the use of ex-post, rather than real-time data. To check whether this might have affected the estimated sign of the output gap coefficient the second order partial adjustment model was also estimated using the alternative measures of the output gap from chapter 7.5. Two of these measures were constructed using the unemployment rate, which should not be subject to the large revisions that GDP data are subject to. Therefore, using these alternative measures should provide a test for whether revisions played a large role in the determination of the sign of the output gap coefficient. The output gap coefficient was found to be negative for all the alternative measures of the output gap, indicating that the output gap coefficient really has the wrong sign in the second order partial adjustment model.55

The empirical finding that $i_{t-2}$ is significant as an explanatory variable, may still merely be the result of a spurious correlation. $i_{t-2}$ could be correlated with some variable that may not even be observable, but has influenced the interest rate determination over the sample. However, this is not a possibility that will be investigated further here. Instead, this issue will be revisited in the section about robustness testing below. In short, a model without omitted variables would be expected to yield coefficient estimates that are robust to the inclusion of alternative explanatory variables. This robustness test is conducted in chapter 7.5.

The final possibility is that $i_{t-2}$ is indeed an invalid instrument. In this case $i_{t-2}$ should be dropped from the instrument set. Dropping $i_{t-2}$ as an instrument, however, does not have a significant impact upon the baseline model. The most likely explanation for this is that the key policy rate time-series has a strong degree of autocorrelation, which means that the third lag of the key policy rate ($i_{t-3}$) is likely to capture much of the same information as $i_{t-2}$. This is evident by considering the smoothing coefficient, which in the baseline model was estimated to be 0.9. In fact, controlling for $i_{t-3}$ yields very similar results to controlling for

---

55 The output gap measures that are based on the unemployment rate have been calculated so as to retain the same sign interpretation.
Therefore, $i_{t-3}$ can be rejected as an omitted variable by the same logic as $i_{t-2}$. Dropping both $i_{t-2}$ and $i_{t-3}$ as instruments yields the model estimated in table 7.3.

**Table 7.3: The baseline model: dropping $i_{t-2}$ and $i_{t-3}$ as instruments.**

<table>
<thead>
<tr>
<th></th>
<th>$i^*$</th>
<th>$\rho$</th>
<th>$\beta$</th>
<th>$\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6.47***</td>
<td>0.89***</td>
<td>3.05**</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>(1.43)</td>
<td>(0.04)</td>
<td>(1.19)</td>
<td>(0.58)</td>
</tr>
</tbody>
</table>

Estimation method: 2SLS
No. of instruments: 19
Estimation period: 1999(1)-2008(3)
Sigma: 0.4107
Observations: 39
RSS: 5.9054

First stage F-test – inflation gap: $F(17,20) = 27.45$ [0.000]***
First stage F-test - output gap: $F(17,20) = 20.89$ [0.000]***
Sargan test: $\chi^2(15) = 18.14$ [0.254]
J-test: $\chi^2(15) = 16.28$ [0.363]

AR(1-3) F-test: $F(3,32) = 10.7$ [0.000]***
ARCH(1-3) F-test: $F(3,33) = 2.13$ [0.113]
HETERO F-test: $F(6,32) = 3.13$ [0.015]***

Normality $\chi^2(2) = 6.97$ [0.030]**

Notes:
The coefficients are for: $i_t = (1 - \rho) i^* + \rho i_{t-1} + (1 - \rho) \beta (E[\pi_{t,4} | \Omega_t]) + (1 - \rho) \gamma E[\tilde{y}_{t,4} | \Omega_t] + \epsilon_t$, where the horizon for inflation is set to four quarters ahead ($k=4$) and the horizon for the output gap is set to one quarter ahead ($q=1$). The instrument set includes: $\pi_{t-4}, \ldots, \pi_{t-4}, \tilde{y}_{t-4}, \ldots, \tilde{y}_{t-4}, i_{t-4}, wcpi_{t-4}, \ldots, wcpi_{t-4}, lre\varepsilon_{t-4}, \ldots, lre\varepsilon_{t-4}$ and a constant. */**/*** denotes significance at the 10%/5%/1% level, respectively. Standard errors are reported in parentheses.

The results in table 7.3 show that dropping both $i_{t-2}$ and $i_{t-3}$ as instruments yields over-identification tests that are comfortably insignificant at all standard significance levels. In combination with high F-statistics this is an indication of a valid instrument set. The misspecification tests remain virtually unchanged from the baseline model. The point estimates are also very similar to those in the baseline model, which mean that they are consistent with a priori expectations. In fact, the model in table 7.3 offers statistical evidence of the Taylor principle being followed, as the inflation coefficient is marginally greater than unity at the 10% significance level. This increased significance is partly due to lower standard errors, and partly due to a higher inflation coefficient. The output gap coefficient remains insignificant and retains the correct sign. The long-run key policy rate is estimated to be slightly higher, yielding a 1.88 percentage point gap to the average key policy rate. This still does not constitute a significant difference, but could be a sign that the key policy has been

---

$^{56}$ $i_{t-3}$ is significant at the 5% level as a control variable. Note also that the fourth lag of the key policy rate is insignificant as a control variable, and therefore is considered a valid instrument.
relatively low over the estimation sample. The implied long-run real interest rate is 4.28 percent.\(^{57}\)

In sum, the model estimated in table 7.3 appears to be an improvement on the baseline empirical model. Despite being subject to the same significant misspecification tests as the baseline model, this model relies on an instrument set that seems to be valid. This removes one source of inconsistency for the point estimates. While doing this, the point estimates remain consistent with a priori expectations. Thus, while there are still reasons to be skeptical about both point estimates and inference drawn from this model, it is likely to provide a better estimation of Norges Bank’s reaction pattern than the baseline model.

### 7.3 Investigating Autocorrelation

Among the remaining misspecification problems, as indicated by the significant misspecification tests, the presence of autocorrelation is likely to represent the biggest problems to the model estimated in table 7.3. Based on its own assumptions the model should have an inherent MA(3) structure in the error term, which should contribute to the presence autocorrelation. However, the strength of this effect is unknown, as it is possible that most of the autocorrelation can be due to other factors which can be controlled for. In fact, the significant test for autocorrelation does not offer any direct evidence of the error term having a MA structure. To assess the structure of the error term, its correlogram is plotted in figure 7.1.

