University of Oslo

Faculty of Social Science

Department of Economics

# Monetary Policy and Norwegian Housing Prices: An Empirical Analysis

Sara Midtgaard

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# Monetary Policy and Norwegian Housing Prices:
# An Empirical Analysis

*Does centrality play a role in the transmission of monetary policy shocks to Norwegian housing prices?*

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# Abstract

The historically high housing prices in Norway are known for being among the greatest threats to financial stability, and therefore also the macroeconomic stability. Furthermore, one of the key driving factors of housing prices is the interest rate. This thesis aims to understand what role centrality plays in the transmission of monetary policy to Norwegian housing prices. Using panel data methods on a data set for 45 municipalities in Norway over the period 2003 Q1 – 2017 Q4, I analyze the response to housing prices in different regions of Norway. The approach used is local-projection methods developed by Jordà (2005). I identify monetary policy shocks using a narrative shock series constructed by Holm et al. (2019). My results demonstrate a marked difference in the short-run response of housing prices to a monetary policy shock in the most central areas - versus the least central areas in the panel data. Oslo stands out from the rest of the municipalities: the additional effect of a monetary policy shock in Oslo is estimated to be 7 percent after one year and 9.5 percent after two years. The effect of monetary policy on housing prices for the areas that are not defined as the most, or least central, is relatively similar. In the long run, housing prices in all municipalities are affected by the shock, but with different orders of magnitude.

# Preface

This master thesis represent the end of my studies at the University of Oslo. I am grateful for all the years at the Department of Economics and all the knowledge, people and experiences that have followed through.

The greatest acknowledgment is to my supervisor, André Kallåk Anundsen, for introducing me to the topic and being an excellent supervisor. His support, insightful comments and suggestions have been indispensable. Also, thanks to Erling Røed Larsen for giving me the experience writing my master thesis for Housing Lab.

I am grateful for all my fellow students that made the years at the university unforgettable and to my family and friends for their great support.

During the last years, I have been fortunate to work at Norges Bank. I want to thank them for supplying me with necessary microdata.

Although my master thesis was written during my time working for Norges Bank, all the views of this thesis are my own and do not necessarily reflect those of Norges Bank. Any remaining errors are solely my responsibility.

Oslo, November 2019
Sara Midtgaard

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# 1. Introduction

The functioning of the housing market is important for the macroeconomy and for financial stability considerations. It is also important when discussing whether central banks should use the interest rate to enhance financial stability, thereby, also economic stability (Aastveit & Anundsen, 2017). This thesis will answer the following research question: *Does centrality play a role in the transmission of monetary policy shocks to Norwegian housing prices?*

Why is this an important question to answer? One of the key vulnerabilities in the Norwegian financial system is the historically high level of housing prices (Norges Bank, 2018).[1] It is well known that high levels of housing prices is great risk for macroeconomic and financial stability (Lindquist & Riiser, 2018). Earlier literature proves that one of the main driving factors of housing prices is the interest rate (Jacobsen & Naug, 2005). According to a survey conducted by Williams (2015), a one-percentage point increase in the interest rate leads to a 6 percent decline – on average across studies – in housing prices, after two years. Housing prices in Norway and debt are closely related (Anundsen & Jansen, 2013). Anundsen and Mæhlum (2017) analyzed the regional differences in housing prices and debt in Norway, and concluded that debt-to-income was higher in the cities compared to the districts. Keeping in mind that 90 percent of Norwegian households live in urban areas (Kommunal- og moderniseringsdepartementet, 2018), and the fact that housing is the most valuable asset of most households in Norway (Statistics Norway, 2019) [2] – centrality is an important aspect to consider when analyzing the effect of monetary policy to the housing prices.

A fall in housing prices will reduce the equity of household, which in turn may affect consumption. Mian, Rao and Sufi (2013) highlight the role of debt and wealth shocks in explaining the decline in consumption in United States from 2006 to 2009, and show that there is a substantial housing wealth effect on consumption. Bostic, Gabriel and Painter (2009) found significant results of changes in housing wealth on household consumption for

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[1] Financial Stability Report 2018: vulnerabilities and risk.

