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Abstract

This thesis focuses on different economic measures of the output gap and potential output in Norway during the pandemic years, where we utilize various univariate and multivariate methods for output gap estimation on real data for the Norwegian economy and simulated data from a simple New Keynesian model. Our results find that the various methods provide very similar results of the output gap on real data, where all methods show a strongly negative output gap during the pandemic years. Furthermore, we discuss whether the various output gap estimation methods provide adequate estimates in the presence of demand and productivity shocks according to New Keynesian theory. We find that one of the multivariate unobserved component models provides significantly better results on the output gap than the univariate unobserved component model, as the latter provides insufficient estimates of the output gap in the presence of both productivity and demand shocks. In the case of productivity shocks, the multivariate unobserved component model that takes into account both actual output and inflation estimates the output gap somewhat similar to the New Keynesian output gap but tends to misinterpret the productivity shocks´ effects on the output gap throughout the majority of the estimation sample. Our results lead us to believe that the output gap estimation methods presented by Furlanetto et al. (2023) misinterpret the effect of large and sudden productivity shocks. Therefore, we believe that these estimation methods are problematic in the presence of supply-side shocks and are not sufficient when estimating the output gap during the pandemic, as it does not take into account the degree of the sudden reduction in potential output due to social and economic shutdowns.

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1 Introduction

In this thesis paper, we focus on different measures of the output gap and potential output in Norway during the pandemic years. We provide a discussion around the nature of the pandemic shocks in light of existing literature and a simple New Keynesian model. Additionally, we perform various univariate and multivariate methods for output gap estimation on real data for the Norwegian economy and discuss whether they provide reasonable estimates of the output gap. We apply the output gap estimation methods on simulated data from the New Keynesian model, to answer the question of whether the various output gap estimation methods provide adequate estimates in the presence of demand and productivity shocks according to New Keynesian theory. Lastly, as a robustness check, we consider the estimation methods´ sensitivity to changes in the specification of monetary policy.

Pandemic, war in Europe, and energy crisis are a brief way of summarizing the last couple of years, in which central banks worldwide have faced new and extraordinary issues. Within just three years, the Norwegian central bank, Norges Bank, has reached the lowest policy rate in all of Norway´s history at 0 %, as well as implemented the highest policy rate since 2008. In March 2020, when the Covid-19 pandemic became a reality in Norway, the government introduced the most invasive measures on the Norwegian society since World War 2. Society was shut down to mitigate and control the spread of the coronavirus, which led to a significant decrease in economic activity and increased unemployment rates, where in April 2020, registered unemployment reached its highest level in the last 15 years. In an extraordinary monetary policy meeting in May 2020, Norges Bank lowered the policy rate to 0 % for the first time in Norwegian history, as a result of the increasing coronavirus outbreaks and uncertainties surrounding its implications for the Norwegian economy (Norges Bank, 2020). After keeping the policy rate at 0 % for a considerable period of time, Norges Bank gradually started to raise the policy rate in September 2021. By that time, economic activity had recovered back to pre-pandemic levels and unemployment had declined substantially as society started to reopen (Norges Bank, 2021b). Activity in the economy continued to increase, and higher inflation on imported goods, as well as higher energy prices, resulted in domestic inflation exceeding the inflation target of 2 %. Russia´s invasion of Ukraine in February 2022 would amplify the already existing economic trends, as it created a lot of uncertainties on an international basis. Disturbances in supply value chains caused prices of raw materials to increase, and energy prices continued to rise. In response, Norges Bank continued to increase the policy rate, and by May 2023, the policy rate had reached 3.25 %. There has not been a higher level of the policy rate since 2008.

As a practitioner of flexible inflation targeting, Norges Bank has an objective of keeping inflation low and stable at around 2 % over time, maintaining high and stable production and employment, as well as considering financial stability. In that sense, inflation and the output gap are two important factors they take into account when adjusting the policy rate. The output gap is defined as the difference between actual output and potential output, where the output gap and potential output are unobservable variables that need to be estimated. While some define potential output as a trend in GDP growth (CBO, 2001), others may define it as a measure of the maximum level of production that implies a sustainable use of the available resources over time (EU IFI, 2020). Because the output gap and potential output are unobservable variables, and there are different ways of defining them, there are a lot of uncertainties surrounding the estimation methods used to calculate them. Furlanetto et al. (2023) provided a paper describing a suite of models used by Norges Bank to estimate the Norwegian output gap. From that paper, we will apply the univariate unobserved component model and three versions of the multivariate unobserved component model, as well as two different Hodrick-Prescott filters, to estimate output gaps in the Norwegian economy. The aim is to determine whether these output gap estimation methods provide reasonable estimates of the output gap for the Norwegian economy, and how well they capture productivity and demand shocks.

There have been discussions concerning the nature of the economic shocks induced by Covid-19, and to what extent it was a demand shock and productivity shock. During the pandemic years, Norges Bank reported a strongly negative output gap, where it was reported that the majority of the decline in the output gap was caused by a reduction in household consumption (Norges Bank, 2021a). Unemployment rates rose substantially as a result of the pandemic, leaving people with a loss of income and therefore having to reduce their consumption of goods and services. In addition, the fear of getting infected by the coronavirus lead people to stay home, resulting in a further decline in consumption. These factors provide an argument in favor of the fact that the Covid-19 pandemic partially was a negative demand shock. As a response to the pandemic shocks, Norges Bank took significant monetary policy actions, but these actions were not without criticism. One point of contention was their estimation of the Norwegian output gap during the pandemic, which was analyzed and discussed in the Norges Bank Watch 2023 report. In the report, Holm and Martinsen (2023) estimated the Norwegian output gap using indicators such as the degree of openness in various sectors of the economy. The main criticisms of Norges Bank's policy decisions were that they were too drastic in initially lowering the policy rate and that they waited too long to raise the policy rate from its all-time low of 0 %. They also argued that Norges Bank viewed the pandemic as too much of a negative demand shock and underestimated the productivity shock that came with the pandemic. As the Norwegian society went into lockdown, several businesses had to shut down or reduce their operating capacity, and employees were furloughed or were even left unemployed. This resulted in spare capacity in the economy. Workers and capital in the economy remained unused, meaning that the economy was not producing at its potential level because of the strict containment measures, whereby the effects of the pandemic can partially be categorized as a negative productivity shock. Using existing literature, we provide a discussion around the nature of the shocks induced by the pandemic, as well as simulate a simple New Keynesian model to consider the shocks´ implications for the output gap.

The New Keynesian model will be used as a benchmark model to understand the dynamics of the economy when shocks occur. We will focus on understanding the implications of negative demand and productivity shocks, and discuss the shocks´ effects on the output gap within the framework of a New Keynesian model. By simulating data from the New Keynesian model, we can apply the output gap estimation methods as presented by Furlanetto et al. (2023) on the simulated variables, and compare the results to the original output gap simulated within the New Keynesian model. By comparing the New Keynesian output gap with the estimated output gaps, we can determine to what extent the various estimation methods capture the effects of demand and productivity shocks in the output gaps. As a robustness check, we test how changes in the specification of monetary policy affect the output gap estimates. Based on the results, we will shed light on the challenges that arise in these traditional estimation methods when the economy faces supply-side shocks.

2 Theory

2.1 Monetary Policy in Norway

Historically, monetary policy aims at the goal of promoting full employment while at the same time preventing inflation. Milton Friedman had the belief that economic systems work best when all stakeholders can proceed with full confidence that the average level of prices will behave in a known way in the future and preferably that it will be highly stable

(Friedman, 1995). Monetary policy decision-makers can provide a significant contribution toward promoting economic stability by setting a steady course and keeping to it. This course should be one of moderate growth in the money supply, and creating a monetary climate favorable to the operation of the true drivers of economic growth for enterprise, ingenuity, invention, hard work, and thrift (Friedman, 1995). Monetary decision-making is practiced through either expansionary or contractionary policies. An expansionary monetary policy typically involves increasing the money supply in an economy and lowering interest rates to encourage borrowing and increase spending in hopes of stimulating economic growth. The goal of expansionary policy is to increase aggregate demand, which can lead to higher output and employment, as well as increased inflation. Contractionary monetary policy, on the other hand, has the opposite effect, where policymakers decrease the money supply and raise interest rates to slow down the economy in hopes that rapid inflationary pressures in the economy are reduced.

In Norway, Norges Bank is responsible for the implementation of monetary policy (Norges Bank, 2022b). Since Norges Bank was established in 1816, the monetary policy regime has changed frequently throughout the years. Up until 1992, Norges Bank practiced exchange rate targeting, where the main objective was to stabilize the Norwegian economy through the Norwegian krone, which was held fixed against other European currencies. However, as the European exchange rate system collapsed in 1992, Norway implemented a floating exchange rate regime. The Norwegian krone remained stable until 1996 when Norway started to generate large oil revenues. Great fluctuations in the Norwegian economy and the krone arose, which weakened the purpose of having the exchange rate as a nominal anchor for monetary policy in Norway. As a result, monetary policy started to shift from stabilizing the exchange rate to aiming for price stability (Gjedrem, 2004).

As of 2001, Norges Bank adopted the practice of inflation targeting, where the goal was to keep inflation low and stable at 2.5 % over time. In the years prior, Norway had generated substantial oil revenues, where large amounts were fused into the Norwegian economy to develop the Norwegian welfare state. Despite that Norway´s most important trading partners operated with inflation targets of 2 %, the high level of public spending in Norway justified having an inflation target of 2.5 %. However, the economic situation in Norway would change. As the period of expanding the public sector had passed, the reasonings for having an inflation target of 2.5 % were no longer present. Therefore, the Norwegian government decided to modernize the monetary policy regulation in 2016, which is the regulation that

Norges Bank follows to this day. The regulations implemented in 2016 included a reduction in the inflation target from 2.5 % to 2 %, implying an operational target of maintaining annual consumer price inflation close to 2 % over time. The regulations on monetary policy further state that inflation targeting shall be forward-looking and flexible so that it can contribute to high and stable production and employment, while also counteracting the build-up of financial imbalances. Norges Bank's flexible inflation targeting regime involves a two-divided target of keeping inflation low and stable at 2 % over time, as well as obtaining high and stable production and employment measured by the output gap, rather than strict inflation targeting which purely aims at stabilizing the inflation rate and disregarding the real economy (Bech-Moen, 2023). Since the introduction of the inflation target in 2001, Norges Bank has been able to maintain inflation at around 2% and contributed to keeping fluctuations in the real economy moderate (Olsen, 2016b).

2.1.1 Monetary Policy in Norway during Covid-19

2019 was considered a great year for the Norwegian economy. Production levels and employment rates were slightly above their potential, and inflation was close to the target at 2 %. Throughout 2019, the policy rate had increased three times, from 0.75 % to 1.5 %, and by the end of the year, the top of the boom was assumingly reached. The prospects for the Norwegian economy were good, until March 2020, when the first cases of the coronavirus were confirmed in Norway. The situation had shifted drastically, as society had to shut down due to containment measures, which resulted in a large reduction in economic activity and increased unemployment rates. As a result, Norges Bank issued its first policy rate decision following the emergence of the first confirmed Covid-19 cases, where they reduced the policy rate from 1.5 % to 1 %. Only one week later, the policy rate was further reduced to 0.25 %, and finally, in an extraordinary monetary policy meeting in May 2020, the policy rate reached an all-time low of 0 %. Norges Bank stated that a lower policy rate could dampen some of the fall in economic activity, and that a reduction in the costs of lending could help stimulate the economy once the situation normalized and society opened up. Despite that economic activity fell and unemployment rates rose due to the pandemic, inflation seemed to be on its way up. In a speech in May 2020, Norges Bank´s Governor at the time, Øystein Olsen, stated that the depreciation of the Norwegian krone, as well as high energy prices and increased costs due to the coronavirus, would contribute to high inflation in the near future. While lowering the policy rate would contribute to stimulate economic activity, it could also result in a further increase in inflation. However, Norges Bank emphasized that their priority at the time was to stabilize production and employment, which suffered profoundly due to the coronavirus outbreak. In October 2020, Øystein Olsen stated in a speech that Norges Bank's experience with flexible inflation targeting had been positive, going on to say that living with some inflation variability around the target poses no problem as long as inflation prospects are anchored close to the target (Olsen, 2020b).

Throughout 2021, the economic activity started to recover, and during the summer of 2021, the economic activity returned to pre-pandemic levels. Unemployment rates dropped to their lowest levels since before the Great Recession in 2008, the labor market was tight, and many businesses were operating at maximum capacity. Furthermore, inflation rose substantially above the target of 2 %. The tightness in the labor market would contribute to higher wage expectations, which in turn would result in higher inflation on domestic goods and services. Additionally, frictions on an international basis would also contribute to increasing inflation, as the pandemic had resulted in disturbances in production and distribution services, causing prices on international shipping to increase. Moreover, Russia´s invasion of Ukraine caused a further increase in energy prices, as well as increased prices of raw materials. As a result, Norwegian actors were facing higher inflation on imported goods, as well as higher inflation on domestically produced goods and services, leading to inflation rising substantially above the target of 2 %. At the beginning of the pandemic, Norges Bank´s priority was to stimulate production and employment, but as of September 2021, Norges Bank started to increase the policy rate in hopes of getting inflation under control (Bache, 2022). From September 2021 until May 2023, Norges Bank increased the policy rate from 0 % to 3.25 %. There has not been a higher policy rate in Norway since 2008.

2.1.2 Limitations of the Policy Rate

In the presence of severe economic downturns, monetary policy has several limitations, as central banks´ ability to use conventional monetary policy tools to stimulate economic activity is reduced. The policy rate has an effective lower bound, which refers to a point where further cuts in the policy rate will no longer have the desired expansionary impact on the economy. The effective lower bound is hard to measure, but experiences from other countries imply an effective lower bound below zero (Olsen, 2016a). Operating with negative interest rates can potentially lead to a misallocation of capital and liquidity, as capital flows to riskier assets and away from traditional investments. Additionally, it can create imbalances in the financial system, as savers and investors may be incentivized to take on more debt than is typically advised.

The effective lower bound has also been referred to as the zero lower bound. Before the Great Recession of 2008, most economists perceived zero as the lower bound for a country´s policy rate, but experiences from the past decade have changed this perspective, as several countries have operated with negative policy rates after the Great Recession (Olsen, 2020b). Negative policy rates have never been put into practice in Norway, and what implications this has for the Norwegian economy are currently unknown. Therefore, former Governor of Norges Bank, Øystein Olsen, stated in a speech in 2020 that Norges Bank did not expect to lower the policy rate below zero during the pandemic, but that the possibility of a negative policy rate in Norway should not be ruled out.

The policy rate is Norges Bank´s main instrument for stabilizing the economy, but as the policy rate reaches its effective lower bound, less traditional policy tools may potentially become necessary. At the beginning of the pandemic, there was substantial turbulence in the financial and credit markets, in which Norges Bank offered extraordinary F-loans to banks. The goal was to improve market liquidity, as well as ensure that the cuts in the policy rate passed through to money market rates and bank lending rates. The extraordinary F-loans had longer maturities than normal, and the banks could borrow as much as desired at a rate equal to or slightly above the policy rate. Additionally, the collateral requirements for the banks were eased. (Olsen, 2020b). Furthermore, Norges Bank decided to intervene in the foreign exchange market during the pandemic, which is perceived as an unusual policy tool in Norway and is not applicable in normal situations (Olsen, 2019). Norges Bank purchased Norwegian kroner to provide support to the currency, as the krone depreciated to historically weak levels as a result of the pandemic (Olsen, 2020b).

In addition to unconventional monetary policy tools, forward guidance is a frequently used tool and becomes especially important when the policy rate is restricted by the zero lower bound. The practice of forward guidance implies that the central bank gives signals about the future path of the policy rate, to strengthen the policy rate´s pass-through to the economy. Forward guidance can be implemented through verbal communication, often through projections on output and inflation, but also through the publication of policy rate forecasts. Norges Bank has pursued the latter approach since 2005, and during the pandemic, their policy rate forecasts projected that the policy rate would be kept at zero percent for some time ahead. During the Covid-19 pandemic, the economic models used by the central bank implied that a negative policy rate was necessary to stabilize the economy. However, as the policy rate was restricted by the zero lower bound, the role of forward guidance became important. Economic agents are assumed to be forward-looking and rational, so instead of implementing a negative policy rate, the central bank could signal that the policy rate would remain low for a substantial period. When agents expect that the policy rate will remain low for some time, demand and inflation will increase somewhat faster, given that the central bank is credible (Olsen, 2020b).