**Figure 7.1: Correlogram of error term from the estimation reported in table 7.3.**

![Correlogram](image)

The correlogram shows the autocorrelation (red bars) and partial autocorrelation (blue bars) of the error term to its lags. The x-axis shows the number of lags, while the y-axis indicates the strength of the correlation. For the error term to have the expected MA(3) structure,\(^{57}\)

---

\(^{57}\) The long-run real interest rate is calculated in the same way as in chapter 7.1.
autocorrelation and partial autocorrelation should be positive and significant for the first three lags. While the first lag is consistent with this, the later lags are not. All things considered, the correlogram seems to indicate a mixture of a MA(1) and an AR structure. Considering that the source of the inherent MA structure is the substitution of unobservable variables with observable ones, this indicates that the forecast errors are strongly significantly correlated with their own first lags. Of course, this assumes that the empirically observed MA structure is a product of the inherent one. It does, however, seem reasonable that forecasts should be significantly improved with the availability of 2-3 quarters of new data.

While, the correlogram in figure 7.1 suggests that there might be some inherent autocorrelation in the model from table 7.3, there are still other potential sources of autocorrelation that might be accounted for. First, either by necessity or error, Norges Bank may have deviated from their usual reaction pattern. Such deviations can cause large residuals, and thereby lead to significant misspecification tests and inaccurate point estimates. It is also possible that the observed MA(1) structure is not inherent to the model, as estimating a forward-looking model when the underlying data generating process is backward-looking can yield a MA(1) structure in the error term. 58 Second, a potential source of autocorrelation is omitted variables, but as mentioned earlier, the possibility of omitted variables will be addressed by the use robustness tests in chapter 7.4.

### 7.3.1 Controlling for Outliers

As noted the possibility that Norges Bank at some point within the sample has deviated from its standard reaction function, is something that we should try to control for. After all, the estimated reaction functions are only supposed to capture how Norges Bank conducts monetary policy in “normal” times. On the assumption that the model estimated in table 7.3 represents a reasonably good approximation of the standard reaction pattern, any such deviations are likely to show up as substantial residuals i.e. outliers. In order to inspect the residuals from table 7.3 graphically, they are scaled with respect to the estimation standard error and graphed in figure 7.2.

---

58 This is shown Bårdesen et al. (2005) p. 292 for a model of inflation.
From figure 7.2 the residuals associated with the third quarter of 2002 (2002(3)) and the third quarter of 2003 (2003(3)) stand out as the most significant. To control for a large residual, however, there needs to be a clear historical reason for doing so. Large residuals can of course also be due to weaknesses in the model, in which case controlling for them could yield an artificially well-specified model. Therefore, the historical basis for 2002(3) and 2003(3) representing deviations from Norges Bank standard reaction pattern are assessed in the following sections.

As noted by Bjørnland et al. (2004), the interest rate setting in the second half of 2002 was affected by “massive forecast failures”. While the economy was sliding into a recession Norges Bank projected robust economic growth, and as a result raised the key policy rate by 50 basis points on July 3rd 2002. It is realistic to assume that this led monetary policy to become too tight throughout the rest of 2002, as Norges Bank did not start to cut interest rates until December 11th 2002. Consequently, the interest rate setting in 2002(4) was also affected by the same factors as in 2002(3). Noting that 2002(4) constitutes the third most significant residual in figure 7.2, and that it has a direct connection to the most significant residual, 2002(4) is also considered a residual possibly worth controlling for. Finally, it is important to note that Norges Bank in all likelihood followed their standard reaction pattern with respect to their own forecasts in these quarters, but that the forecasts were inaccurate. Since the forecasts in the estimated model apparently do not capture these forecast errors, it makes sense to consider controlling for these residuals.

Monetary policy in 2003 was characterized by aggressive cuts in the key policy rate. This was especially the case around 2003(3), as the interest rate was cut by 100 basis points on both June 25th and August 13th, and then followed by a cut of 50 basis points on September 17th.
Bjørnland et al. (2004) noted that the two later cuts seemed a bit “heavy handed”, but that Norges Bank otherwise deserved credit for the easing policy of 2003. Ekeli et al. (2003) concluded similarly, stating that Norges Bank deserved credit for their speed and determination, but that the interest rate reductions may have been “on the generous side”. In addition, Bjørnland et al. (2004) noted that there were signs of economic recovery in August, which Norges Bank should have considered. Still, all of the reductions seem to have been rooted in legitimately low CPI-ATE inflation, as CPI-ATE inflation over 2003 ended up at just 0.1 percent. Therefore, the case for interest rate setting in 2003(3) representing a deviation from Norges Bank’s standard reaction pattern, does not seem as clear cut as for 2002(3). Nonetheless, 2003(3) will still be considered a possible deviation, and by similar logic as for 2002(4), the subsequent quarter (2003(4)) will also be considered.

To control for a significant residual, a dummy variable is used. The dummy variable is one for the quarter associated with the outlier it controls for, and is set to zero for all other observations. The quarters that are considered plausible to control for are 2002(3), 2002(4), 2003(3) and 2003(4). In the case that Norges Bank had deviated from its standard reaction pattern, controlling for all of the departures, or a subset of them, should significantly lower the remaining autocorrelation. However, autocorrelation remains significant at the 1% level when controlling for all plausible combinations of the considered quarters, indicating that this is not a very important source of autocorrelation. Nonetheless, controlling for these quarters may still be beneficial for the model, as other misspecification tests might be remedied by controlling for them. For this reason, table 7.4 presents estimation results derived by controlling for the residuals from the aforementioned quarters.

59 Controlling for 2002(3), 2002(4) and 2003(4) yields insignificant autocorrelation at the 1% level, but this is not considered a realistic scenario, as the source for the residual in 2003(4) largely is the interest rate reductions in 2003(3). Therefore, controlling for 2003(4) without controlling for 2003(3) does not seem consistent with the historical basis for controlling for these quarters. In addition, autocorrelation is only marginally insignificant at the 1% level.
Table 7.4: Controlling for dummies in the model estimated in table 7.3.