[2] Housing account for about sixty-six percent of total household wealth in 2017 (Statistics Norway, 2019).

US. Furthermore, the empirical findings in Aron, Duca, Muellbauer, Murata and Murphy (2012) highlight the importance of credit constraints for consumer spending in the UK, the US and Japan. A drop in housing prices also affects important economic variables, such as default rate on mortgages (Carrillo, Doerner & Larson, 2018). Developments in the housing market are therefore important for the macroeconomy and financial stability, see also the discussion in Muellbauer (2015).

Leamer (2007) and Leamer (2015) found that drops in housing investments makes out a strong leading indicator for future recessions in the US. Similar results have been established in a panel of countries by Aastveit, Anundsen and Herstad (2019b). In addition, Anundsen, Gerdrup, Hansen and Kragh-Sørensen (2016) found that booms in credit to both households and non-financial enterprises are important for evaluating the stability of the financial system. It is therefore of paramount interest to understand what are the most important factors affecting housing prices, given that housing and credit markets are tightly interconnected.

Since the interest rate is one of the most important driving factors of housing prices, it is important to quantify the relationship between monetary policy and housing prices. In general, the research on this topic is popular and investigated for several other countries. Recent research like Jordà, Schularick and Taylor (2015), used local projection methods to analyze the link between the monetary conditions, credit growth and house price booms. When applying the method to a panel of 17 counties, they found that changes in monetary policy has significant and persistent effect on real housing prices. Research with VAR models have been heavily used to analyze the transmission of monetary policy shocks to the housing market; see Del Negro and Otrok (2007) and Dokko et al. (2009). Williams (2015) survey several papers looking at the effect of monetary policy on housing prices, and conclude that there is a significant and economically important effect of monetary policy on housing prices, both across countries and over time.

According to Statistics Norway (2017), 83 percent of all Norwegian household live in a self-owned accommodation. Furthermore, compared to other countries (e.g., the US), relatively many Norwegians have floating interest rates on their mortgages (Almklov, Tørum & Skjæveland, 2006). It is therefore reasonable to expect that the monetary policy have an even greater impact on Norwegian housing prices, compared to countries with mostly fixed-rate mortgages. According to Bjørnland and Jacobsen (2010), monetary policy has strong effects on the housing prices - but the effect differs between countries and time horizons; for instance, the effect is greater in Norway and UK than in Sweden.

Nevertheless, research on the nexus between monetary policy and regional housing prices in Norway is scarce. No research, to the best of my knowledge, have explored the role centrality plays in the transmission mechanism of monetary policy to the housing market. Still, it is reasonable to believe that housing supply differs between regions in Norway, depending on centrality. First, the supply elasticity has a significant role in how monetary policy affect housing prices, shown in Aastveit and Anundsen (2017) and Aastveit, Albuqerque and Anundsen (2019a), using data the US. Their results shows that monetary policy affects housing prices significantly more when housing supply is inelastic. Second, since house price levels differ – it follows that debt levels also differ. This is because most housing purchases are debt-financed. For this reason, the interest rate burden varies across regions, which could affect the responsiveness of housing prices with respect to the interest rate.

In order to analyze whether centrality plays a role in the transmission of monetary policy to the housing market, I will start with a short presentation of the Norwegian housing market in Section 2, followed up by the theoretical motivation for the thesis in Section 3. Section 4 will present the data used in the model. In order to estimate the expected housing price change followed by a monetary policy shock, I use the local projection method developed by Jordà (2005). Empirical results are presented in Section 6, followed by discussion and conclusion. The statistical software used in order to analyze the research question is STATA (SE version15).