2.2 Output Gap and Potential Output

Internationally, central banks and policy institutions employ a variety of models and indicators to estimate output gaps for economies worldwide. Output gap estimation is an important tool that can help identify underlying trends in the economy, and is essential when shaping monetary and fiscal policy. The output gap is defined as the difference between actual and potential output, which are both unobservable variables and can differ based on what estimation methods are used. Potential output has seen much disagreement based on its definition because at its best it is an uncertain estimation and not a precise measurement tool (Okun, 1962). Additionally, there is no clear definition of the output gap, nor optimal methodology for its calculation, although it is a widely used concept among policy institutions internationally (Ódor et al., 2014).

Okun (1962) defined potential output as the maximum level of production and employment obtained in the absence of inflationary pressure and is given by the productive capacity in the economy, such as technology knowledge, capital stock, natural resources, skill, and education of the labor force. Potential output is only observable when at target unemployment, otherwise it must be viewed as a hypothetical measure (Okun, 1962). The Congressional Budget Office in the US (2001) defined potential output as the trend growth in the productive capacity of the economy and is an estimate of the level of GDP attainable when the economy is operating at a high rate of resource utilization. Furthermore, potential output is a measure of maximum sustainable output and the level of real GDP in a given year that is consistent with a stable rate of inflation (CBO, 2001). The phrasing of sustainable output implies that output when at its potential, is not excessively influenced in any particular direction by economic, financial, or internal imbalances in the economy (EU IFI, 2020). Although some define potential output as a measure of the productive capacity in the economy, others define it as a long-term trend in GDP, where fluctuations in the business cycle are smoothed out, and actual GDP is divided into a trend and a cycle. However, these simplistic trend measures struggle to estimate potential output in real-time, as the methods only rely on past data on actual output. Even though actual output is an observable statistical measure, the actual value of output remains uncertain as the data is subject to constant revisions, in which the measure of potential output for a given period may change as time passes (Frøyland & Nymoen, 2000).

When defining the output gap, Kiley (2013) provided three distinct definitions: the deviation of output from its long-run stochastic trend, the deviation of output from the level consistent with current technologies and normal utilization of capital and labor, or the deviation of output from a flexible-price or natural rate level. Each definition has its unique benefits, with one capturing short-term efficiency, while another offering insights into medium-term growth prospects. Kiley (2013) goes on to further state that the most prevalent definition at policy institutions appears to be a production-function approach, where the output gap is defined as the deviation of output from the level that would occur if capital and labor inputs were utilized at "normal" rates, given the current technology.

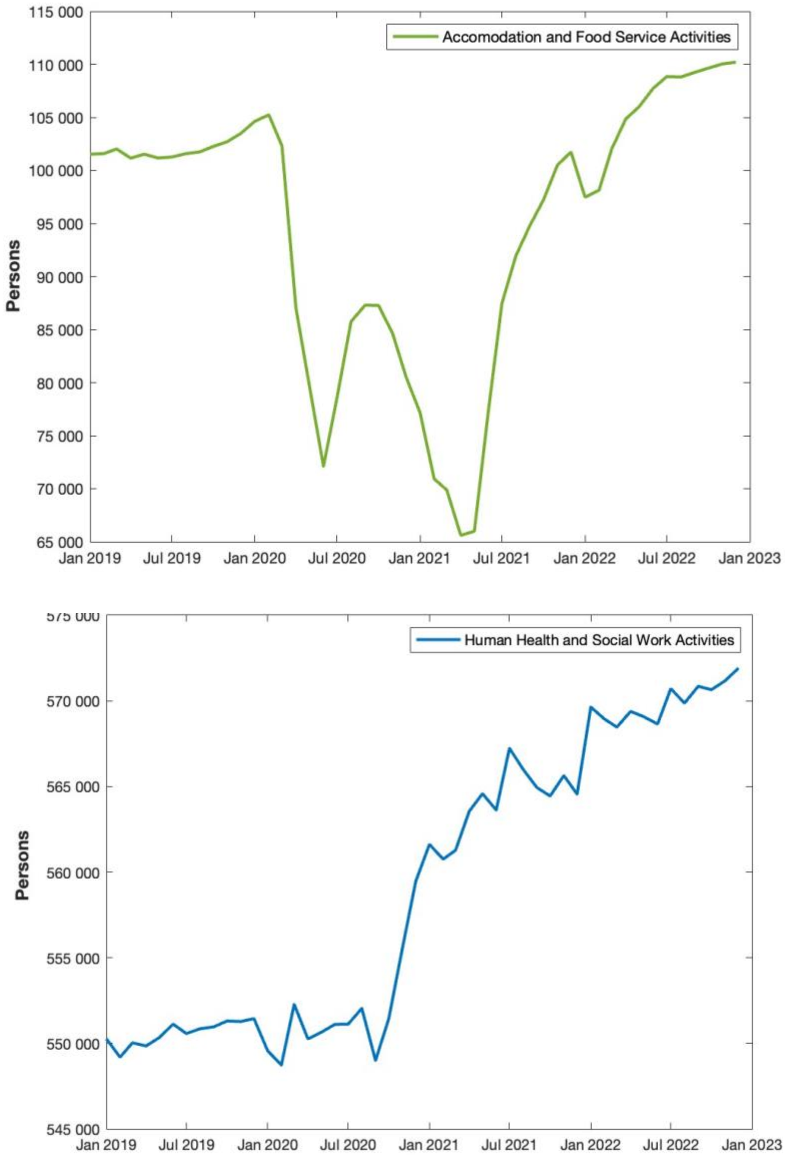
The measure of the output gap is a central component for central banks when evaluating the current economic situation to determine the optimal policy rate response. In Norway, Norges Bank utilizes a multivariate approach to estimate the Norwegian output gap, not only using data on GDP, but also other key variables such as unemployment, wages, inflation, investment, credit growth, and house price growth (Furlanetto et al., 2023). If the actual output is higher than the potential output, this is considered a positive output gap, indicating pressures in the economy and overutilization of resources (Bjørnland et al., 2005). In isolation and in the absence of any shocks, this is usually accompanied by rising inflation rates and tighter monetary policy. Similarly, when actual output falls below its potential, this is considered a negative output gap and is a sign of spare capacity in the economy, price pressures ease and the rate of inflation tends to fall (CBO, 2001).

Despite the differences in definitions as previously stated, from an academic perspective, the definition of the output gap represents the deviation from the efficient level of output, which serves as the natural benchmark (Kiley, 2013). Efficient output refers to the hypothetical level of output that would prevail under flexible prices and wages and perfect competition (Vetlov et al., 2011). However, the measure of the output gap is surrounded by considerable uncertainty originating from both constant data revisions of actual output and uncertain potential output estimates (EU IFI, 2020).

2.3 Productivity and Demand Shocks in Light of the Pandemic

In retrospect of the Covid-19 pandemic, there have been discussions around the nature of the shocks induced by the pandemic. As society as a whole was shut down, businesses temporarily had to reduce their production capacity to a large degree to abide by the containment measures, in which the Covid-19 shock can be understood as a temporary negative productivity shock. A negative productivity shock can be interpreted as a shock that reduces the economy´s capacity to produce goods and services, at given prices (Brinca et al., 2020). The pandemic resulted in spare capacity in several sectors of the economy, as workers had to stay home, and capital remained unused. The shutdown had asymmetric effects on different sectors, where service industries suffered in particular (Guerrieri et al., 2022). In Norway, the shutdown mainly affected the domestic service sectors and travel-related sectors (Holm & Martinsen, 2023), which had to adapt to social distancing, reduced indoor capacity, and travel restrictions. For example, the accommodation and food service sectors in Norway experienced a large decline in the number of employees as a result of the pandemic, while the sectors for human health and social work activities experienced an increase throughout the pandemic years, presented in Figure 1. Bratsberg et al. (2020) found that at the beginning of the pandemic in Norway, workers in the most contact-intensive sectors, such as hair salons and restaurants, suffered most from temporary and permanent layoffs. As the economic crisis became more apparent and the demand for goods and services in the most contact-intensive sectors declined, the less contact-sensitive sectors would also suffer from layoffs. They also found that the businesses with low labor productivity would suffer from layoffs to a larger degree at the beginning of the pandemic, which shifted towards affecting “the average” business as the crisis expanded. The findings of Bratsberg et al. (2020) paints a picture of the degree of reduced capacity and support the fact that different sectors were hit asymmetrically by a productivity shock as a result of the shutdown in Norway.

Figure 1*: Number of employees by industry division. Final figures 2019:M1 – 2022:M12*



Source: Statistics Norway

Throughout the pandemic, Norges Bank consistently reported the output gap as negative in their monetary policy reports. At the beginning of 2020, they reported that a substantial part of the reduction in aggregate output was due to a sharp drop in household consumption, but towards the end of the year, household consumption would pick up and become higher than expected (Norges Bank, 2021a). The shutdown of society had a large impact on the service sector, which resulted in consumers shifting their demand from services to goods, as seen in Figure 2. Considering Norges Bank´s interpretation of the output gap, as well as their discussion around changes in consumption during the pandemic, Norges Bank understood and perceived the pandemic as a large negative demand shock. A demand shock is a shock that reduces consumers´ ability or willingness to consume goods and services, at a given price (Brinca et al., 2020). Containment measures in the service sector resulted in reduced capacity among firms and businesses, but at the same time, people´s fear of contagion resulted in them staying at home and reduced their demand for these services. Loss of income resulted in reduced spending overall in the economy, despite that demand for some goods and services shifted towards the sectors that were not affected by the lockdown. The size and persistency of the shock would to a large degree be determined by the containment measures, as well as the fear and uncertainty concerning the pandemic (Weder di Mauro, 2020). Therefore, we may consider the pandemic as a temporary negative demand shock.

Figure 2: *Household consumption of goods and services in NOK million. Constant 2020-prices, seasonally adjusted.*

Source: Statistics Norway

Guerrieri et al. (2022) considered the effects of how a transitory supply shock induced by the pandemic asymmetrically affected an economy consisting of several sectors. They discussed the fact that a negative supply shock in one sector, which reduced the potential output in that sector, may have caused a large drop in aggregate demand such that overall output fell below its potential. They categorized these disturbances as large, asymmetric, transitory supply shocks, and modeled the shocks in a two-sector model with nominal wage rigidities, where one sector was shut down while the other sector remained open. The goal of this was to conclude whether the pandemic shock was a Keynesian supply shock, meaning that a shock to aggregate supply would lead to a reduction in aggregate demand that was larger than the original supply shock. This would in turn imply that a reduction in potential output in one sector could cause aggregate output to fall below its potential in the economy overall.

The findings in the paper suggested that when some sectors were shut down due to containment measures, the set of goods available to the consumers was limited, in which consumers reallocated their spending away from the shutdown sector and towards the open sector. Guerrieri et al. (2022) pointed out that defining whether the goods and services in the shutdown and open sectors were complementary or substitutes was essential to determine whether overall spending would fall below the level of what they were initially spending in the shutdown sector. If the goods were complementary, meaning that the deficiency of a good from the shutdown sector resulted in reduced spending on a good in the open sector, overall spending would fall, and the recession would spread. Therefore, an initial shutdown in one sector could result in reduced demand also in the open sector.

Secondly, the workers in the sector that was shutdown experienced a loss of income, which reduced total spending in the rest of the economy. Parts of the reduced demand were compensated by the workers in the open sector switching some demand from the shutdown sector towards the open sector. Still, Guerrieri et al. (2022) argued that these effects might not have been strong enough to avoid a recession in the active sector as well, since the workers in the open sector´s marginal propensity to consume were lower than that of the workers in the shutdown sector.

Taking these effects into account, Guerrieri et al. (2022) concluded that the Covid-19 shock was a Keynesian supply shock, such that the initial supply shock resulted in a demand shortage, making aggregate output fall below its potential.

In this subsection, we have explored the nature of the shocks induced by the pandemic. On one side, the economy was hit by a negative productivity shock, reducing the economy's production capacity, while there was also a negative demand shock, affecting consumers´ willingness and ability to consume specific goods and services. Both monetary and fiscal policy can be used to stabilize an economy after being hit by these types of shocks, but each shock requires different measures of policy. Therefore, it is important to determine to which extent the economy was hit by a demand shock and a productivity shock, to design a policy that minimizes the long-term effects of the pandemic.

As discussed, the productivity shock had asymmetric effects across different sectors of the economy, which may also hold for the demand shock. When taking sectoral differences into account when determining the effects of the pandemic, Norges Bank may have overestimated the size of the demand shock compared to the productivity shock. Holm & Martinsen (2023) evaluated the conduct of Norges Bank´s monetary policy of 2022 in a published Norges Bank Watch report. They used a more unconventional method to estimate the output gap, by looking at different sectors of the economy individually. To assess which sectors were impacted negatively, they utilized The Oxford Covid-19 Government Response Tracker (OxCGRT), which is an index capturing the extent of pandemic policy measures in several countries. By calculating the correlation between the OxCGRT index for Norway and the different components of mainland GDP, they found that mostly domestic service sectors and travel-related sectors were negatively affected by the shutdowns. The findings from the report further indicated that household consumption was the most impacted part of mainland GDP, where they calculated potential output based on the components of household consumption's coincident correlations with the OxCGRT. The correlation coefficient worked as an estimate of the relative impact the containment measures had on actual and potential output. Using this method, Holm & Martinsen obtained a measure of the output gap which suggested a smaller decline in capital utilization than Norges Bank indicated at the time. They concluded that Norges Bank likely interpreted the shocks from the pandemic as too much of a negative demand shock, causing the output gap to be strongly negative, rather than a negative productivity shock, which would cause a reduction in potential output and limiting the fall in the output gap.

3 Research Methodology

There are numerous methods for estimating the output gap, of which different methods may provide differing results. While actual output is defined as an observable variable, there are still uncertainties concerning the data when performing estimations, since the data is continuously revised. Therefore, estimating the output gap in real-time is challenging, as the data from the recent periods aren't complete and will be revised as time passes (Bjørnland et al., 2005).

Furlanetto et al. (2023) described different methods that can be used to calculate the output gap and categorized them into univariate and multivariate methods. Univariate methods are solely based on information and data on actual output, whereas most of the methods calculate the trend in the data as an expression of potential output (Bjørnland et al., 2005). When only using actual output in the estimations, potentially useful information derived from other variables may be lost, which limits the economic content of the model (EU IFI, 2020). An often-used univariate method is the Hodrick-Prescott filter, which we will use to estimate potential output. We will also look into utilizing the univariate unobserved component method. On the contrary, multivariate models use several variables to estimate either potential output or the output gap, which can indicate there is a relationship between the variation in output and other observable variables (Bjørnland et al., 2005). We will also utilize the multivariate unobserved component method.

We begin our research by collecting real data for the Norwegian economy and applying the output gap estimation methods presented by Furlanetto et al. (2023). The estimation is followed by a discussion of the benefits and challenges arising from using these models to estimate the output gap, and what implications this had during the pandemic years. Based on this discussion, we will look at a simple New Keynesian model as a benchmark for our analysis, where we simulate data that is induced by shocks every period. As argued in section 2.3, the Covid-pandemic shock can be characterized as a combination between a negative productivity shock and a demand shock. We will therefore simulate one New Keynesian model hit by negative demand shocks, one model with negative productivity shocks, and one with both types of shocks. The model itself is not constructed to study the effects of Covid-19, but it is helpful to study the most important elements of the pandemic and what implications it had on policy design. Using the data from the simulations, we will estimate output gaps using both univariate and multivariate methods. These output gap estimations will further be compared to the simulated output gap produced by the New Keynesian model. The New Keynesian model is a stylized reality, where the simulated output gap from the model is the true output gap, and portrays how the output gap should react to demand and productivity shocks within the given framework. We will discuss whether the output gap estimation methods provide sufficient results of the output gap in the presence of demand and productivity shocks by comparing them to the New Keynesian output gap. Based on our discussion, we will be able to identify the challenges concerning the output gap estimation methods.

3.1 Data

In this section, we discuss the data used in the output gap estimations. We use data for the Norwegian economy, collected from Statistics Norway. Some of the estimations will differ in estimation frequency, in which we collect both quarterly and yearly data. One of the estimation methods includes real wages as a variable, which is considered to be very noisy on a quarterly basis. Therefore, estimations concerning real wages will be estimated using annual data.