<table>
<thead>
<tr>
<th>i*</th>
<th>ρ</th>
<th>β</th>
<th>γ</th>
<th>2002(3)</th>
<th>2002(4)</th>
<th>2003(3)</th>
<th>2003(4)</th>
<th>J-test</th>
<th>Sargan</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.47***</td>
<td>0.89***</td>
<td>3.05**</td>
<td>0.25</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.295</td>
<td>0.254</td>
</tr>
<tr>
<td>(1.43)</td>
<td>(0.04)</td>
<td>(1.19)</td>
<td>(0.58)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.30***</td>
<td>0.86***</td>
<td>2.96***</td>
<td>0.18</td>
<td>9.00**</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.466</td>
<td>0.314</td>
</tr>
<tr>
<td>(1.09)</td>
<td>(0.04)</td>
<td>(0.90)</td>
<td>(0.43)</td>
<td>(3.54)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.22***</td>
<td>0.84***</td>
<td>2.91***</td>
<td>0.13</td>
<td>8.35***</td>
<td>6.24**</td>
<td>-</td>
<td>-</td>
<td>0.508</td>
<td>0.263</td>
</tr>
<tr>
<td>(0.87)</td>
<td>(0.03)</td>
<td>(0.71)</td>
<td>(0.33)</td>
<td>(2.73)</td>
<td>(2.53)</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.95***</td>
<td>0.89***</td>
<td>2.49**</td>
<td>0.35</td>
<td>9.54**</td>
<td>-</td>
<td>-10.43*</td>
<td>-</td>
<td>0.325</td>
<td>0.1351</td>
</tr>
<tr>
<td>(1.20)</td>
<td>(0.03)</td>
<td>(0.96)</td>
<td>(0.50)</td>
<td>(3.83)</td>
<td>-</td>
<td>(5.15)</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.97***</td>
<td>0.87***</td>
<td>2.56**</td>
<td>0.25</td>
<td>8.76***</td>
<td>6.05**</td>
<td>-</td>
<td>-7.76**</td>
<td>-</td>
<td>0.341</td>
</tr>
<tr>
<td>(0.94)</td>
<td>(0.03)</td>
<td>(0.76)</td>
<td>(0.37)</td>
<td>(2.92)</td>
<td>(2.63)</td>
<td>(3.70)</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.31***</td>
<td>0.88***</td>
<td>2.47***</td>
<td>0.15</td>
<td>8.55**</td>
<td>-</td>
<td>-10.0**</td>
<td>-6.25**</td>
<td>0.244</td>
<td>0.069*</td>
</tr>
<tr>
<td>(1.04)</td>
<td>(0.03)</td>
<td>(0.84)</td>
<td>(0.42)</td>
<td>(3.23)</td>
<td>-</td>
<td>(6.09)</td>
<td>(3.99)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.21***</td>
<td>0.86***</td>
<td>2.51***</td>
<td>0.12</td>
<td>8.11***</td>
<td>5.38**</td>
<td>-</td>
<td>-7.84**</td>
<td>-5.08**</td>
<td>0.199</td>
</tr>
<tr>
<td>(0.86)</td>
<td>(0.03)</td>
<td>(0.68)</td>
<td>(0.34)</td>
<td>(2.59)</td>
<td>(2.36)</td>
<td>(3.35)</td>
<td>(2.44)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
The coefficients are for: $i_t = (1 - \rho)q_t + \rho i_{t-1} + (1 - \rho)\beta E[t_{t,k} | \Omega_t] + (1 - \rho)\gamma E[y_{t,k} | \Omega_t] + \epsilon_t$, where the horizon for inflation is set to four quarters ahead (k=4) and the horizon for the output gap is set to one quarter ahead (q=1). The instrument set includes: $\pi_{t-1}, ..., \pi_{t-4}, y_{t-1}, ..., y_{t-4}, i_{t-1}, i_{t-4}, wcpi_{t-1}, ..., wcpi_{t-4}$.

Notes:

60 This holds for all estimations controlling for 2003(3) in table 7.4.

Notes:

The first estimation in table 7.4, is the model from table 7.3, which is reported for the purpose of comparison. Apart from in this estimation, 2002(3) is always controlled for in table 7.4. The reason for this is that 2002(3) was found to be the quarter most likely to be associated with a deviation from the standard reaction pattern of Norges Bank, and that it is consistently the most significant quarter when controlled for. Controlling for 2003(3) makes the test for heteroscedasticity insignificant, but also makes the Sargan test marginal at the 10% level. In addition, the argument for controlling for 2003(3) is considered substantially weaker than for 2002(3). Therefore, I decide not to control for 2003(3). This also eliminates 2003(4) from consideration, and leaves only the dummies for 2002(3) and 2002(4) as possible control variables. Thus the three top estimations in table 7.4 are the remaining candidates. All of these estimations have very similar point estimates, and clearly insignificant over-identification tests. The difference between them is that controlling for dummies leads to substantially lower standard errors, and thus higher significance. In addition, misspecification tests are found to perform better when dummies are controlled for. The model that performs the best on both of...
these accounts is the one that controls for both 2002(3) and 2002(4). I therefore prefer this model. The full estimation results for the model are reported in table 7.5.

**Table 7.5: Controlling for 2002(3) and 2002(4).**

<table>
<thead>
<tr>
<th></th>
<th>i*</th>
<th>ρ</th>
<th>β</th>
<th>γ</th>
<th>2002(3)</th>
<th>2002(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6.22***</td>
<td>0.84***</td>
<td>2.91***</td>
<td>0.13</td>
<td>8.35***</td>
<td>6.24**</td>
</tr>
<tr>
<td></td>
<td>(0.87)</td>
<td>(0.03)</td>
<td>(0.71)</td>
<td>(0.33)</td>
<td>(2.73)</td>
<td>(2.53)</td>
</tr>
<tr>
<td>Estimation method:</td>
<td>2SLS</td>
<td>No. of instruments:</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimation period:</td>
<td>1999(1)-2008(3)</td>
<td>Sigma:</td>
<td>0.3529</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observations:</td>
<td>39</td>
<td>RSS:</td>
<td>4.1120</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First stage F-test – inflation gap</td>
<td>F(17,18) = 25.53 [0.000]***</td>
<td>Normality $\chi^2(2)$ = 2.18 [0.334]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First stage F-test - output gap</td>
<td>F(17,18) = 18.02 [0.000]***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sargan test</td>
<td>$\chi^2(15)$ = 17.98 [0.263]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J-test</td>
<td>$\chi^2(15)$ = 15.22 [0.508]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AR(1-3)</td>
<td>F(3,30) = 6.92 [0.001]***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARCH(1-3)</td>
<td>F(3,33) = 0.63 [0.599]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HETERO</td>
<td>F(6,30) = 3.13 [0.016]**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
The coefficients are for: $i_t = (1 - \rho)i_t' + \rho i_{t-1} + (1 - \rho)\beta(E[\pi_t|\pi_{t-1}]) + (1 - \rho)\gamma E[\pi_{t-1}|\pi_{t-1}] + \epsilon_t$, where the horizon for inflation is set to four quarters ahead (k=4) and the horizon for the output gap is set to one quarter ahead (q=1). The instrument set includes: $\pi_{t-1}, ..., \pi_{t-r}, \gamma_{t-1}, ..., \gamma_{t-1}, i_{t-1}, i_{t-2}, wcpi_{t-1}, ..., wcpi_{t-4}$, $brex_{t-1}, ..., brex_{t-4}$, a constant and the two dummies that are controlled for.*/**/*** denotes significance at the 10%/5%/1% level, respectively. Standard errors are reported in parentheses.

The model in table 7.5 yields very similar results to the model in table 7.3, but there are a few notable changes. First, the normality test is insignificant at the 10% level and the test for autoregressive conditional heteroscedasticity is much less significant than previously. Second, the standard errors for all of the point estimates are considerably lower. In combination with robust point estimates, this means that all of the point estimates, except the output gap coefficient, have become more significant. A consequence of this is that the inflation coefficient now is significant at the 1% level, and that it is greater than unity at the 5% level. The long-run key policy rate is also found to be significantly higher than the estimation sample average key policy rate at the 10% level. This provides formal statistical evidence for the interest rates being relatively low in this period, which would be consistent with inflation averaging roughly 0.75 percentage points below target. Still, autocorrelation and heteroscedasticity remain, and as a result point estimates and standard errors may be unreliable. The model in table 7.5 is preferred ahead of the model in table 7.3.
### 7.3.2 Controlling for Misspecification

In the event that the “true” reaction function is backward-looking rather than forward-looking, estimating a forward-looking model could yield a MA(1) structure in the error term (see Bårdsen et al. (2005) p. 292). To check whether such misspecification might be the source of the observed MA structure in the forward-looking model, a backward-looking model is estimated. Since backward-looking models do not include forecasts, they should not have any inherent MA structure in the error term, and thus no inherent source of autocorrelation. This means that a correctly specified backward-looking model would be expected to be free of autocorrelation. To make the backward-looking model only rely on lags of inflation and output gap, the horizon is set to one quarter back for inflation \((k=-1)\) and one quarter back for the output gap \((q=-1)\). Since only observed variables are used in this model it is estimated with OLS. The results are reported in table 7.6.

**Table 7.6: Estimation results for a backward-looking model.**

<table>
<thead>
<tr>
<th></th>
<th>(i^*)</th>
<th>(\rho)</th>
<th>(\beta)</th>
<th>(\gamma)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>5.73</strong>*</td>
<td>0.75***</td>
<td>1.82***</td>
<td>0.46**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.53)</td>
<td>(0.08)</td>
<td>(0.35)</td>
<td>(0.21)</td>
</tr>
</tbody>
</table>

Estimation method: OLS  
Sigma: 0.3705  
Estimation period: 1999(1)-2008(3)  
RSS 4.8058  
Observations: 39  

| AR(1-3) | F(3,32) = 10.6 [0.000]**   |
| ARCH(1-3) | F(3,33) = 1.50 [0.468]   |
| HETERO | F(6,32) = 3.15 [0.200]   |

Normality \(\chi^2(2) = 7.54 [0.190]\)

Notes:

The coefficients are for:  
\[ i_t = (1 - \rho) i_t^* + \rho i_{t-1} + (1 - \rho) \beta \left( E \left[ R_{t,k} | \Omega_t \right] \right) + (1 - \rho) \gamma \left( \tilde{y}_{t,q} | \Omega_t \right) + \epsilon_t, \]

where the horizon for inflation is set to one quarter back \((k=-1)\) and the horizon for the output gap is set to one quarter back \((q=-1)\). **/*** denotes significance at the 10%/5%/1% level, respectively. Standard errors are reported in parentheses.

Table 7.6 shows that the backward-looking model yields point estimates that are consistent with theory, and that most of the misspecification tests are insignificant. From a robustness perspective, this indicates that the model is robust to being formulated as a backward-looking model. The test for autocorrelation, however, is found to be significant at the 1% level. The

---

\(^{61}\) Note that the correlogram for the model in table 7.5 has the same basic structure as the correlogram reported in figure 7.1.
correlogram of the error term, reported in figure 7.4, shows that there is still a MA(1) structure in the error term.

Figure 7.3: Correlogram for the model estimated in table 7.6.

To see whether the observed MA structure is due to a few brief deviations from the standard reaction pattern, the dummies from chapter 7.3.1 are controlled for. However, no combination of these dummies yields insignificant autocorrelation at the 1% level nor absence of a MA(1) structure. While the observed autocorrelation in the backward-looking model can be caused by many other factors not investigated here, the continued presence of it is taken as a sign that the observed MA(1) structure in the forward-looking model is not due to the correct model being backward-looking.

7.4 Robustness Tests

To test whether the model estimated in table 7.5 is a robust model, this chapter presents several robustness tests. First, alternative measures of the output gap are used in order to check whether the theoretical results derived by using the standard measure still holds. Second, some additional explanatory variables are introduced to check whether this affects the model. Finally, the model is estimated with GMM.

7.4.1 Alternative measures of the output gap

Since the output gap is a difficult variable to estimate, it is important for a model to be robust to the use of different measures. Robustness here would indicate that the model performs well irrespective of which of the different measures that are used. In addition, this robustness test also provides a test to see whether the use of ex-post data rather than real-time data has a large effect on the estimates. This is done by constructing an output gap measure that is based on data not subject to the same large revisions that GDP data are. In this case, this is done by
using unemployment data. Two output gap measures are created using unemployment data. First, OECD’s non-accelerating inflation rate of unemployment (NAIRU) estimate for Norway is subtracted from the unemployment rate. This should yield an alternative measure of the output gap, since the output gap, interpreted as the slack in production capacity is likely to be correlated with the unemployment rate. This measure is called “Unemp gap 1” in table 7.7. Second, the average unemployment rate over the sample is subtracted from the unemployment rate. This assumes that the output gap was roughly zero over the sample, and creates a measure like the previous one, except that the NAIRU is assumed to be constant. This measure is called “Unemp gap 2” in table 7.7.

Note that both of the output gap measures calculated using the unemployment rate have been multiplied by -1 to keep the original sign interpretation. In addition, I estimate the model using an output gap measure like the one described in chapter 6.1.3, only that it is constructed using $\lambda = 1600$. This means that the trend level of GDP is less persistent than for the standard measure. This measure is referred to as “$\lambda = 1600$” in table 7.7. The estimates are presented in table 7.7.