In the estimations, we use the demeaned values of the variables, as done by Furlanetto et al. (2023). If the variables are not demeaned, we obtain unreasonably positive and volatile estimates of the Norwegian output gap when applying the multivariate models. Therefore, we use the demeaned variables for both the univariate and multivariate unobserved component models.

We collect quarterly seasonally adjusted data on GDP for mainland Norway over the period 1993:Q1-2022:Q3, as well as yearly GDP for mainland Norway over the period 1993-2022. In the estimations, we will use the changes in log GDP. Furthermore, we collect the 12-month rate consumer price index over the period 1993:M6-2022:M9. We calculate the quarterly consumer price index by taking the mean of the months in each quarter, to obtain data for 1993:Q1-2022:Q3. Further, we obtain data on the quarterly unemployment rate for the period 1993:Q1-2022:Q3, as well as the yearly unemployment rate for 1993-2022. Lastly, we collect yearly data on changes in real wages for 1993-2022.

3.2 The New Keynesian Model

The model-based simulation exercise will be based on a simple New Keynesian (NK) model for a closed economy, derived by Bergholt (2018), and is based on the derivations of Galí (2015). The model consists of three agents: a household that maximizes expected lifetime utility by choosing consumption, savings, and labor supply, firms that maximize expected lifetime profits by choosing labor demand and set prices, and a competitive retail sector. All agents are assumed to form rational expectations. The model features two frictions: monopolistic competition, where firms only use labor as input, and nominal price rigidities, which involve that firms´ pricing decisions today have implications for future profits. In this model, we assume Rotemberg pricing, in which all firms can adjust their prices every period, but at a cost.

The New Keynesian model is a log-linear approximation of the model, which allow for faster estimations and simulations, but may however induce approximation errors. The model is given by the following equations:

$$c_t = E_t c_{t+1} - \frac{1}{\sigma}(i_t - E_t\pi_{t+1} - \rho) + \frac{1}{\sigma}(1-\rho_v)v_t \qquad (1)$$

$$w_t = \sigma c_t + \varphi n_t \qquad (2)$$

$$y_t = a_t + n_t \qquad (3)$$

$$y_t = c_t \qquad (4)$$

$$\pi_t = \beta E_t\pi_{t+1} + \lambda mc_t \qquad (5)$$

$$mc_t = w_t - a_t \qquad (6)$$

$$i_t = \rho + \phi_\pi \pi_t + \phi_y \tilde{y} + z_t \qquad (7)$$

$$r_t = i_t - E_t\pi_{t+1} \qquad (8)$$

Equation (1) is the Euler equation, which explains how consumption is dependent on expected consumption in the next period $E_t c_{t+1}$, the discount rate ρ, the inverse intertemporal elasticity σ, the nominal interest rate i_t, expected inflation next period $E_t\pi_{t+1}$ and a demand shock v_t. Equation (2) shows how real wages are dependent on consumption c_t and the parameter for inverse intertemporal elasticity of consumption σ. Further, it includes hours worked n_t and inverse Frisch elasticity φ, which measures the substitution effect of hours worked with respect to wage. Equation (3) illustrates how aggregate demand y_t depends on productivity shocks a_t and hours worked n_t, and the market clearing condition in equation (4) must hold. Further, equation (5) is the Phillips curve, and shows how inflation is dependent on expected inflation next period multiplied by the time discounting factor β, and the price markup mc_t multiplied by $\lambda = \frac{\epsilon-1}{\xi}$. λ takes into account the substitution elasticity between individual goods ϵ, and the Rotemberg price stickiness through the Rotemberg price adjustment costs parameter ξ. Higher values of ξ indicate greater price stickiness, and $\xi = 0$ indicates flexible prices. The price markup is defined in equation (6) as the real wage w_t minus productivity shocks a_t. Equation (7) illustrates the Taylor rule, indicating how the central bank weights inflation through the parameter ϕ_π, and how they weigh the output gap through $\phi_y$when considering the nominal interest rate. ρ is the discount rate, and is given by $\rho = -\log\ \beta$. z_t captures monetary policy shocks. Lastly, through equation (8) the real interest rate is defined as the nominal interest rate adjusted for inflation expectations for the next period.

The model can be simplified into three equations: the New Keynesian Phillips curve, the dynamic IS equation, and the monetary policy rule. We start looking at the Phillips curve and begin by substituting out w_t, n_t and mc_t in equation (6):

$$mc_t = w_t - a_t$$

$$mc_t = \sigma y_t + \varphi n_t - a_t$$

$$mc_t\ = (\sigma + \varphi)y_t - (1 + \varphi)a_t \tag{9}$$

By inserting equation (9) into equation (5), we obtain the New Keynesian Phillips curve:

$$\pi_t = \beta E_t \pi_{t+1} + \kappa(y_t - \psi_a a_t) \tag{10}$$

Where $\kappa = \frac{\epsilon-1}{\xi}(\sigma + \varphi)$ and $\psi_a = \frac{1+\varphi}{\sigma+\varphi}$.

Further, we want to express the dynamic IS equation, and we start by defining the potential output, y_t^*, and the natural real interest rate, r_t^*. In the New Keynesian model, the equilibrium is found in the absence of nominal rigidities. Potential output is, therefore, a hypothetical equilibrium where prices are fully flexible, implying that the natural equilibrium of the marginal cost is zero, $mc_t^* = 0$. From equation (9), this implies:

$$mc_t^* = (\sigma + \varphi)y_t^* - (1 + \varphi)a_t = 0$$

$$y_t^* = \psi_a a_t \tag{11}$$

where $\psi_a = \frac{1+\varphi}{\sigma+\varphi}$. We obtain an expression for the potential output, y_t^*, which is independent of policy and only affected by productivity shocks.

Further, we find the expression for the natural real interest rate, r_t^*. We define r_t^* using the Euler equation (1), the market clearing condition in equation (4), and the fact that $E_t a_{t+1} = \rho_a a_t$:

$$y_t^* = E_t y_{t+1}^* - \frac{1}{\sigma}(r_t^* - \rho) + \frac{1}{\sigma}(1-\rho_v)v_t$$

$$r_t^* = \rho + \sigma E_t \psi a_{t+1} - \sigma \psi_a a_t + (1-\rho_v)v_t$$

$$r_t^* = \ \rho - \sigma\psi(1-\rho_a)a + (1-\rho_v)v_t$$

$$r_t^* = \ \rho - \sigma\frac{1+\varphi}{\sigma+\varphi}(1-\rho_a)a + (1-\rho_v)v_t \quad (12)$$

Before deriving the dynamic IS curve, we define the output gap $\bar{y}_t$ as the difference between actual output y_t and potential output y_t^*:

$$\bar{y}_t = y_t - y_t^* \quad (13)$$

From the Euler equation (1) and the market clearing condition in equation (4), we have:

$$y_t = E_t y_{t+1} - \frac{1}{\sigma}(i_t - E_t\pi_{t+1} - \rho) + \frac{1}{\sigma}(1-\rho_v)v_t \quad (14)$$

By combining (13) and (14), we can derive the dynamic IS curve:

$$\bar{y}_t = E_t y_{t+1} - \frac{1}{\sigma}(i_t - E_t\pi_{t+1} - \rho) + \frac{1}{\sigma}(1-\rho_v)v_t - E_t y_{t+1}^* + \frac{1}{\sigma}(r_t^* - \rho) - \frac{1}{\sigma}(1-\rho_v)v_t$$

$$\bar{y}_t = E_t y_{t+1} - E_t y_{t+1}^* - \frac{1}{\sigma}(i_t - E_t\pi_{t+1} - r_t^*)$$

$$\bar{y}_t = E_t \bar{y}_{t+1} - \frac{1}{\sigma}(i_t - E_t\pi_{t+1} - r_t^*) \quad (15)$$

Where $r_t^* = \ \rho - \sigma\frac{1+\varphi}{\sigma+\varphi}(1-\rho_a)a + (1-\rho_v)v_t$ and $y_t^* = \psi_a a_t$.

Lastly, the monetary policy rule is given by equation (7):

$$i_t = \rho + \phi_\pi \pi_t + \phi_y \bar{y}_t + z_t \quad (7)$$

There are three sources of shocks in the model, where the shocks are assumed to follow an AR(1) process.

Productivity shock:

$$a_t = \rho_a a_{t-1} + \sigma_a \epsilon_{a,t} \quad (16)$$

Demand shock:

$$v_t = \rho_v v_{t-1} + \sigma_v \epsilon_{v,t} \tag{17}$$

Monetary policy shock:

$$z_t = \rho_z z_{t-1} + \sigma_z \epsilon_{z,t} \tag{18}$$

$\epsilon_{i,t}$ is an error term which is identically and independently distributed, drawn from a normal distribution with mean 0 and variance 1. ρ_i denotes the autoregressive coefficients, and σ_i denotes the volatility of the shocks.

3.2.1 Parameters in the New Keynesian Model

For the parameters in the New Keynesian model, we use the calibrated parameters presented in Galí (2015), which correspond to a quarterly model. The time discount factor $\beta = 0.99$ implies a steady state real return on financial assets of about 4 %. The log utility is $\sigma = 1$ and $\varphi = 5$ implies a Frisch elasticity of 0.2. To determine the Rotemberg adjustment cost parameter ξ, we examine another method for determining price stickiness, through Calvo pricing. Calvo pricing implies that firms can reset their price in any given period with a probability of $1 - \theta$, where θ is referred to as the Calvo parameter, implying what fraction of producers keeps their prices unchanged. From the Phillips curve in equation (5), we have that $\lambda = \frac{\epsilon-1}{\xi}$ through Rotemberg pricing, but through Calvo pricing, $\lambda = \frac{(1-\theta)(1-\beta\theta)}{\theta}$. To obtain the value for ξ, we set λ for Rotemberg and Calvo pricing equal. When solving for ξ, we obtain the following expression: $\xi = \frac{(\epsilon-1)\theta}{(1-\theta)(1-\beta\theta)}$. Now, the Rotemberg parameter is straightforward to calibrate and implies a relationship between the Rotemberg price adjustment cost, ξ, and the fraction of firms´ price adjustments, $1 - \theta$. The Calvo parameter is $\theta = \frac{3}{4}$, implying an average price duration of four quarters, which is consistent with empirical evidence (Galí, 2015, p.7). $\epsilon = 9$ indicates a markup over marginal cost of $\frac{\epsilon}{\epsilon-1} = 12.5$ %. From the monetary policy rule, $\phi_\pi = 1.5$ and $\phi_y = 0.125$ are consistent with Taylor´s original rule. $\rho_a = 0.75$ implies a persistent technology shock that takes some time to die out. $\rho_z = 0.5$ and $\rho_v = 0.5$ indicates a moderately persistent monetary policy shock and demand shock respectively. $\sigma_a = 1$ and $\sigma_v = 0.75$ represents the volatility of the productivity shock and demand shock respectively. $\sigma_z = 0.0625$ is consistent with a monetary policy shock of 25 basis points.

Table 1: *Parameters in the New Keynesian model*

β	σ	φ	θ	ϵ	ϕ_π	ϕ_y	ρ_a	ρ_z	ρ_v	σ_a	σ_z	σ_v
0.99	1	1	$\frac{3}{4}$	9	1.5	0.125	0.75	0.5	0.5	1	0.0625	0.75

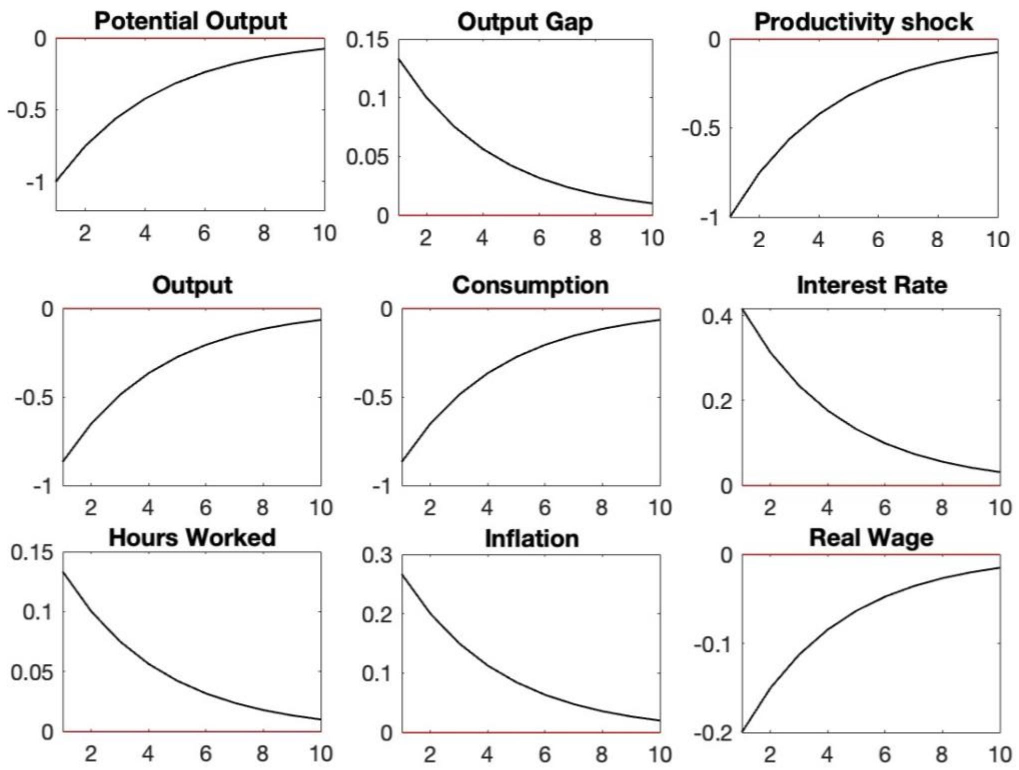
3.2.2 Impulse Response Functions in the New Keynesian Model

We begin discussing how demand and productivity shocks affect the baseline New Keynesian model.

First, we observe the effects of a negative productivity shock, where the impulse response functions are presented in Figure 3. A negative productivity shock results in a reduction in the capacity to produce goods and services, which causes potential output to fall by the same amount as the size of the productivity shock. Due to the loss of productivity, the level of actual output will also fall. The effect on the output gap will largely be determined by whether prices are flexible or rigid. In our model, we assume nominal rigidities, which will dampen the effects of a productivity shock, and therefore, we experience a fall in potential output that is greater than the fall in actual output, resulting in a positive output gap (Galí, 2015). The productivity shock causes inflation to rise, as businesses face higher marginal costs which results in increased prices. The fall in real wages is largely caused by reduced consumption and will dampen some of the increase in inflation. Furthermore, the results from our model imply an increase in hours worked, as reduced productivity enhances the need for labor to produce. As a response to the productivity shock, the New Keynesian model implies that the central bank will increase interest rates, due to the changes in inflation and the output gap. The increase in inflation is relatively higher than the increase in the output gap, where the increased inflation is the dominant factor in the response of the interest rate.