**Table 7.7: Robustness test using alternative measures of the output gap.**

<table>
<thead>
<tr>
<th></th>
<th>$i^*$</th>
<th>$\rho$</th>
<th>$\beta$</th>
<th>$\gamma$</th>
<th>2002(3)</th>
<th>2002(4)</th>
<th>J-test</th>
<th>Sargan</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Table 7.5</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$i^*$</td>
<td>6.05***</td>
<td>0.84***</td>
<td>2.91***</td>
<td>0.13</td>
<td>8.35***</td>
<td>6.24**</td>
<td>0.508</td>
<td>0.263</td>
</tr>
<tr>
<td></td>
<td>(0.86)</td>
<td>(0.03)</td>
<td>(0.71)</td>
<td>(0.33)</td>
<td>(2.73)</td>
<td>(2.53)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\lambda = 1600$</td>
<td>6.30***</td>
<td>0.85***</td>
<td>2.72***</td>
<td>0.39</td>
<td>8.38***</td>
<td>6.47**</td>
<td>0.522</td>
<td>0.278</td>
</tr>
<tr>
<td></td>
<td>(1.09)</td>
<td>(0.03)</td>
<td>(0.79)</td>
<td>(0.57)</td>
<td>(2.71)</td>
<td>(2.59)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unemp gap 1</td>
<td>6.49***</td>
<td>0.84***</td>
<td>3.08***</td>
<td>-0.07</td>
<td>8.11***</td>
<td>5.93**</td>
<td>0.072*</td>
<td>0.018**</td>
</tr>
<tr>
<td></td>
<td>(0.85)</td>
<td>(0.03)</td>
<td>(1.12)</td>
<td>(1.17)</td>
<td>(2.71)</td>
<td>(2.51)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unemp gap 2</td>
<td>6.30***</td>
<td>0.83***</td>
<td>2.83***</td>
<td>0.24</td>
<td>7.93***</td>
<td>5.73**</td>
<td>0.073*</td>
<td>0.014**</td>
</tr>
<tr>
<td></td>
<td>(0.73)</td>
<td>(0.03)</td>
<td>(0.87)</td>
<td>(0.95)</td>
<td>(2.53)</td>
<td>(2.39)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
The coefficients are for: $i_t = (1 - \rho)i_t^{*} + \rho i_{t-1} + (1 - \rho)\beta (E[\hat{\pi}_{t,k} | \Omega_t]) + (1 - \rho)\gamma E[\hat{y}_{t,q} | \Omega_t] + \epsilon_t$, where the horizon for inflation is set to four quarters ahead ($k=4$) and the horizon for the output gap is set to one quarter ahead ($q=1$). The instrument set includes: $\pi_{t-1}, ..., \pi_{t-4}, \hat{\pi}_{t-1}, ..., \hat{\pi}_{t-4}, i_{t-1}, i_{t-4}, wcpt_{t-1}, ..., wcpt_{t-4}, brex_{t-1}, ..., brex_{t-4}$, a constant and the dummies that are controlled for. */**/*** denotes significance at the 10%/5%/1% level, respectively. Standard errors are reported in parentheses.

The results in table 7.7 show that the point estimates are robust to the use of alternative measures of the output gap. The output gap coefficient is estimated to be negative in one of the models, but it is not significant at all. The over-identification tests become significant when the output gap is measured using the unemployment rate. This is likely to be because
the instrument set not being suited for forecasting the unemployment rate. Since the main concern here is the robustness of the estimates, this will not be investigated further. In sum, the model seems to be robust to the use of other measures of the output gap. The point estimates also indicate that the use of ex-post rather than real-time data is unlikely to have had a serious effect on the estimates, at least in terms of changing the sign of the estimated output gap coefficient.

7.4.2 Introducing extra explanatory variables

If the model is correctly specified and does not have any omitted variables, it should be expected to yield robust estimates when extra explanatory variables are introduced. To check whether this is the case, contemporaneous values of extra explanatory variables are added as endogenous explanatory variables, and four lags of this variable are added to the instrument list. The extra variable \( z \) has the coefficient \( \eta \). The extra variables that are added are: Y/Y growth in house prices (“HP Y/Y” in table 7.8), calculated from a price index of all residential buildings in Norway from Statistics Norway; Y/Y growth in the Oslo Stock Exchange All-Share Index (“OSEAX Y/Y” in table 7.8) from Oslo Stock Exchange; Y/Y growth in the M2 money supply (“M2 Y/Y” in table 7.8), calculated with data from Statistics Norway; and finally Y/Y growth in the C2 credit indicator of domestic debt (C2 Y/Y), calculated with data from Statistics Norway. The results from including these additional explanatory variables are shown in table 7.8 (next page).

The results in table 7.8 are largely consistent with the main results above being robust. However, there is notable large variation in the estimation of the long-run key policy rate, which yields some highly unrealistic estimates. The inflation coefficient, however, is very robust and remains strongly significant throughout all the estimations. The output gap coefficient varies around zero, which indicates very low significance. All of the alternative explanatory variables that are controlled for in table 7.8 should be expected to have a positive coefficient, and all except one has. The significance of the Sargan test when house prices are controlled for is not viewed to be a major problem, given the fact that robustness is the main issue here. In total, the results from table 7.8 indicate a fairly robust model, especially with respect to the inflation coefficient. There may of course exist omitted variables, but the results from table 7.8 is interpreted as an indication that the model should be reasonably robust with respect to the inclusion of alternative explanatory variables.
Table 7.8: Robustness test using alternative extra explanatory variables.

<table>
<thead>
<tr>
<th></th>
<th>i*</th>
<th>ρ</th>
<th>β</th>
<th>γ</th>
<th>η</th>
<th>2002(3)</th>
<th>2002(4)</th>
<th>J-test</th>
<th>Sargan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 7.5</td>
<td>6.05*** (0.86)</td>
<td>0.84*** (0.03)</td>
<td>2.91*** (0.71)</td>
<td>0.13 (0.33)</td>
<td>8.35*** (2.73)</td>
<td>6.24** (2.53)</td>
<td>0.508</td>
<td>0.263</td>
<td></td>
</tr>
<tr>
<td>HP Y/Y</td>
<td>4.11* (2.39)</td>
<td>0.89*** (0.04)</td>
<td>2.13** (1.01)</td>
<td>0.69 (0.63)</td>
<td>0.09 (0.14)</td>
<td>10.8** (4.82)</td>
<td>7.94* (4.07)</td>
<td>0.100</td>
<td>0.016**</td>
</tr>
<tr>
<td>C2 Y/Y</td>
<td>-1.83 (3.63)</td>
<td>0.87*** (0.03)</td>
<td>3.46*** (0.78)</td>
<td>-0.48 (0.35)</td>
<td>0.83** (0.35)</td>
<td>10.6*** (3.22)</td>
<td>7.22** (2.70)</td>
<td>0.766</td>
<td>0.495</td>
</tr>
<tr>
<td>OSEAX Y/Y</td>
<td>6.66*** (0.57)</td>
<td>0.75*** (0.08)</td>
<td>2.41*** (0.55)</td>
<td>-0.08 (0.21)</td>
<td>-0.02* (0.01)</td>
<td>5.21** (2.34)</td>
<td>3.97* (1.98)</td>
<td>0.703</td>
<td>0.413</td>
</tr>
<tr>
<td>M2 Y/Y</td>
<td>2.36 (2.29)</td>
<td>0.86*** (0.03)</td>
<td>3.16*** (0.75)</td>
<td>-0.36 (0.35)</td>
<td>0.47* (0.24)</td>
<td>9.20*** (2.98)</td>
<td>5.44** (2.60)</td>
<td>0.607</td>
<td>0.310</td>
</tr>
</tbody>
</table>