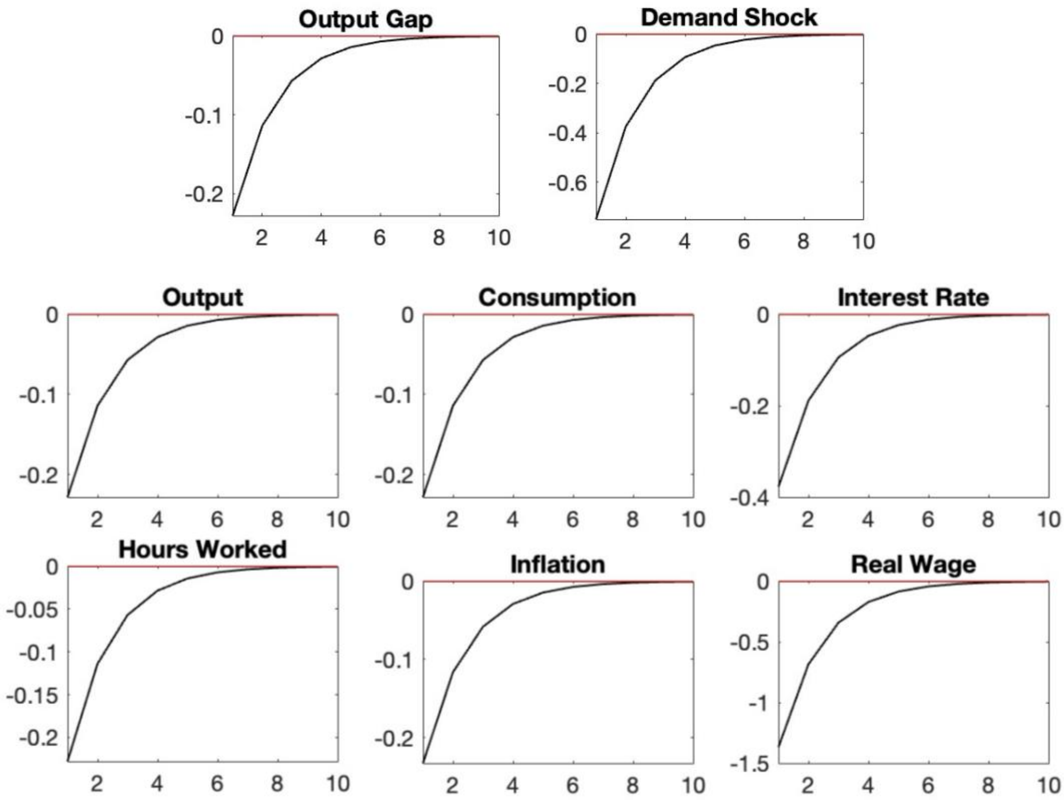
One of the main takeaways from the impulse response function is that the output gap will *increase* as a result of a negative productivity shock. Increasing interest rates will dampen the increase in inflation, while actual and potential output will move back toward their steady state as the productivity shock wears off. Despite there being a reduction in actual output due to the productivity shock, it would not be optimal to decrease the interest rate to stimulate demand and output. If so, the output gap would become even more strongly positive after the productivity shock wears off and would push inflation even higher.

Figure 3: *Impulse response functions from a negative productivity shock*



Next, we observe the effects of a negative demand shock. The impulse response functions in Figure 4 show that the shock has contractionary effects on the economy. We observe a decline in actual output, which is directly caused by a contraction in consumption due to the shock. Potential output on the other hand is shown to be unaffected, as we know this variable is only affected by productivity shocks. Therefore, the output gap falls by the same amount as actual output. The shock also results in lower hours worked and real wages, as less demand for goods and services creates less labor demand. To accommodate the decline in output and inflation, the model implies that the central bank will reduce the interest rate. By lowering the interest rate, the real interest rate decreases and makes it more attractive to consume today rather than save, which in turn will cause output and inflation to increase.

Figure 4: *Impulse response functions from a negative demand shock*



3.3 Output Gap Estimation

In this section, we introduce three methods for output gap estimation: the Hodrick-Prescott filter (HP filter), the univariate unobserved component (UUC) method, and the multivariate unobserved component (MUC) method. The UUC and MUC methods are based on the methods applied in Furlanetto et al. (2023), where they present a suite of models used by Norges Bank to estimate the output gap. The UUC and MUC are estimated as a "maximum likelihood" system, applying the Kalman filter in combination with a minimization algorithm to search for the posterior mode of the distribution in the model. The estimated posterior mode and the Kalman smoother are then used to obtain the output gap estimate.

3.3.1 The Kalman Filter

The Kalman filter, which is used in the UUC and MUC, is an estimation method useful for estimating equation systems consisting of one or more unobservable variables in real time (Bjørnland et al., 2005). The filter obtains two types of equations: time update equations and measurement update equations. The time update equations are a prediction that projects the current state forward in time to obtain a prior estimate for the next period. Furthermore, the measurement update equations are a predictor-corrector that adjusts the projected prior estimate by an actual estimate at that time, called a posterior estimate. (Welch & Bishop, 1997). The posterior estimates are further used to estimate the output gap.

3.3.2 Hodrick-Prescott Filter

The Hodrick-Prescott filter is a simple univariate statistical filter that is widely used when estimating potential output, but it is also one of the most criticized methods in academic literature (EU IFI, 2020). The HP filter is based on a minimization problem, which minimizes the difference between actual and potential output, as well as penalizes variations in potential growth. The HP filter relies on two main assumptions:

1. Actual output should not deviate too much from its trend.
2. The growth in potential output should be relatively smooth, and not too volatile.

(Murray, 2014, cited in EU IFI, 2020, p.21)

Using the HP filter, potential output can be calculated using the following expression:

$$min\{y_t^*\}_{t=1}^{T} = \sum_{t=1}^{T}(y_t - y_t^*)^2 + \lambda \sum_{t=1}^{T}[(y_{t+1}^* - y_t^*) - (y_t^* - y_{t-1}^*)]^2 \quad (19)$$

y_t denotes actual output and y_t^* is potential output. The expression places a relative weight on goodness-of-fit, $\sum_{t=1}^{T}(y_t - y_t^*)^2$, and degrees-of-smoothness, $\lambda \sum_{t=1}^{T}[(y_{t+1}^* - y_t^*) - (y_t^* - y_{t-1}^*)]^2$. The weights on each element are determined by the positive exogenous smoothing parameter λ, which determines how much variation in potential growth is being allowed. When $\lambda = 0$, the output gap vanishes as we allow for no degree of smoothness in the data. If $\lambda \rightarrow \infty$, the HP filter approaches a linear time trend, as there will be minimal variation in potential growth (EU IFI, 2020). The value of λ needs to be determined exogenously. Kydland and Prescott (1990) argued that $\lambda = 1600$ is a reasonable estimate for US quarterly data. Later, Marcet and Ravn (2004) found that $\lambda = 1600$ holds for several OECD countries, with the exceptions of Spain, Italy, and Japan (Benedictow & Johansen, 2005). In that sense, there has been wide consensus about $\lambda = 1600$, and this has resulted in it becoming an international standard (Bjørnland et al., 2005). On the contrary, Johansen and Eika (2000) argued that $\lambda = 40\ 000$ gives an adequate description of the Norwegian business cycle on a quarterly basis for the last 30 years, and is the value of λ used by Statistics Norway when estimating potential output (Benedictow & Johansen, 2005). Based on this, we will consider both $\lambda = 1600$ and $\lambda = 40\ 000$ in our estimations.

While the HP filter is a simple method to use and provides a good measure of capacity utilization (Furlanetto et al., 2023), it has also received criticism. Variations in actual output at the beginning and the end of the period are affecting the level of potential output to a larger degree than what the rest of the data on actual output does. This is referred to as the end-of-sample problem (EU IFI, 2020). As seen through equation (19), potential output depends on observations backward and forward in time, also called two-sided filtering. When estimating the last observations of potential output, only observations in previous periods are available, gradually making it a one-sided filter that is more dependent on the value of actual output. This also applies to the first number of observations in the data. Higher values of λ will make this problem more apparent, and it may lead to spurious distortions in the estimates (EU IFI, 2020). A suggested method to solve the end-of-sample problem is extending the time series for actual output by using forecasted estimates (Bjørnland et al., 2005). Additionally, when considering the two main assumptions for the HP filter, we can already tell that the filter will have problems estimating the output gap in extreme events, such as the Covid-19 pandemic. The pandemic resulted in significant a drop in output, implying a large deviation from its trend, and additionally, an abrupt decline in potential output. Despite the apparent issues associated with the HP filter, the method still plays a central role in output gap estimation among several policy institutions (Furlanetto et al., 2023), e.g., Statistics Norway.

3.3.3 The Univariate Unobserved Component Method

The univariate unobserved component (UUC) method is based on the fact that actual output can be decomposed into two unobservable factors: potential output and the output gap. The following equation shows the decomposition of actual output:

$$y_t = y_t^* + \bar{y}_t \tag{20}$$

where y_t denotes actual output, y_t^* is potential output, and $\bar{y}_t$ is the output gap. The expression is based on the idea that the unobservable variables, y_t^* and $\bar{y}_t$, are assumed to affect the observed variable, y_t. Further, the model specifies how the output gap evolves:

$$\bar{y}_t = \lambda_y \bar{y}_{t-1} + \epsilon_t \tag{21}$$

The output gap is an AR(1) process, depending on the output gap in previous periods and a white noise shock, ϵ_t. Furthermore, the growth in potential output is modeled as follows:

$$\Delta y_t^* = G_t + \eta_t \tag{22}$$

$$G_t = C_G + \lambda_G(G_{t-1} - C_G) + \psi_t \tag{23}$$

The change in potential output depends on potential growth, G_t, and a white noise shock, η_t. Potential growth is allowed to vary over time, where ψ_t is a white noise shock to potential growth, and the persistence of the growth is governed by the parameter λ_G. When $\lambda_G = 1$, potential growth follows a random walk. Lastly, C_G is a constant. (Furlanetto et al., 2023).

The UUC model can directly estimate potential output and the output gap, which allows us to estimate the standard deviation of the output gap to identify the uncertainty surrounding the estimations (Bjørnland et al., 2005).

3.3.4 The Multivariate Unobserved Component Method

The multivariate unobserved component (MUC) method is an expansion of the UUC method, which includes additional variables that explain the output gap, such as domestic inflation and unemployment. Furlanetto et al. (2023) confirmed the findings by Fleischman and Roberts (2011), that using data on other variables, unemployment in particular, is useful to obtain reliable estimates of the output gap in the US, which also applies for Norway. Furlanetto et al. (2023) discussed the use of data on inflation in addition to GDP by following Kuttner (1994), who introduced the literature on the output gap and Phillips curve in estimations of unobserved component models. Additionally, Clark (1989), Apel and Jansson (1999), and Sinclair (2009) showed how the output gap and unemployment according to Okun´s law can be used to estimate unobserved component models.

We will use three MUC models in the analysis:

1. *MUC 1* uses quarterly data on GDP for mainland Norway and changes in domestic inflation.

2. *MUC 2* uses quarterly data on GDP for mainland Norway, domestic inflation, and unemployment rates.

3. *MUC 3* uses annual data on GDP for mainland Norway, unemployment rates, and real wage growth.

MUC 1 includes quarterly data on GDP and changes in domestic inflation in the estimations. As shown in equation (20)-(23) in the UUC model, the definition of GDP is given by:

$$y_t = y_t^* + \bar{y}_t \tag{20}$$

The process for the output gap is given by:

$$\bar{y}_t = \lambda_y \bar{y}_{t-1} + \epsilon_t \tag{21}$$

The process for growth in potential output is modeled as follows:

$$\Delta y_t^* = G_t + \eta_t \tag{22}$$

$$G_t = C_G + \lambda_G (G_{t-1} - C_G) + \psi_t \tag{23}$$

Further, the process for the change in domestic inflation is given by:

$$\Delta \pi_t = \gamma \bar{y}_t + \upsilon_t + \delta \upsilon_{t-1} \tag{24}$$

$$\upsilon_t = \eta_t \tag{25}$$

where $\Delta \pi_t = \pi_t - \pi_{t-1}$. Equation (24) shows that the change in inflation depends on the output gap $\bar{y}_t$, as well as the white noise terms υ_t and υ_{t-1}. Modeling inflation in first differences implies that potential GDP corresponds to the level of GDP consistent with constant inflation.

MUC 2 includes quarterly data on GDP, domestic inflation, and unemployment. The definition of GDP remains the same as in equation (20). In this model, unemployment is introduced, which is defined by the following expression:

$$u_t = \bar{u}_t + u_t^* \tag{26}$$

where u_t is actual unemployment, $\bar{u}_t$ is the unemployment gap and u_t^* is equilibrium unemployment. Same as for GDP, equilibrium unemployment and the unemployment gap are unobservable variables. The process for the unemployment gap can be modeled as follows:

$$\bar{u}_t = \lambda_u \bar{u}_{t-1} + \omega_t \tag{27}$$

The equation follows an AR(1) process, where ω_t is a white noise term. Further, the process for the trend in unemployment is given by:

$$\Delta u_t^* = \Delta u_{t-1}^* + \nu_t \tag{28}$$

Equation (28) illustrates NAIRU, which is the lowest unemployment rate that can be sustained without causing wage growth and inflation to rise (RBA, n.d.). ν_t is a white noise term.

After introducing unemployment, the process for the output gap is modeled as following:

$$\bar{y}_t = \bar{y}_{t-1} + \beta \bar{u}_t + \epsilon_t \tag{29}$$

The process is based on Okun´s law, which illustrates a relationship between unemployment and the output gap. The output gap in equation (29) depends on previous observations of the output gap, together with the unemployment gap $\bar{u}_t$, and a white noise term ϵ_t. The process for growth in potential output is modeled in equation (22) and (23). Lastly, the process for domestic inflation is:

$$\pi_t = \lambda_\pi \pi_{t-1} + \gamma \bar{u}_{t-2} + \upsilon_t \tag{30}$$

The process depends on domestic inflation with one period lag, the unemployment gap with two periods lagged, as well as a white noise term υ_t.

MUC 3 includes annual data on GDP, unemployment, and real wage growth. The definition of GDP and the process for the output gap remains the same as in equation (20) and (21) respectively, and the process for growth in potential GDP is defined by equation (22) and (23).

The definition of real wage is given by the following expression:

$$W_t = \bar{W}_t + W_t^* \tag{31}$$

Where $\bar{W}_t$ and W_t^*denote the real wage gap and trend in real wages respectively. Further, the process for the real wage gap is defined by the Phillips curve for real wages:

$$\bar{W}_t = \lambda_W \bar{W}_{t-1} + \gamma \bar{y}_t + \upsilon_t \tag{32}$$

The process depends on the last period´s real wage gap, the output gap, and a white noise term v_t. The process for the trend in real wages is given by the following expression:

$$\Delta W_t^* = C_W + \lambda_{\overline{W}}(\Delta W_{t-1}^* - C_W) + \mu_t \tag{33}$$

Where C_W is a constant and μ_t is a white noise term. When $\lambda_{\overline{W}} = 1$, the process follows a random walk.

Lastly, unemployment is defined as the sum of the unemployment gap and the equilibrium unemployment, as shown in equation (26). The process for the unemployment gap is given by:

$$\bar{u} = \lambda_u \bar{u}_{t-1} + \beta \bar{y}_t + \omega_t \tag{34}$$

The unemployment gap depends on the last period´s unemployment, the output gap, and a white noise term ω_t. Further, the process for the change in unemployment trend, also called the NAIRU as explained above, is defined as:

$$\Delta \bar{u}_t = \lambda_{\bar{u}} \Delta \bar{u}_{t-1} + v_t \tag{35}$$

The expression follows an AR(1) process with a white noise term v_t.

The advantages of the MUC are that it provides direct estimates of the unobservable variables, by using more information in the estimations than what the UUC does, and it allows us to estimate the standard deviation of the output gap to identify the uncertainty surrounding the estimates. Additionally, we rely on making some assumptions about the relationship between the observable and unobservable variables, in which the quality of the estimated output gap relies on how realistic the assumptions are (Bjørnland et al., 2005).

3.3.5 Parameters in the Output Gap Estimations

When performing the UUC and MUC estimations, the parameters in the models require to be calibrated and estimated. Using Bayesian methods, point estimates are obtained by using the mode of the posterior distribution from the models. For each parameter, a prior value and prior distribution are chosen, which is a prior belief about the value and probability distribution of the parameter (Franke, 2023). We are applying the same priors for the parameters as in Furlanetto et el. (2023) in our output gap estimations. After the estimation, the prior is adjusted, and we obtain a posterior value of the parameter which is based on the new evidence of the model. The prior and posterior values for the univariate and multivariate unobserved component models are presented in Table 2 to Table 5.

Every parameter is assigned a prior distribution, of either uniform, gamma, or inverse gamma distribution. Uniform distribution is a probability distribution where all the outcomes had an equal probability of happening. The distribution makes minimal assumptions about the model, is based on a chosen maximum and minimum value, and will therefore have little impact on the posterior distribution (Frost, n.d.-b). The gamma distribution is used to model right-skewed data, to model the time between independent events which occur at a constant average rate (Frost, n.d.-a). The inverse gamma is the reciprocal of the gamma distribution, as is a useful prior for positive parameters. The tails of the distribution are "thin" and keep probability further from zero than the gamma distribution (Bois, 2022).

Table 2: *Estimated parameters for UUC. Standard deviations are in parentheses.*

Parameter	Prior	Prior distribution	Posterior
λ_y	0.9 (0.2)	Gamma	0.87 (0.19)
σ_ϵ	0.7 (10)	Inverse Gamma	1.17 (0.24)
σ_η	0.1 (10)	Inverse Gamma	0.04 (0.02)

Table 3: *Estimated parameters for MUC 1. Standard deviations are in parentheses.*

Parameter	Prior	Prior distribution	Posterior
λ_y	0.9 (0.2)	Gamma	0.86 (0.06)
γ	[0,1]	Uniform	0.09 (0.04)
δ	0.3 (0.2)	Gamma	0.95 (0.04)
σ_ϵ	0.7 (10)	Inverse Gamma	1.18 (0.07)
σ_η	0.1 (10)	Inverse Gamma	0.04 (0.01)
σ_υ	0.2 (10)	Inverse Gamma	0.78 (0.05)

Table 4: *Estimated parameters for MUC 2. Standard deviations are in parentheses.*

Parameter	Prior	Prior distribution	Posterior
λ_y	$0.8\ (0.1)$	Gamma	$0.65\ (0.11)$
β	-3.45	Calibrated	
λ_u	$0.9\ (0.2)$	Gamma	$0.52\ (0.1)$
γ	$[-1,0]$	Uniform	$-0.03\ (0.21)$
λ_π	$0.5\ (0.2)$	Gamma	$0.75\ (0.07)$
σ_ϵ	$0.7\ (10)$	Inverse Gamma	$1.59\ (0.12)$
σ_η	$0.1\ (10)$	Inverse Gamma	$0.04\ (0.02)$
σ_ω	$0.2\ (10)$	Inverse Gamma	$0.35\ (0.03)$
σ_ν	$0.1\ (10)$	Inverse Gamma	$0.08\ (0.02)$
σ_υ	$0.2\ (10)$	Inverse Gamma	$0.77\ (0.05)$

Table 5: *Estimated parameters for MUC 3. Standard deviations are in parentheses.*

Parameter	Prior	Prior distribution	Posterior
λ_y	0.7 (0.2)	Gamma	0.8 (0.14)
λ_G	0.9 (0.2)	Gamma	0.79 (0.15)
λ_W	0.75 (0.25)	Gamma	0.97 (0.07)
$\lambda_{\overline{W}}$	0.6 (0.2)	Gamma	0.46 (0.15)
λ_u	0.5 (0.2)	Gamma	0.32 (0.1)
$\lambda_{\overline{u}}$	0.9 (0.1)	Gamma	0.84 (0.1)
γ	0.29	Calibrated	
β	-0.29	Calibrated	
σ_ϵ	2 (10)	Inverse Gamma	1.48 (0.27)
σ_η	2 (10)	Inverse Gamma	0.87 (0.31)
σ_ψ	1 (10)	Inverse Gamma	0.35 (0.18)
σ_ω	0.4 (10)	Inverse Gamma	0.21 (0.06)
σ_μ	2 (10)	Inverse Gamma	0.87 (0.16)
σ_ν	0.2 (10)	Inverse Gamma	0.06 (0.03)
σ_υ	0.5 (10)	Inverse Gamma	0.17 (0.11)

4 Empirical Analysis

4.1 Results of Output Gap Estimations from the Norwegian Economy

Figure 5 presents the output gap estimates from the HP filter, the univariate unobserved component model and the three multivariate unobserved component models applied to real data for the Norwegian economy. Our quarterly output gap estimations, consisting of UUC, MUC 1-2, and the HP-filter methods, begin in the second quarter of 1993, while the annual estimation, MUC 3, begins in 1994. We observe that every estimation method, excluding MUC 3, provides similar estimates of the output gap throughout the period. The estimation period begins by the time the Norwegian economy started to recover from the banking crisis of 1991/1992. From 1993, the Norwegian economy experienced substantial growth, resulting from lower interest rates, and increased public spending in the wake of the banking crisis (Benedictow, 2005). The quarterly output gap estimates seem to move up and down quite a lot in the beginning, but these movements are of small size. This may be caused by the fact that there are fewer backwards-looking data to base the estimations on at the beginning of the estimation period. At the same time, we observe that the HP filter with $\lambda = 40\ 000$ deviates from the rest of the estimates at the beginning of the estimation. As discussed in section 3.3.2, this can be a result of the end-of-sample problem related to the HP filter, since higher values of λ will make the end-of-sample problem more apparent (EU IFI, 2020). Compared to the univariate and multivariate unobserved component methods, the HP-filter method with $\lambda = 1600$ does not suffer from this problem to the same extent, due to a lower value of λ.

Throughout the estimation period, UUC, MUC 1-2 and the HP-filter methods follows each other closely. Still, there are periods where some of the methods slightly deviate from the others. For example, there was a fall in inflation through 2003 and the first half of 2004 in the wake of the dot-com bubble (Bjørnland et al., 2005), which results in MUC 1 showing a somewhat more negative output gap than the rest of the estimates, as it only depends on GDP and inflation. As Norges Bank decreased the policy rate substantially between 2002 and 2004, household demand would increase, the Norwegian krone would weaken, and unemployment rates would fall (Cappelen & Eika, 2010). This can be observed in the output gap estimates as the largest boom within the estimation period, where MUC 2 presents one the most positive output gaps, as this period was known for having the lowest unemployment rates during the estimation period. We also see a boom in MUC 3, as real wages grew by 15 percent from 2003 to 2007 (Cappelen & Eika, 2010), as well as the unemployment rates were low. The top of the boom was reached towards the end of 2007 for all estimation methods.

We also observe some differences in the output gap estimates before the pandemic, where inflation through 2018 and 2019 was higher than the inflation target, pulling the estimate of MUC 1 higher than the other estimates. Model MUC 2 also shows a more positive output gap than UUC before the pandemic, because of high inflation and low unemployment rates.

The pandemic resulted in a severe decrease in production and a significant increase in the unemployment rate, which causes a severe downturn in UUC as it is only dependent on GDP. MUC 2 also suffers from this, as both increasing unemployment rates and decreasing GDP pull down the output gap. In MUC 1, the downturn is not as severe, because the estimate depends on GDP, which pulls the output gap downward, but also inflation, where the relatively high inflation during this period dampens some of the downturn. As containment measures were lifted in the autumn of 2021, activity in the Norwegian economy recovered swiftly. Norges Bank reported an increase in GDP for Mainland Norway of 4.2 % in 2021 (Norges Bank, 2022a), which explains why the output gaps become positive through 2021. During this period inflation increased substantially, and continued to rise through 2022 due to high electricity prices and increased prices of raw materials, more generally following Russia´s invasion of Ukraine. This results in MUC 1 having a more positive output gap than the rest of the estimations in the wake of the pandemic. We also observe that MUC 2 is more positive than UUC since low unemployment rates and high inflation pulls the estimate upward in this period. In December 2021, containment measures were reintroduced, which caused the activity in the economy to fall once again. We observe that the output gap estimates fell in the first quarter of 2022, which results in UUC and MUC 2 showing negative output gaps. This is a result of the fall in GDP and increases in the unemployment rates due to containment measures (Norges Bank, 2021c). MUC 2 does not become as negative as UUC, as the high inflation at the time pulls the estimate upward. To compare, MUC 1 shows a relatively high, positive output gap, where the high inflation is causing the estimate to be positive.

MUC 3, which is estimated using annual data and includes real wages, shows a somewhat different path of the output gap throughout the estimation period. The estimate seems to be less volatile than the other estimates since there are fewer observations taken into account when using annual data. This difference becomes especially apparent because of the drop in oil prices in the autumn of 2014. The MUC 3 output gap experiences a sharp decline compared to the other methods during this period and indicates a large negative output gap. This can be explained by the sharp decline in real wage growth during the oil price fall, as well as increased unemployment rates. At the beginning of 2016, the output gap begins to recover as real wages grow and unemployment rates start to fall, but it remains negative until the Covid-19 pandemic begins in 2020. The output gap declines once again and becomes even more negative than it was during the oil price fall of 2014, and ultimately reaches its lowest level in 2020. The output gap from MUC 3 does not become as negative as the other output gaps, which may be caused by the fact that it is based on annual data. During the pandemic, a lot happened in a short matter of time, of which the important events have not been captured in the annual model. The Norwegian economy was shut down in March 2020, but as the number of infections declined, containment measures were eased in July 2020. Cases of infection would once again increase due to the easing in containment measures, in which society had to shut down once again in the autumn of 2020 until the spring of 2021. In September 2021, all of the containment measures were lifted in Norway but were reintroduced in December 2021. Finally, in February 2022, the most invasive containment measures were lifted, and society could return to normal (Regjeringen, 2021). In the output gap from MUC 3, the data for 2020 only paints a picture of the second shutdown, which may explain why this output gap is not as negative as the others. In 2021, we only observe data from when society was fully open, which explains the steady increase in the output gap towards 2022.

Figure 5: *Output gap estimates for the Norwegian economy*

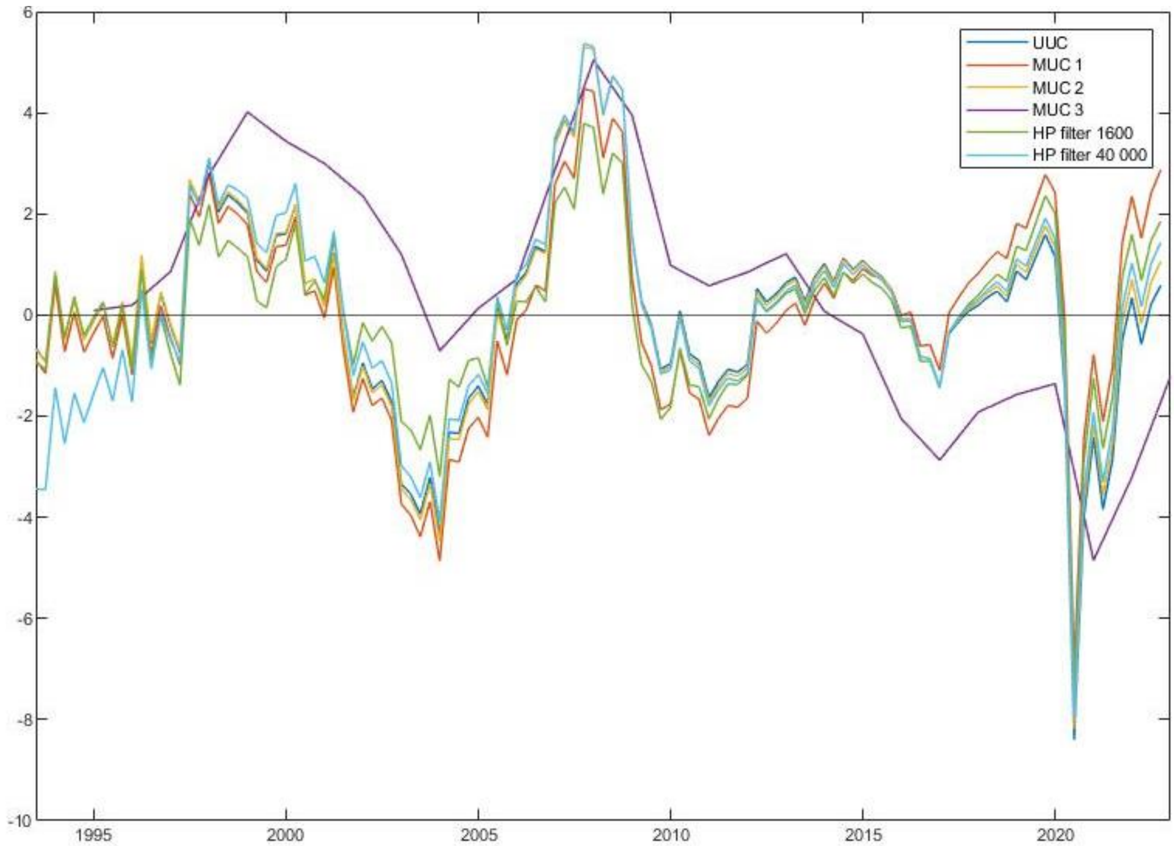


Table 6 shows a statistical summary of the output gap estimates, which are relevant to discuss the differences in the estimations. Bjørnland et al. (2005) pointed out that obtaining an average value of the output gap close to zero over time is a criterion used to determine whether the estimates are reasonable. Model MUC 3 is the method that differs most from the rest, with an average output gap of 0.49. As discussed earlier, this method is based on annual data and will therefore stand out compared to the other methods. MUC 2 also has a slightly higher average than the others of 0.1, but all estimates remain close to zero. Furthermore, looking at the degree of fluctuations is also a good criterion to determine soundness, where the standard deviations, as well as minimum and maximum values, can give indications. Still, using these measures is challenging, as we do not have an indication of what a reasonable scale of standard deviation, minimum, and maximum value is and should be. However, an output gap should not be “too wide” or “too narrow” (Bjørnland et al., 2005). MUC 3 has the largest standard deviation, but its maximum and minimum value does not stand out compared to the other estimates. UUC, MUC 2, and HP filter 40 000 have very similar and relatively high standard deviations, and they have some of the highest maximum points and lowest minimum points among all estimates.

Table 6: *Statistical summary of the output gap estimates.*

	UUC	MUC 1	MUC 2	MUC 3	HP 1600	HP 40 000
Average	0.08	−0.003	0.1	0.49	0.03	0.05
Standard deviation	1.99	1.94	2	2.35	1.55	2.06
Minimum	−8.4	−6.9	−8.2	−4.9	−7.4	−8
Maximum	5.3	4.5	5.3	5	3.8	5.4

Furthermore, Table 7 shows the correlation coefficients between the different output gap estimation methods. The correlation between every estimate is high, especially for UUC and MUC 2, with a correlation close to 1. In general, the estimates move closely with each other throughout the estimation period, which we also observed in Figure 5. We have not included the correlation coefficients of MUC 3, as this is annual data and consists of a different frequency of observations than the quarterly estimates. Still, we would expect the correlations with MUC 3 to be significantly lower than for the other estimates, once again because the estimate differs due to the annual data, as well as it contains data on real wages, which is not included in any of the other estimates.

Table 7: *Correlation between the output gap estimation methods*

	UUC	MUC 1	MUC 2	HP 1600	HP 40 000
UUC	1	0.92	0.998	0.94	0.95
MUC 1		1	0.94	0.95	0.91
MUC 2			1	0.95	0.96
HP 1600				1	0.93
HP 40 000					1

Based on this discussion, we can conclude that the different quarterly output gap estimations provide very similar results of the output gap during the estimation period. During the Covid-19 pandemic, the output gap estimates are strongly negative. This indicates that the estimation methods interpret the reduction in actual output as much larger than the reduction in the potential output. As observed in the impulse response functions in Figure 4 this effect arises through a negative demand shock. However, likely, the estimates do not take into account the scope of the reduction in potential output as a result of the pandemic, as we would expect from a negative productivity shock as seen in the impulse response function in Figure 3. During our estimation period, there are no events that can be compared to that of the pandemic, in which we can assume that the specific effects the pandemic had on potential output are not taken into account by the estimation methods. As discussed in section 2.3, the capacity of the economy was severely reduced during the pandemic, where service sectors and travel-related sectors were hit the hardest, implying a reduction in the potential capacity of these sectors. At the same time, household consumption constituted most of the decline in GDP. Taking this into consideration, we would expect to see a less negative output gap if the output gap estimation methods take into account the severely reduced capacity in these sectors. Holm & Martinsen (2023) argued that the development in service consumption during the pandemic was a function of how much capacity was open for the public. Implementing this type of effect in the output gap estimations could result in less negative output gap estimates during the pandemic. In the Norges Bank Watch report, they argued that these kinds of output gap estimation methods, only using aggregate series for GDP, might not be appropriate when the economy faces a shutdown.

In a paper by Grgurić et al. (2021), they estimated the output gap during the pandemic using several univariate and multivariate methods, where they differentiated between the effects of supply and demand shocks. They decomposed the fall in GDP into supply and demand shocks, and the results showed how different calibrations of the supply and demand shocks would provide very different results of the output gap. The output gap that was unilaterally affected by a demand shock was strictly more negative than an output gap solely affected by a supply shock. This technique can be relevant to implement when estimating the output gap for the pandemic years, however, implementing this kind of method goes beyond the scope of this thesis report. Still, we consider the methods of Grgurić et. (2021) as useful for further research on the output gap during Covid-19.