Notes:
The coefficients are for: \( i_t = (1 - \rho) i^* + \rho i_{t-1} + (1 - \rho) \beta (E[\bar{\pi}_{t,1}|z_t]) + (1 - \rho) \gamma E[\bar{\gamma}_{t,1}|z_t] + \)
\( (1 - \rho) \eta E[\bar{\eta}_{t,1}|z_t] + \epsilon_t \), where the horizon for inflation is set to four quarters ahead (k=4) and the horizon for the output gap is set to one quarter ahead (q=1). The instrument set includes: \( \pi_{t-1}, ..., \pi_{t-4}, \bar{\gamma}_{t-1}, ..., \bar{\gamma}_{t-4}, \eta_{t-1}, \eta_{t-4}, \)
\( w_c p_i_{t-4}, ..., w_c p_i_{t-4}, r e x_{t-4}, ..., r e x_{t-4}, z_{t-1}, ..., z_{t-4}, \) a constant and the dummies that are controlled for.

*/**/*** denotes significance at the 10%/5%/1% level, respectively. Standard errors are reported in parentheses.

7.4.3 Alternative method of estimation

The model in table 7.5 have strongly significant tests for both autocorrelation and heteroscedasticity. This can cause inconsistent point estimates and inaccurate estimates of the variance. Therefore, estimating the model with GMM, which should be robust to autocorrelation and heteroscedasticity, can indicate whether this is a major problem for the 2SLS estimator. To estimate the model from table 7.5 with GMM I use EViews 9.5. I choose the Newey-West weighting matrix which should be robust to heteroscedasticity and autocorrelation. For weight updating, I choose “iterate to convergence”. In other respects default settings were used. For information on GMM and how EViews 9.5 applies GMM, see Davidson and MacKinnon (2009) Ch. 9 and EViews 9 User’s Guide II (2016). One problem with estimating the model from table 7.5 with GMM is that the two dummies for 2002(3) and 2002(4) are troublesome instruments here. They seem to make the over-identification restrictions hold perfectly, which means that GMM cannot be used. To work around this problem, we have noted that the two dummies have very similar estimated coefficients. This means that controlling for both of these quarters with one dummy should yield similar results as controlling for them with two dummies. Doing this with 2SLS yields results almost identical to table 7.5. Therefore, this is done for GMM. The results from estimating the model from table 7.5 with GMM in EViews 9.5 are shown in table 7.9.
Table 7.9: Robustness test with GMM.

<table>
<thead>
<tr>
<th></th>
<th>(i^*)</th>
<th>(\rho)</th>
<th>(\beta)</th>
<th>(\gamma)</th>
<th>2002(3-4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7.03***</td>
<td>0.91***</td>
<td>1.84***</td>
<td>0.28</td>
<td>7.19***</td>
</tr>
<tr>
<td></td>
<td>(0.36)</td>
<td>(0.01)</td>
<td>(0.39)</td>
<td>(0.21)</td>
<td>(1.05)</td>
</tr>
</tbody>
</table>

Estimation method: GMM
No. of instruments: 19
Estimation period: 1999(1)-2008(3)
Sigma: 0.4436
Observations: 39
RSS: 6.6918

\[ \chi^2(15) = 6.41 \{0.971 \} \]

Notes:
The coefficients are for: \(i_t = (1 - \rho)i_{t-1} + \rho i_{t-1} + (1 - \rho)\beta (E[\pi_{t,k} | \Omega_t]) + (1 - \rho)\gamma (E[\mu_{t,q} | \Omega_t]) + \epsilon_t \), where the horizon for inflation is set to four quarters ahead \((k=4)\) and the horizon for the output gap is set to one quarter ahead \((q=1)\). The instrument set includes: \(\pi_{t-1}, ..., \pi_{t-4}, \gamma_{t-1}, ..., \gamma_{t-4}, i_t, i_{t-4}, wcpi_{t-1}, ..., wcpi_{t-4}, lrex_{t-1}, ..., lrex_{t-4}\), a constant and the dummy that is controlled for. */***/*** denotes significance at the 10%/5%/1% level, respectively. Standard errors are reported in parentheses.

The reported long-run coefficients are calculated in the same manner as for 2SLS, and the variance calculated by the delta method. The results in table 7.9 shows that the point estimates appear fairly robust. The inflation coefficient is markedly lower than with 2SLS, but it remains significantly higher than unity. The output gap coefficient remains close to zero and insignificant, while the long-run key policy rate continues to be higher than the sample average. The long-run key policy rate is in fact significantly higher than the sample average at the 1% level, indicating that the key policy rate was relatively low over the sample. Thus all the theoretical insights from table 7.5 seem to apply to table 7.9 as well. Autocorrelation and heteroscedasticity do not seem to have caused too much trouble for the 2SLS estimation.

7.5 Full Sample

Since the model from table 7.5 seemingly provides a robust estimation of Norges Bank’s reaction pattern during the baseline estimation period, the estimation is now extended to the full sample. If Norges Bank has maintained the same criteria for conducting monetary policy throughout the estimation period, the model from table 7.5 should yield similar results when estimated for the full sample. The average key policy rate for the full sample is 3.49, which implies that a reduction in the long run key policy rate estimate of roughly 1 percentage point should be expected. Apart from this, however, a stable monetary policy regime from Norges Bank should imply pretty stable point estimates. Since the four quarter horizon of inflation means that four observations must be used for the rational expectations assumption, the full sample equates to 1999(1)-2015(2) when estimated. The results from estimating the model from table 7.5 for the full sample are reported in table 7.10.
Table 7.10: Estimation for the full sample

<table>
<thead>
<tr>
<th>i*</th>
<th>ρ</th>
<th>β</th>
<th>γ</th>
<th>2002(3)</th>
<th>2002(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.61</td>
<td>0.91***</td>
<td>-0.15</td>
<td>1.50**</td>
<td>11.6**</td>
<td>8.29</td>
</tr>
<tr>
<td>(1.34)</td>
<td>(0.02)</td>
<td>(1.30)</td>
<td>(0.59)</td>
<td>(5.93)</td>
<td>(5.03)</td>
</tr>
</tbody>
</table>

Estimation method: 2SLS
No. of instruments: 21
Estimation period: 1999(1)-2015(2)
Sigma: 0.4266
Observations: 66
RSS: 10.924

First stage F-test – inflation gap F(17,45) = 5.425 [0.000]***
First stage F-test - output gap F(17,45) = 21.02 [0.000]***
Sargan test χ²(15) = 17.98 [0.001]***
J-test χ²(15) = 33.23 [0.004]***