4.2 Results of Output Gap Estimations on Simulated Data

In this section, we discuss how reasonable the output gap estimation methods presented in section 4.1 are in light of New Keynesian theory. We simulate the New Keynesian model by inflicting productivity and demand shocks every period. The simulated data from the New Keynesian model will be used to simulate output gaps using the methods discussed in the previous sections. Based on the variables we obtained from simulating the New Keynesian model, we restrict ourselves to only applying the models UUC and MUC 1 in this exercise. We collect and store simulated data on actual output and inflation from the New Keynesian model to estimate UUC and MUC 1 output gaps, and we will compare them to the simulated output gap from the New Keynesian model. The New Keynesian (NK) output gap is the true output gap in light of the shocks that have occurred, and by comparing it to UUC and MUC 1, we can determine to what extent the output gap estimation methods capture the effects of the different shocks. We first study the effects of productivity shocks, then demand shocks, and finally the effects of both productivity and demand shocks occurring simultaneously.

In Figure 6, negative productivity shocks have been inflicted on the New Keynesian model. The figure compares the output gaps from UUC and MUC 1 with the NK output gap. Table 8 provides a statistical summary of the NK output gap´s relationship with UUC and MUC 1. First, we observe that UUC deviates from the NK output gap to a large degree. The $R^2 = 0.1$ implies that only a minimal amount of the variation in UUC is explained by variations in the NK output gap. There is a negative correlation of -0.32, indicating that a negative productivity shock where the NK model generates a positive output gap, results in a negative output gap in UUC. Therefore, UUC does not adequately estimate the output gap in the case of productivity shocks, as it misinterprets the characteristics of the shocks.

MUC 1 performs relatively better than UUC. However, when observing the second graph in Figure 6, MUC 1 smooths the effect of the productivity shocks when estimating the output gap. The $R^2 = 0.73$ expresses that a substantial part of the variation in MUC 1 is explained by variations in the NK output gap. There is a high positive correlation of 0.86, in which MUC 1 seems to provide a somewhat appropriate output gap in case of productivity shocks. However, MUC 1 seems to overestimate the output gap at the beginning of the estimation sample where the output gap is strongly positive, but appears to underestimate the effects of the productivity shocks in the rest of the sample. In a few instances, MUC 1 provides an output gap of opposite signs of the NK output gap, such that when the output gap is positive in the NK model, MUC 1 provides a negative output gap. This leads us to believe that MUC 1 to some degree misinterprets the effects of productivity shocks when estimating the output gap.

Figure 6: *Output gap from the New Keynesian model, UUC and MUC. Productivity shocks.*

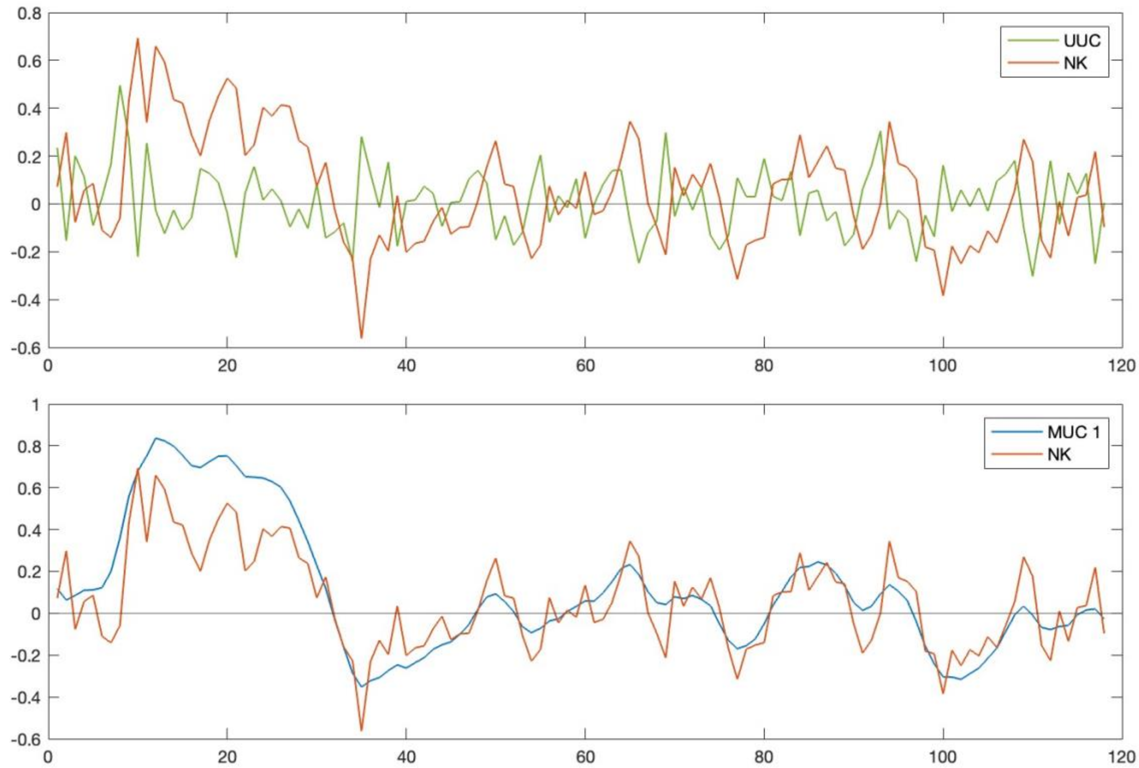


Table 8: *Statistical summary of the relationship between the New Keynesian output gap and output gap estimations. Productivity shock.*

	Correlation	$\boldsymbol{R^2}$
UUC	-0.32	0.1
MUC 1	0.86	0.73

Figure 7 compares the NK output gap with UUC and MUC 1 after the NK model has been hit by negative demand shocks, and Table 9 provides correlation coefficients and R^2 for the models. UUC performs relatively better in the case of demand shocks than for productivity shocks, but the explanatory power remains relatively low at $R^2 = 0.14$. There is a positive correlation of 0.37, indicating that UUC and the NK output gap provide output gaps with the same signs to some extent, but there are some cases where UUC estimates an output gap of the opposite sign than the NK model, especially in the beginning of the estimation sample. This indicates that the UUC in some cases misinterprets demand shocks.

MUC 1 provides a significantly better estimate of the output gap than UUC. By looking at the graphs and taking into account the $R^2 = 0.78$, variations in the NK output gap explain a relatively large amount of the variation in MUC 1. The output gaps seem to follow each other closely from a simple observation of the graph, which is also captured in the high positive correlation of 0.89. However, MUC 1 seems to slightly underestimate the effects of the demand shock in several periods, as we observed in the case of productivity shocks, but overall, the effects of demand shocks are well captured by MUC 1.

Figure 7: *Output gap from the New Keynesian model, UUC and MUC. Demand shocks.*

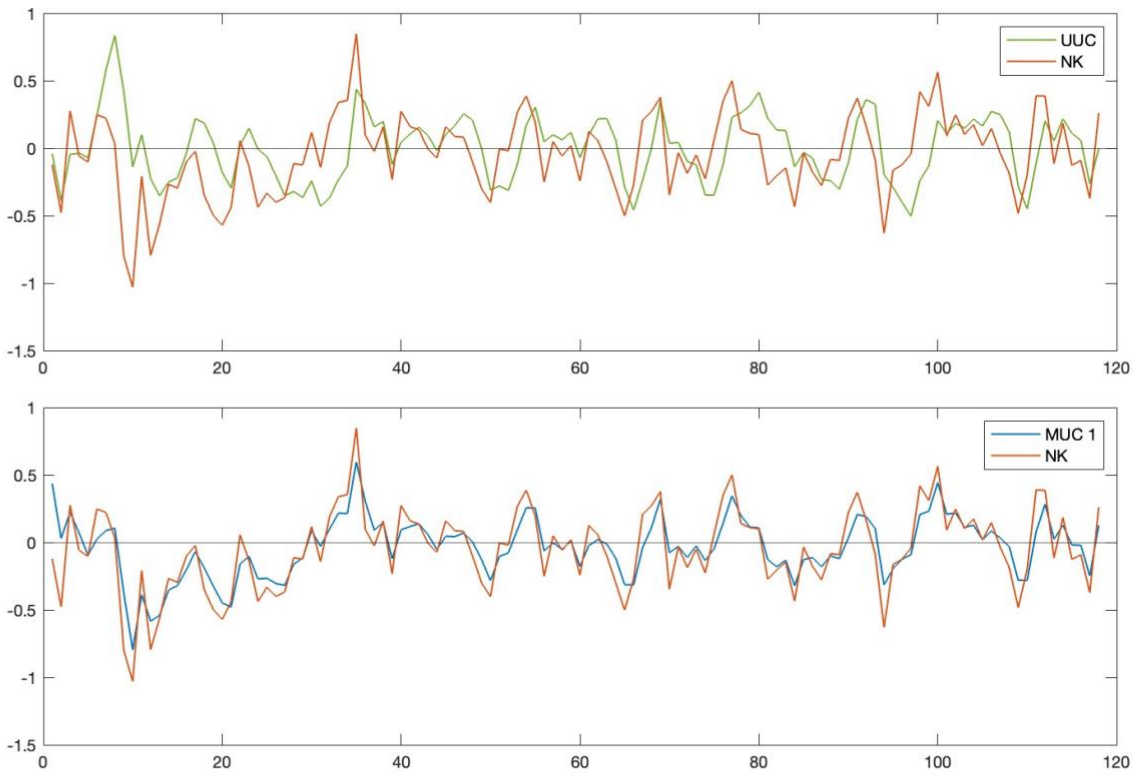


Table 9: *Statistical summary of the relationship between the New Keynesian output gap and output gap estimations. Demand shock.*

	Correlation	$\boldsymbol{R^2}$
UUC	0.37	0.14
MUC 1	0.89	0.78

In Figure 8, the New Keynesian model is hit by both negative productivity and demand shocks simultaneously and Table 10 provides the corresponding correlation coefficients and R^2, which explains the NK output gap´s relationship with UUC and MUC 1. UUC has low explanatory power of $R^2 = 0.006$, as well as a negative correlation of -0.08. Given the framework of the NK model, UUC provides an insufficient estimate of the output gap, which can also be observed from the graph. However, MUC 1 provides a better estimate, with the relatively high explanatory power of $R^2 = 0.7$. The correlation is high and positive with a value of 0.84, implying that MUC 1 interprets many of the shocks in the same way as the NK model. However, MUC 1 provide a smoother output gap than the NK output gap and does not seem to capture the spikes that occur in the NK output gap, which results in the two output gaps having opposite signs in some periods.

Figure 8: *Output gap from the New Keynesian model, UUC and MUC. Demand and productivity shocks.*

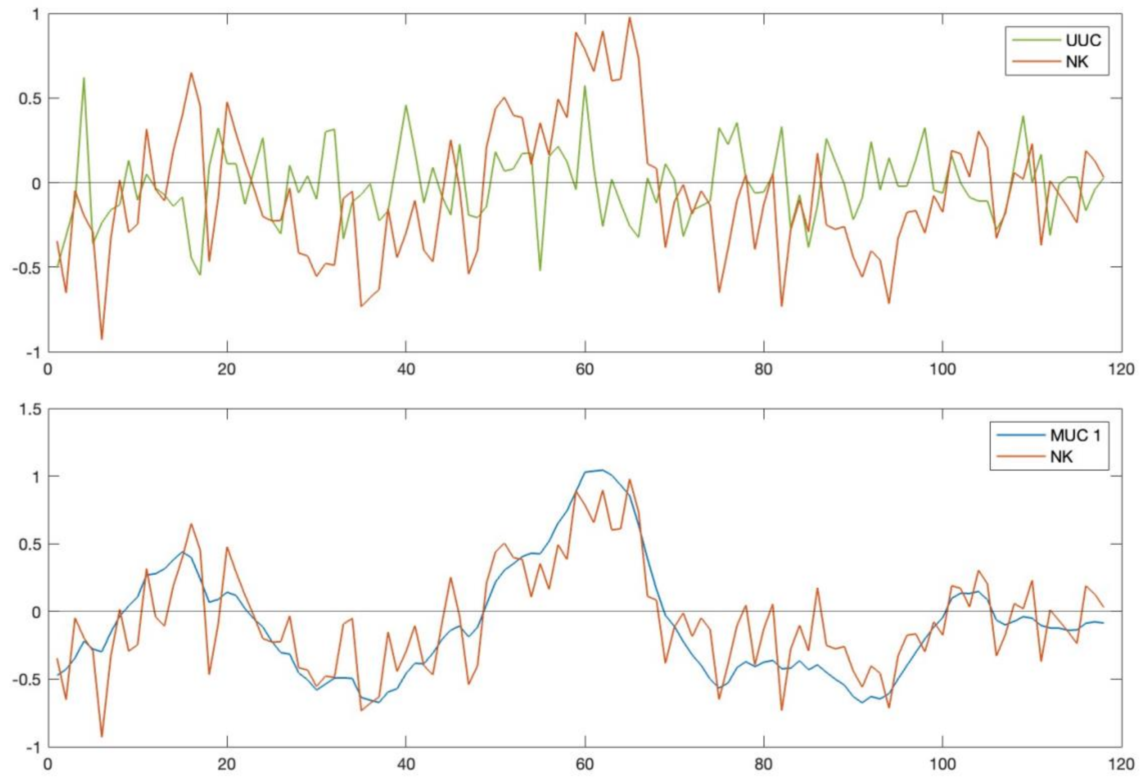


Table 10: *Statistical summary of the relationship between the New Keynesian output gap and output gap estimation methods. Demand and productivity shock.*

	Correlation	R^2
UUC	-0.08	0.006
MUC 1	0.84	0.7

Overall, model UUC can be seen as an insufficient method when estimating the output gap as seen in our simulations. UUC captures the effects of demand shocks to a small degree, but it does not capture the effects of productivity shocks. When combining the effects of both shocks, UUC still performs poorly. However, the poor performance of UUC may come as a result of the fact that the estimation method only considers the variable of actual output, thus leaving out important information about other properties of the discussed shocks.

Moreover, MUC 1 provides significantly better results than UUC when estimating the output gap. MUC 1 generally tends to underestimate the output gap in the case of productivity shocks, and the estimation method seems to smooth the effects of the shocks to some degree. Furthermore, MUC 1 performs better in the presence of demand shocks, as the demand shocks are well captured in the MUC 1 output gap. When combining productivity and demand shocks, MUC 1 performs a little worse than under productivity and demand shocks separately and provides a relatively smooth estimate of the output gap, which does not fully capture the range of the spikes from the NK output gap. As a result, MUC 1 provides opposite signs than what the NK model does, implying that all shocks are not fully captured by the estimation method.

4.2.1 The Effect of Monetary Policy

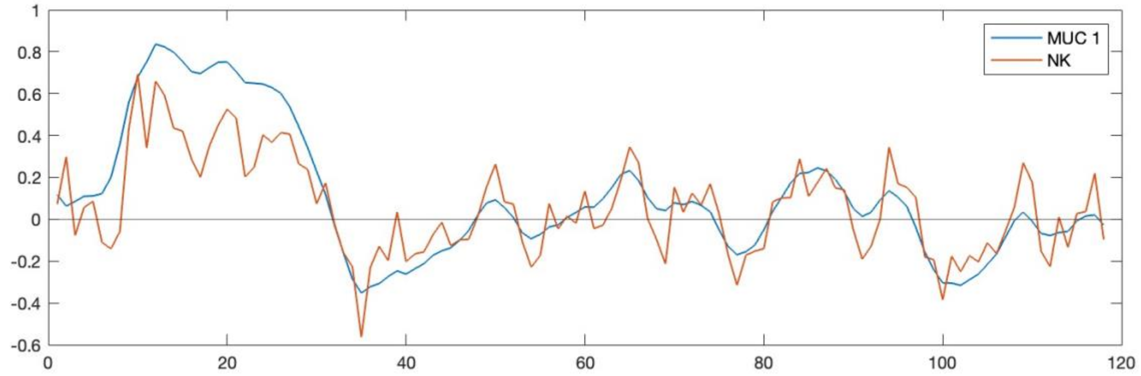
As a robustness test, it is of interest to study the models´ sensitivity to changes in monetary policy by adjusting the coefficients in the Taylor rule. From the Taylor rule, ϕ_π and ϕ_y denote the central bank´s reaction to changes in inflation and the output gap respectively, whereas in the analysis above we use $\phi_\pi = 1.5$ and $\phi_y = 0.125$. The first adjustment entails $\phi_\pi = 3$ and $\phi_y = 0.8$, which implies a relatively high weight on inflation compared to the weight on the output gap, and the second adjustment involves $\phi_\pi = 1.2$ and $\phi_y = 1$, which indicates a relatively low weight on inflation compared to the output gap.

When changing the coefficients of the weights, the UUC output gaps still do not capture the effects of the demand and productivity shocks. Changing the values of the coefficients does not change the UUC output gaps, as the estimates seems to remain the same for all coefficients of ϕ_π and ϕ_y (see Appendix A-Appendix **C**). Therefore, the UUC output gap estimation method is not sensitive to the specification of monetary policy.

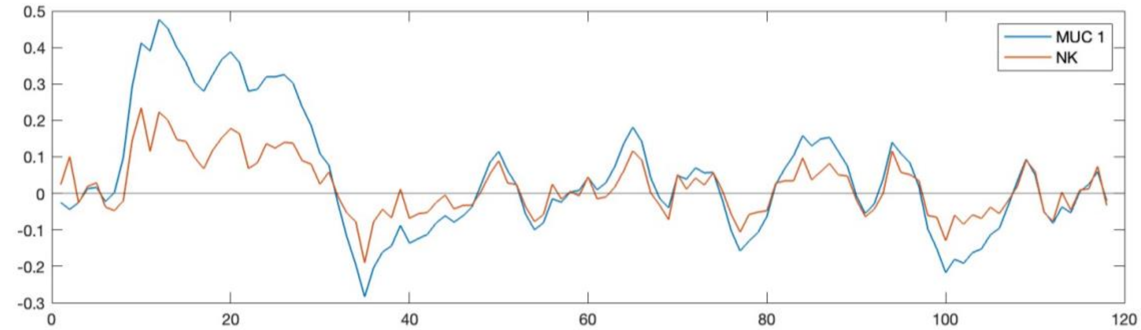
In contrast, changes in monetary policy seem to have a larger effect on the multivariate unobserved components model. When increasing the weight on inflation relative to the output gap in the interest rate rule, MUC 1 in the case of productivity shocks improves, where the correlation increases from 0.86 to 0.93, and R^2 increases from 0.73 to 0.87, presented in Table 11. In the second graph in Figure 9, we observe that MUC 1 follows the spikes in the NK output gap more closely, as a result of the central bank adding more weight and emphasis on stabilizing inflation, but it does seem to overestimate the output gap throughout the estimation period. In contrast, when lowering the weight on inflation relative to the output gap, the correlation and R^2 declines compared to what was observed in the initial case, but not to a significant degree.

Figure 9: *MUC 1 and New Keynesian output gap for different Taylor rule coefficients. Productivity shock.*

$\boldsymbol{\phi_\pi = 1.5}$ **and** $\boldsymbol{\phi_y = 0.125}$



$\boldsymbol{\phi_\pi = 3}$ **and** $\boldsymbol{\phi_y = 0.8}$



$\boldsymbol{\phi_\pi = 1.2}$ **and** $\boldsymbol{\phi_y = 1}$

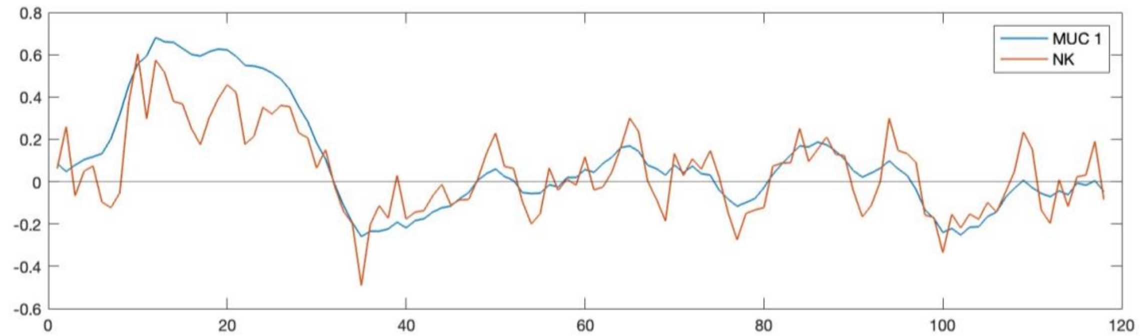


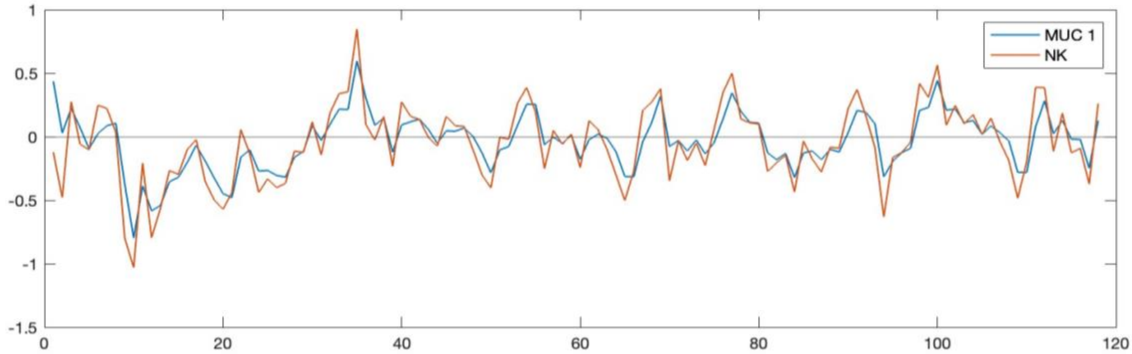
Table 11: *MUC 1 and New Keynesian output gap for different Taylor rule coefficients. Productivity shock.*

	Correlation	$\boldsymbol{R^2}$
$\phi_\pi = 1.5\ and\ \phi_y = 0.125$	0.86	0.73
$\phi_\pi = 3\ and\ \phi_y = 0.8$	0.93	0.87
$\phi_\pi = 1.2\ and\ \phi_y = 1$	0.84	0.7

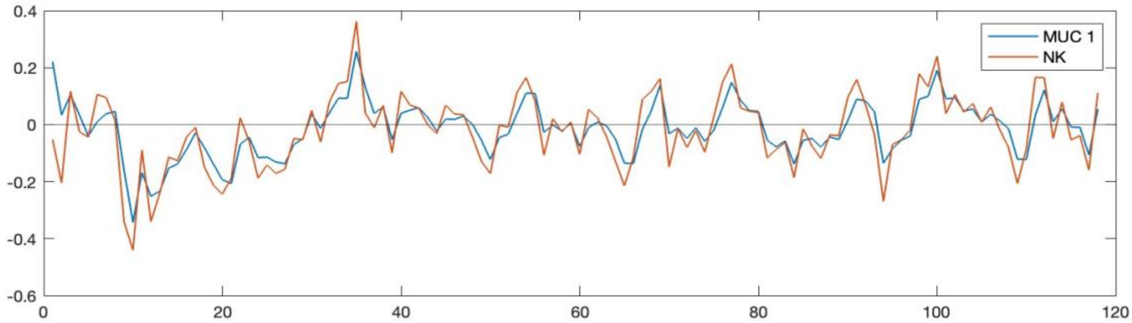
The results from changing the coefficient in the case of demand shocks are presented in Figure 10 and Table 12. There is no significant change in the MUC 1 output gap estimates when the Taylor rule coefficients are changed, implying that the estimation method is not sensitive to changes in monetary policy in the presence of demand shocks.

Figure 10: *MUC 1 and New Keynesian output gap for different Taylor rule coefficients. Demand shock.*

$\boldsymbol{\phi_\pi = 1.5}$ **and** $\boldsymbol{\phi_y = 0.125}$



$\boldsymbol{\phi_\pi = 3}$ **and** $\boldsymbol{\phi_y = 0.8}$



$\boldsymbol{\phi_\pi = 1.2}$ **and** $\boldsymbol{\phi_y = 1}$

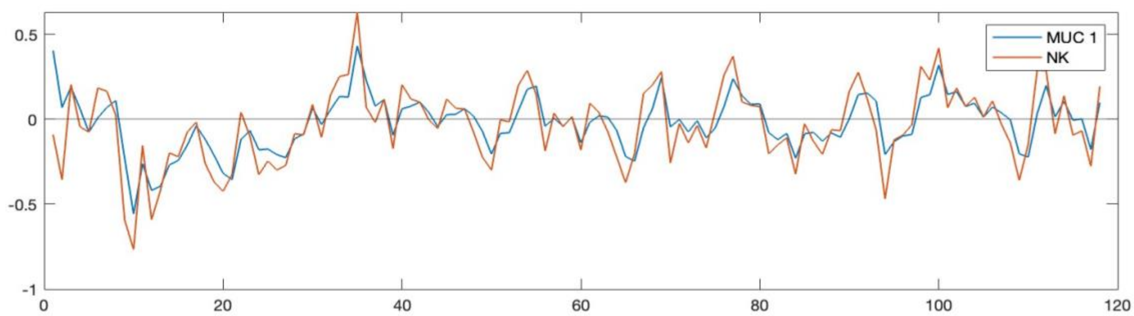


Table 12: *MUC 1 and New Keynesian output gap for different Taylor rule coefficients. Demand shock.*

	Correlation	$\boldsymbol{R^2}$
$\phi_\pi = 1.5\ and\ \phi_y = 0.125$	0.89	0.78
$\phi_\pi = 3\ and\ \phi_y = 0.8$	0.88	0.77
$\phi_\pi = 1.2\ and\ \phi_y = 1$	0.85	0.72

The results of changes in the Taylor rule coefficients on the combined productivity and demand shocks are presented in Figure 11 and Table 13. As a result, MUC 1 does not change much when in the presence of more strict inflation targeting, but when the relative weight on inflation to the output gap decreases, the MUC 1 output gap weakens substantially, as the correlation with the NK output gap becomes negative and R^2 becomes very low. MUC 1 responds substantially more to an easing of inflation targeting than stricter inflation targeting, thus it appears to misinterpret the shocks in the presence of less strict inflation targeting.

Figure 11: *MUC 1 and New Keynesian output gap for different Taylor rule coefficients. Demand and productivity shock.*

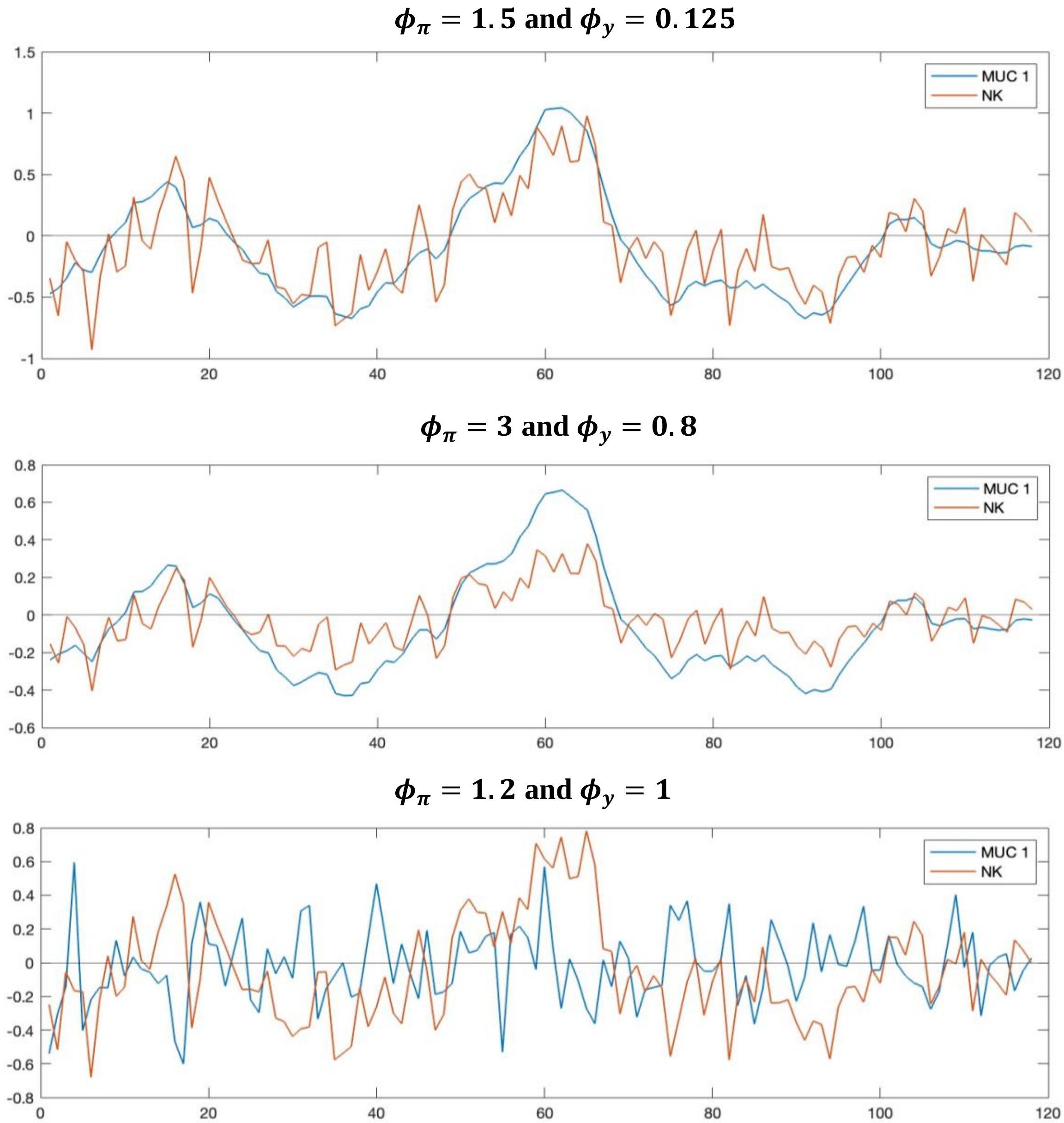


Table 13: *MUC 1 and New Keynesian output gap for different Taylor rule coefficients. Supply and demand shock.*

	Correlation	$\boldsymbol{R^2}$
$\phi_\pi = 1.5$ *and* $\phi_y = 0.125$	0.84	0.7
$\phi_\pi = 3$ *and* $\phi_y = 0.8$	0.83	0.69
$\phi_\pi = 1.2$ *and* $\phi_y = 1$	-0.13	0.02

Overall, MUC 1 is especially sensitive to changes in monetary policy in the presence of productivity shocks, where stricter inflation targeting results in an output gap that is more in line with the NK output gap. On the contrary, MUC 1 is not significantly sensitive to changes in monetary policy when the economy is subject to demand shocks. When the two shocks occur simultaneously, stricter inflation targeting does not have a significant effect on the MUC 1 output gap, but when the inflation targeting is eased, MUC 1 seems to misinterpret the effects of the shocks.

5 Discussion

The estimated output gaps for the Norwegian economy show that despite using several different estimation methods, the results we obtain are quite similar, shown by the strong positive correlation between the output gap estimates. However, the multivariate unobserved component model 3 differs from the other estimates mainly because it uses annual data and real wages in the estimation, whereas the others do not. During the pandemic, the output gaps were estimated as strongly negative, indicating that the methods interpret the Covid-19 pandemic as a significant negative demand shock. By studying the average values of the output gap estimates, which are close to zero for all estimates, they all fulfill the criterion of averaging around zero, indicating that the estimates are reasonable. Still, we are not able to use standard deviations of the output gaps to determine their reasonability, as we do not have a reference point of what the standard deviations should be in this situation. Therefore, we see it relevant to use the results from the simulated New Keynesian model to conclude.

When studying the impulse response functions from the New Keynesian model in the presence of a negative productivity shock, both actual and potential output are expected to fall as a result of the pandemic, where the latter would experience the most significant decline. This would result in a positive output gap in the model, as the model assumes nominal rigidities. Therefore, as society was shut down, the negative productivity shock in isolation is expected to cause the output gap to be positive. On the contrary, the impulse response function from the negative demand shock would indicate a significant fall in actual output, while potential output would be unaffected. The large decline in the demand for goods and services during the pandemic would therefore result in a negative output gap when exclusively observing a demand shock.