AR(1-5) F(5,55) = 6.92 [0.000]***
ARCH(1-4) F(4,58) = 0.63 [0.071]**
HETERO F(6,57) = 5.13 [0.000]***

Notes:
The coefficients are for: \( i_t = (1 - \rho) i_t^* + \rho i_{t-1} + (1 - \rho) \beta E[\pi_{t,k} | \Omega_t] + (1 - \rho) \gamma E[\pi_{t,k} | \Omega_t] + \epsilon_t \), where the horizon for inflation is set to four quarters ahead (k=4) and the horizon for the output gap is set to one quarter ahead (q=1). The instrument set includes: \( \pi_{t-1}, ..., \pi_{t-4}, \pi_{t-1}, \pi_{t-4}, i_{t-1}, i_{t-4}, wcp_i_{t-1}, wcp_i_{t-4}, lrex_{t-1}, lrex_{t-4} \), a constant and the two dummies that are controlled for. */**/*** denotes significance at the 10%/5%/1% level, respectively. Standard errors are reported in parentheses.

The results in table 7.10 are nonsensical from an inflation targeting perspective. as the inflation coefficient is estimated to be negative, which goes against the very key insight of inflation targeting. The long-run key policy rate is also estimated to be lower than expected. With a point estimate of 1.61 it is not significantly different from the full sample average, but it does imply a long-run real interest rate of -0.49. The output gap coefficient is now estimated to be 1.50 and significant at the 5% level, indicating a greater weight placed upon it in the latter part of the full sample. This is consistent with Norges Bank (2012), where it was communicated that the central bank had changed the weighting of the arguments in their loss function, and that this had been done to better capture the interest rate setting after the financial crisis of 2008. The change communicated here was mainly an increased weight placed upon the output gap relative to inflation. The model suffers from poor specification, however, so these estimates are likely very unreliable. The instruments are found to be both invalid and weak, and all of the misspecification tests are significant standard significance levels.

62 The gap between the NIBOR and the key policy rate averaged 0.40 percentage points over the full sample. Therefore, the long-run real interest rate is calculated as 1.61-2.50+0.40=-0.49
Inspection of the scaled residuals reveal that, as expected, the residuals associated with the financial crisis of 2008 are substantial. Given how deeply this crisis affected financial markets all over the world, the three most significant residuals associated with the financial crisis are controlled for (2008(4), 2009(1) and 2009(2)). The results of doing this are shown in table 7.11.

Table 7.11: Estimation for the full sample: controlling for the financial crisis.

<table>
<thead>
<tr>
<th>i*</th>
<th>ρ</th>
<th>β</th>
<th>γ</th>
<th>2002(3)</th>
<th>2002(4)</th>
<th>2008(4)</th>
<th>2009(1)</th>
<th>2009(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.96***</td>
<td>0.91***</td>
<td>0.89</td>
<td>1.52***</td>
<td>12.6***</td>
<td>8.95**</td>
<td>-11.9**</td>
<td>-24.0***</td>
<td>-11.7**</td>
</tr>
</tbody>
</table>

(0.96) (0.01) (1.02) (0.48) (4.49) (4.12) (5.10) (7.14) (4.70)

Estimation method: 2SLS
No. of instruments: 24
Estimation period: 1999(1)-2015(2)
Sigma: 0.3116
Observations: 66
RSS: 5.5358

First stage F-test – inflation gap $f(17,42)$ = 6.049 [0.000]***
First stage F-test - output gap $f(17,42)$ = 23.26 [0.000]***
Sargan test $\chi^2(15) = 17.98$ [0.023]**
J-test $\chi^2(15) = 23.95$ [0.065]*

AR(1-5) $f(5,52) = 6.21$ [0.000]***
ARCH(1-4) $f(4,58) = 0.57$ [0.683]
HETERO $f(6,54) = 4.10$ [0.001]***

Notes:
The coefficients are for: $\pi_t = (1 - \rho)\pi_t + \rho\pi_{t-1} + (1 - \rho)\beta(E[\pi_{t+k}|\Omega_t]) + (1 - \rho)\gamma E[y_{t+q}|\Omega_t] + \epsilon_t$, where the horizon for inflation is set to four quarters ahead ($k=4$) and the horizon for the output gap is set to one quarter ahead ($q=1$). The instrument set includes: $\pi_{t-1}, ..., \pi_{t-4}, \gamma_{t-1}, ..., \gamma_{t-4}, i_{t-1}, ..., i_{t-4}, wcpi_{t-1}, ..., wcpi_{t-4}$, $lrex_{t-1}, ..., lrex_{t-4}$, a constant and the two dummies that are controlled for. */**/*** denotes significance at the 10%/5%/1% level, respectively. Standard errors are reported in parentheses.

Table 7.11 shows that the results are better when the financial crisis is controlled for, but that the model still is likely to yield very unreliable estimates. The point estimates are closer to expectations, as the inflation coefficient now is positive and the long-run key policy rate is close to the sample average of the key policy rate. The output gap coefficient remains practically identical to what it was in table 7.10, and is now significant at the 1% level. This supports the claim that Norges Bank increased the weight placed upon the output gap after the financial crisis. However, instruments are still found to be weak and invalid, and the most significant misspecification tests from table 7.10 are still significant at the 1% level. This means that inference drawn from these estimations may well be misleading. Thus, the model from table 7.5 does not seem to be robust to an extension of the estimation sample. At, least not without a thorough analysis of the instrument set. In sum, the changes in the estimated monetary policy reaction function appear to be even larger than what one could expect from
reading the bank’s account about how the “weights” of the interest rate setting were changed after the financial crisis. However, Norges Bank last commented on this in 2012, and it would be interesting to see an update from the central bank on this issue.

8. Concluding Remarks

In this master’s thesis I have estimated forward-looking reaction functions for Norges Bank’s key policy rate. These reaction functions have been based on the ones used by Clarida et al. (1998) and Clarida et al. (2000), and have mainly been estimated using 2SLS. The main objective for the thesis was to derive a well-specified model for how Norges Bank has adjusted the key policy rate, and to draw inference from the estimation results of this model. The baseline model was found to provide point estimates consistent with theory, but the model was likely unreliable because of misspecification. Investigation of possible sources of misspecification led to two instruments being dropped, and two dummies being controlled for. This reduced the number of potential sources of misspecification, but autocorrelation and heteroscedasticity remained strongly significant. Still, estimating the model with GMM instead of 2SLS revealed that the presence of autocorrelation and heteroscedasticity did not represent major problems. The model was also found to be robust to using different measures of the output gap and the inclusion of extra explanatory variables. From this model we found the inflation coefficient to be significantly greater than unity, which provides evidence for Norges Bank adjusting the key policy rate in accordance with the Taylor principle. The output gap was found to be insignificant, while the long-run key policy was found to be significantly higher than the sample average key policy rate. The latter finding implies that the key policy rate has been relatively low over the baseline estimation period, which perhaps should be expected given how average inflation was roughly 0.75 percentage points below target. In addition, there was found strong evidence in favor of interest rate smoothing on the part of Norges Bank.