Furthermore, we used the simulated data from the New Keynesian model, where shocks are induced every period. We applied the univariate unobserved component model (UUC) and multivariate unobserved component model 1 (MUC 1) to the simulated data. UUC captures the effects of demand shocks to a small degree but misinterprets productivity shocks to a large degree when estimating the output gap. Therefore, UUC provides an insufficient estimate of the output gap in the presence of both productivity and demand shocks. In contrast, MUC 1 provides significantly better results of the output gap than UUC. In the case of productivity shocks to the model, the MUC 1 output gap follows the New Keynesian output gap for the most part. Still, it tends to underestimate the productivity shocks´ effects on the output gap in the majority of the estimation sample. Furthermore, MUC 1 does not capture the shocks to their full extent, as it provides a smoother output gap relative to the New Keynesian output gap. However, the model performs better in the presence of demand shocks, but has a tendency to underestimate the range of the shocks, but this effect is significantly larger for productivity shocks. When productivity and demand shocks occur simultaneously, we obtain a smooth output gap relative to the New Keynesian output gap, which also results in MUC 1 having the opposite sign of the New Keynesian output gap in some periods. Considering that MUC 1 seems to smooth out productivity shocks, the effect of significant and sudden changes in productivity is not captured to its full extent in the output gap. Therefore, MUC 1 seems to work well in normal business cycles but does not perform as well when sudden and large productivity shocks occur. In a situation such as the Covid-19 pandemic, there is a possibility that this estimation method will dampen some of the effects that the negative productivity shock has on the output gap. Additionally, MUC 1 subject to productivity shocks is sensitive to the specification of monetary policy, where the outcome of the estimation method is dependent on how strict the practice of inflation target is, whereas stricter inflation targeting provides better results for MUC 1 in light of the New Keynesian output gap. On the contrary, MUC 1 in the presence of demand shocks is not significantly sensitive to the specification of monetary policy, indicating that the estimation method captures demand shocks well despite changes in the Taylor rule coefficients.

6 Conclusion

To conclude, we believe that the output gap estimation methods presented in Furlanetto et al. (2023) misinterpret the effects of large and sudden productivity shocks when estimating the output gaps. Thus, using these estimation methods to estimate the output gap during the pandemic is not sufficient, as it does not take into account the degree of the sudden reduction in potential output due to the social and economic shutdowns, implying that these estimation methods struggle to interpret supply-side shocks. However, we have only studied this effect on the UUC and MUC 1, and we cannot rule out that other methods can potentially provide more adequate estimates of the output gap in the case of productivity shocks. Therefore, to obtain reasonable output gap estimates during the pandemic, we see it as beneficial to apply similar methods to those of Grgurić et al. (2021) by expanding the univariate and multivariate methods by decomposing the fall in GDP into a productivity and demand shock.

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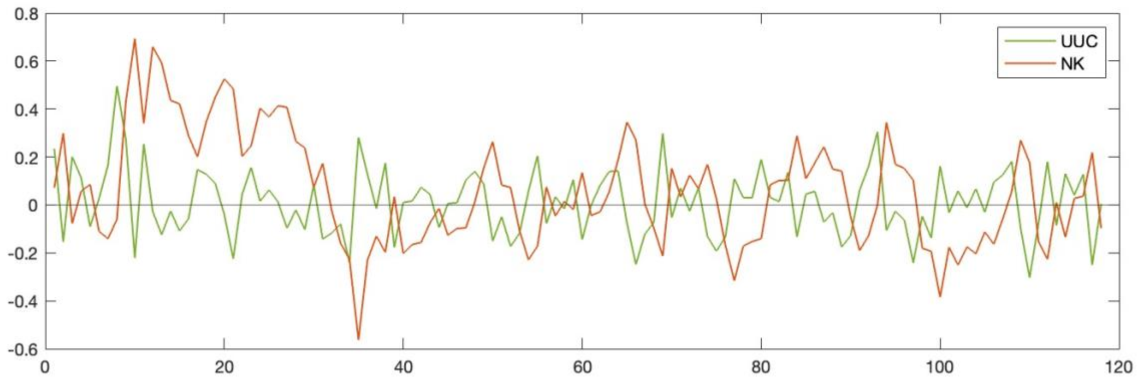
8 Tables

9 Figures

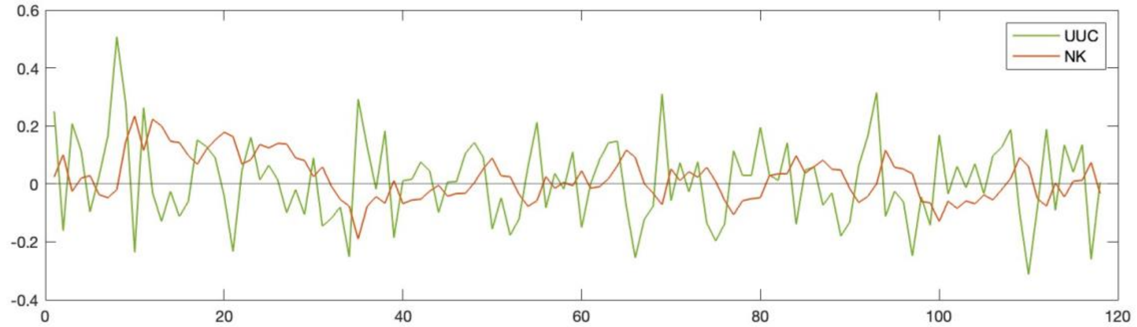
10 Appendix

Appendix A: *UUC and New Keynesian output gap for different Taylor rule coefficients. Productivity shocks.*

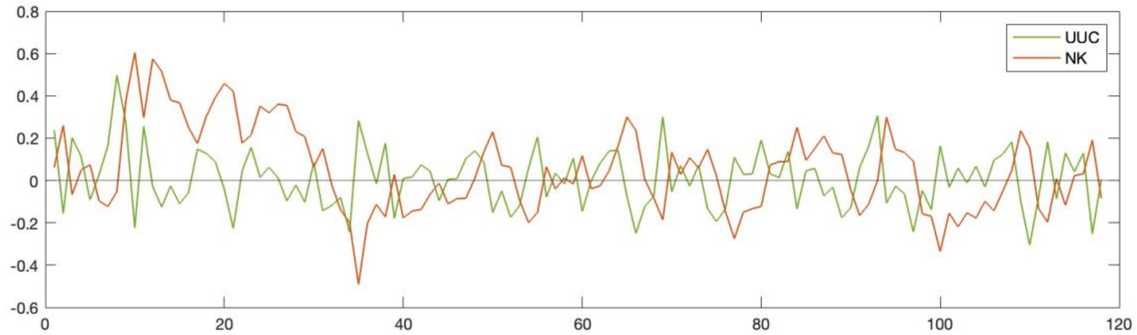
$\boldsymbol{\phi_\pi = 1.5}$ **and** $\boldsymbol{\phi_y = 0.125}$



$\boldsymbol{\phi_\pi = 3}$ **and** $\boldsymbol{\phi_y = 0.8}$



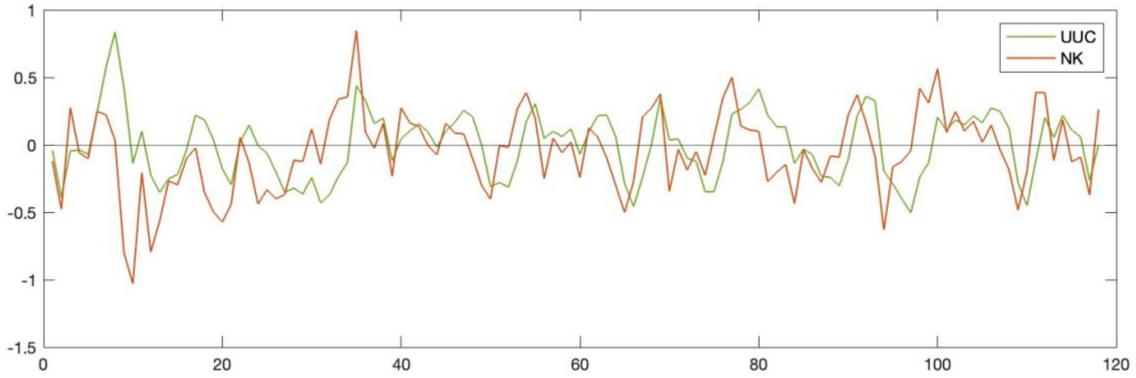
$\boldsymbol{\phi_\pi = 1.2}$ **and** $\boldsymbol{\phi_y = 1}$



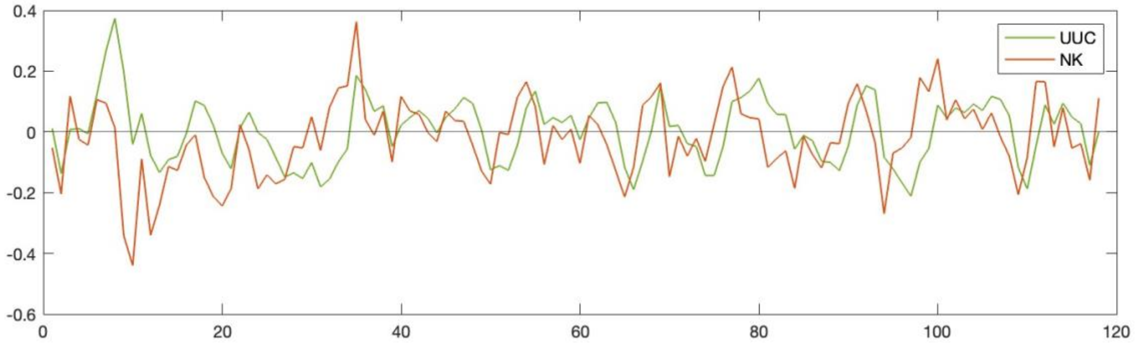
	Correlation	$\boldsymbol{R^2}$
$\boldsymbol{\phi_\pi = 1.5}$ **and** $\boldsymbol{\phi_y = 0.125}$	-0.32	0.1
$\boldsymbol{\phi_\pi = 3}$ **and** $\boldsymbol{\phi_y = 0.8}$	-0.32	0.1
$\boldsymbol{\phi_\pi = 1.2}$ **and** $\boldsymbol{\phi_y = 1}$	-0.32	0.1

Appendix B: *UUC and New Keynesian output gap for different Taylor rule coefficients. Demand shocks.*

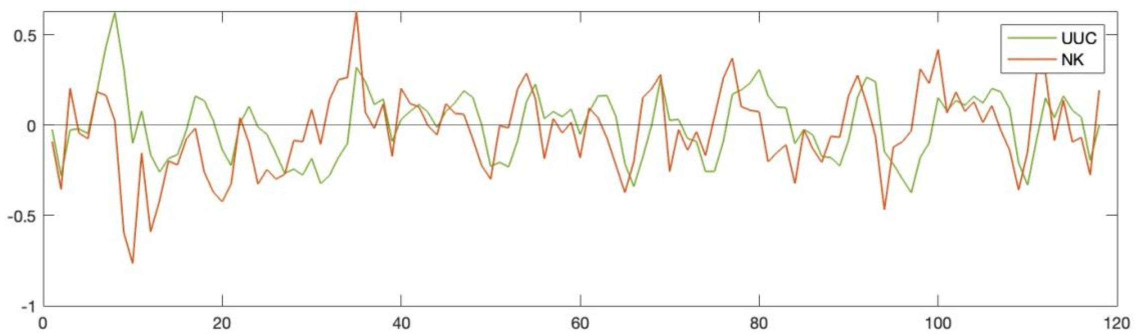
$\boldsymbol{\phi_\pi = 1.5}$ **and** $\boldsymbol{\phi_y = 0.125}$



$\boldsymbol{\phi_\pi = 3}$ **and** $\boldsymbol{\phi_y = 0.8}$



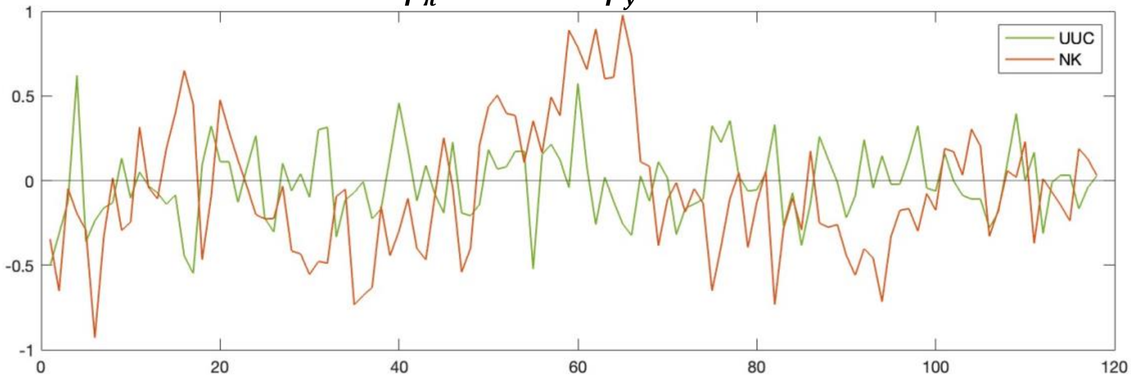
$\boldsymbol{\phi_\pi = 1.2}$ **and** $\boldsymbol{\phi_y = 1}$



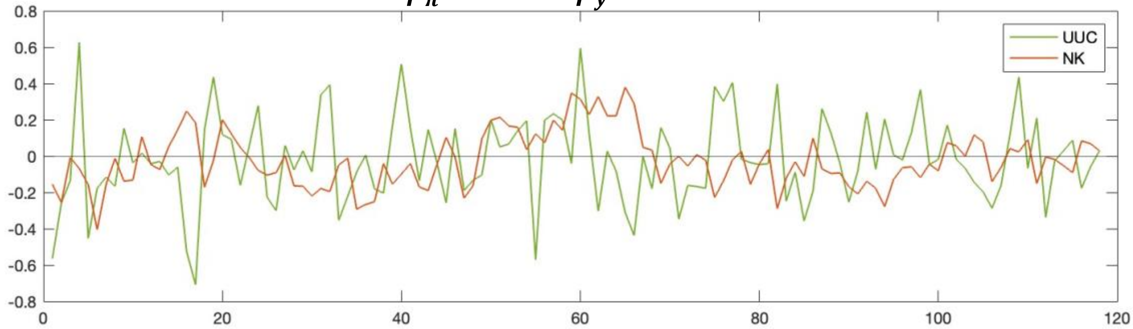
	Correlation	$\boldsymbol{R^2}$
$\boldsymbol{\phi_\pi = 1.5}$ **and** $\boldsymbol{\phi_y = 0.125}$	0.37	0.14
$\boldsymbol{\phi_\pi = 3}$ **and** $\boldsymbol{\phi_y = 0.8}$	0.35	0.12
$\boldsymbol{\phi_\pi = 1.2}$ **and** $\boldsymbol{\phi_y = 1}$	0.37	0.14

Appendix C: *UUC and New Keynesian output gap for different Taylor rule coefficients. Productivity and demand shocks.*

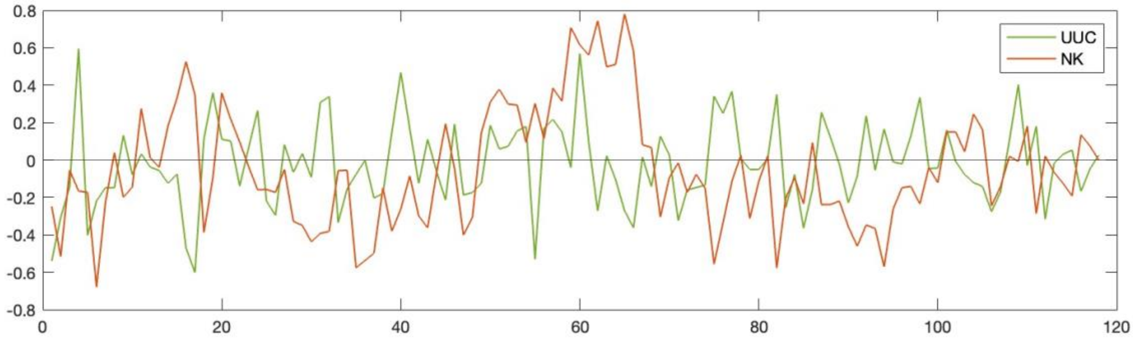
$\phi_\pi = 1.5$ and $\phi_y = 0.125$



$\phi_\pi = 3$ and $\phi_y = 0.8$



$\phi_\pi = 1.2$ and $\phi_y = 1$



	Correlation	R^2
$\phi_\pi = 1.5$ and $\phi_y = 0.125$	-0.008	0.006
$\phi_\pi = 3$ and $\phi_y = 0.8$	-0.11	0.01
$\phi_\pi = 1.2$ and $\phi_y = 1$	-0.13	0.02