For the full sample estimation, results were inconsistent with theory. The large change induced by extending the estimation sample, can be a sign that Norges Bank has changed the way it weights its arguments, as communicated in Norges Bank (2012). The large changes in the point estimates indicated that Norges Bank has started to give the output gap a greater weight and inflation a lower weight after the financial crisis. The full sample model was subject to many potential sources of misspecification, however, so any inference drawn from the full sample model is likely to be very unreliable.

For further research, it could be interesting to investigate the full sample model closer, and see whether a well-specified model can be derived from it. Alternatively, a separate model could be estimated for the period after the financial crisis.
References


Appendix

A.1. Data Sources

World commodity price inflation. Calculated as Y/Y inflation from a world commodity price index. Source: Macrobond.


Seasonally adjusted gross domestic product for Mainland-Norway. Source: Statistics Norway

The 3-month Norwegian Interbank Offered Rate (NIBOR). Source: Oslo Stock Exchange and Norges Bank.

M2 money supply. Source: Statistics Norway.

C2 credit indicator. Source: Statistics Norway.


OECD’s NAIRU estimate for Norway. Source: Macrobond.


Oslo Stock Exchange All-Shares Index (OSEAX). Source: Macrobond.

Inflation. Calculated as Y/Y inflation from the CPI-ATE index. Source: Statistics Norway.

Real exchange rate. Calculated manually. See appendix A.2.

A.2. Real exchange rate calculation

Using Norges Bank’s I-44 weights (Source: Norges Bank), I keep all nations that have had a weight greater than 2%. This includes: Belgium, Canada, China, Germany, Denmark, Spain, EU, Finland, France, UK, Italy, Japan, South Korea, Netherlands, Poland, Russia, Sweden and United States. I collect regular CPI indices for all these countries (Source: Macrobond). These CPI indices are then standardized to be 1 for the first quarter of 2000 (this is done in order for the introduction of the EU to not impact the resulting index). For quarters before the first quarter of 2000 the EU is not included. I take a weighted average of all the CPIs. The surplus weight is divided 50/50 between Germany and the US. After and including the first quarter of 2000, the EU is included. The weights from all EU member states with non-euro currencies are added to the weight of the EU. Thus, the EU CPI is used to represent the CPI of all of its included member states. Then a weighted average is taken of the CPIs, and the surplus weight is divided 50/50 between the EU and the US. Thus a ”world CPI index” is created. I then multiply this with the I-44 import weighted krone (Source: Norges Bank), and then divide by the CPI index of Norway (Source: Statistics Norway). The CPI index for Norway is also standardized to be equal to 1 for the first quarter of 2000. This yields the Real exchange rate of Norway.
A.3 Delta Method

From equation (5.7) we have that: \( \beta = \frac{a_2}{1-a_1} \). Using estimated parameters, and taking a first order Taylor approximation of \( \beta \), using the formula from equation (5.9), yields:

\[
(A.1) \quad \hat{\beta} \approx \frac{\hat{\beta}_{a_2}}{1-\hat{\beta}_{a_1}} + \frac{1}{1-\hat{\beta}_{a_1}} (\hat{\beta}_{a_2} - \hat{\beta}_{a_1}) + \frac{\hat{\beta}_{a_2}}{(1-\hat{\beta}_{a_1})^2} (\hat{\beta}_{a_1} - \hat{\beta}_{a_1})
\]

To get an approximate expected value of \( \hat{\beta} \), we take the expectation of equation (A.1). Since the expected value is the average value, argument two and three will be eliminated and we are left with:

\[
(A.2) \quad E(\hat{\beta}) \approx \frac{\hat{\beta}_{a_2}}{1-\hat{\beta}_{a_1}}
\]

Then the standard formula for variance is followed. This yields:

\[
(A.3) \quad Var(\hat{\beta}) \approx E \left[ \left( \frac{\hat{\beta}_{a_2}}{1-\hat{\beta}_{a_1}} + \frac{1}{1-\hat{\beta}_{a_1}} (\hat{\beta}_{a_2} - \hat{\beta}_{a_1}) + \frac{\hat{\beta}_{a_2}}{(1-\hat{\beta}_{a_1})^2} (\hat{\beta}_{a_1} - \hat{\beta}_{a_1}) \right)^2 \right]
\]

Terms cancel:

\[
(A.4) \quad Var(\hat{\beta}) \approx E \left[ \left( \frac{1}{1-\hat{\beta}_{a_1}} (\hat{\beta}_{a_2} - \hat{\beta}_{a_1}) + \frac{\hat{\beta}_{a_2}}{(1-\hat{\beta}_{a_1})^2} (\hat{\beta}_{a_1} - \hat{\beta}_{a_1}) \right)^2 \right]
\]

Write out the expression:

\[
(A.6) \quad Var(\hat{\beta}) \approx E \left[ \frac{1}{(1-\hat{\beta}_{a_1})^2} (\hat{\beta}_{a_2} - \hat{\beta}_{a_1})^2 + 2 \frac{\hat{\beta}_{a_2}}{(1-\hat{\beta}_{a_1})^3} (\hat{\beta}_{a_2} - \hat{\beta}_{a_1}) (\hat{\beta}_{a_1} - \hat{\beta}_{a_1}) + \frac{\hat{\beta}_{a_2}^2}{(1-\hat{\beta}_{a_1})^4} (\hat{\beta}_{a_1} - \hat{\beta}_{a_1})^2 \right]
\]

Now use the fact that: \( E[(X - \mu_X)^2] = \sigma_X^2 \), and \( E[(X - \mu_X)(Y - \mu_Y)] = \sigma_{X,Y} \). \( \sigma_X^2 \) denotes the variance of X, while \( \sigma_{X,Y} \) denotes the covariance between X and Y.

\[
(A.7) \quad Var(\beta) \approx \left( \frac{1}{1-\hat{\beta}_{a_1}} \right)^2 \left[ \sigma_{a_2}^2 + 2 \left( \frac{\hat{\beta}_{a_2}}{1-\hat{\beta}_{a_1}} \right) \sigma_{a_2,a_1} + \left( \frac{\hat{\beta}_{a_2}}{1-\hat{\beta}_{a_1}} \right)^2 \sigma_{a_1}^2 \right]
\]

\[63 \quad Var(X) = E[(X - E(X))^2].\]