# 2. The Norwegian Housing Market and the Role of Centrality

## 2.1 A Brief Look at the Norwegian Housing Market

Housing prices in Norway have increased rapidly since 1992 and they are on historically high levels (Statistics Norway, 2019). During the period from 1992 to 2018, housing prices have grown by more than 500 percent in nominal terms, whereas CPI inflation has been around 70 percent over the same period. The price growth has been particularly high in Oslo, where the nominal growth has been an astonishing 830 percent. Figure 2.1 shows the development in housing prices from 2003 to 2019 for Norway and some of its larger cities (Oslo, Bergen, Trondheim and Stavanger). In the period of 2013 to 2015, the growth rate was higher in the cities compared to the rest of Norway. Especially the growth in Stavanger and parts of Rogaland and Agder were on high levels compared to all the other cities, but decreased mid-2015 after many years with a high growth (Statistics Norway, 2019). This must be seen in relation to the negative oil price shock hitting the Norwegian economy, since the local economy of Stavanger is more exposed to oil price movements than for instance Oslo. Because of the oil price shock, Stavanger was difficult to include in the analysis. This is because the response of housing prices was so high and the relation to the key interest rate did not make economic sense. Therefore, Stavanger is excluded from the analysis.

Figure 2.1: The development in the regional housing prices and the key interest rate. January 2003=100. 2003 Jan. – 2019 May.

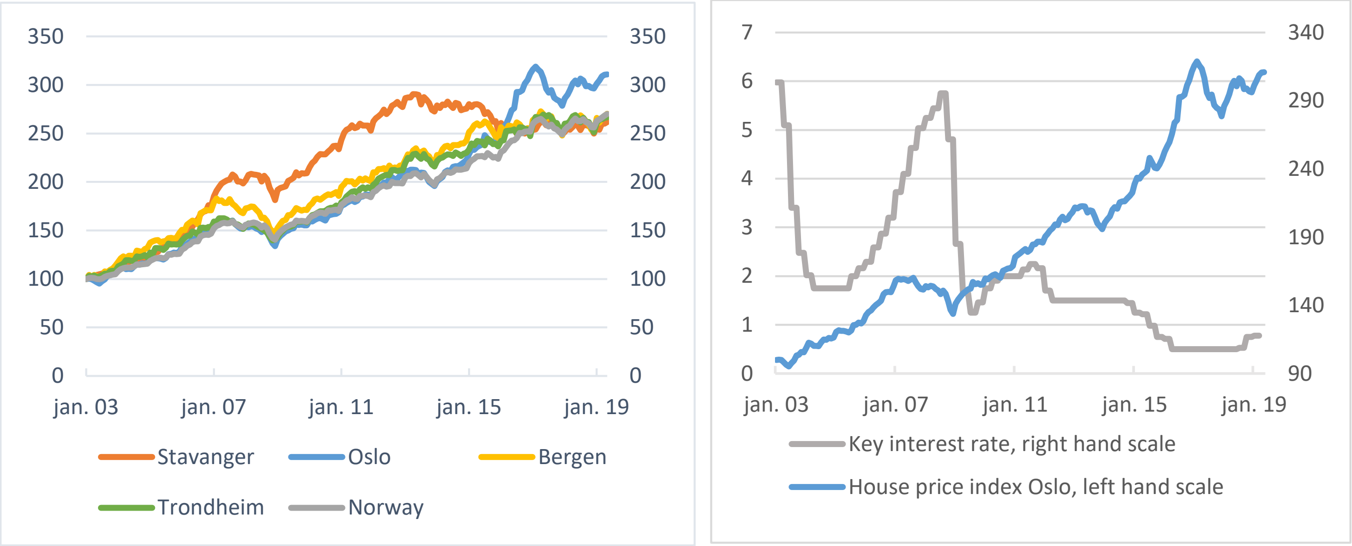

Figure 2.1a Housing price index.

Figure 2.1b Key interest rate and Oslo house price index.

Sources: Norges Bank and Eiendom Norge

Figure 2.1b illustrates the relation between the key interest rate and developments in housing prices in Oslo between January 2003 and May 2019. The correlation is clearly negative. Especially since mid-2010 until today – where the interest rate have been historically low and the level of the housing prices in Oslo is historically high.

Housing price growth, and the corresponding debt growth, is important for the evaluation of the macroeconomy and for financial stability. Financial intermediaries give credit to households depending on their debt-servicing capacity and their collateral – meaning that credit becomes more available when housing prices soar since the households' net worth increases. For this reason, the housing price growth and credit growth are highly correlated and make households more vulnerable to macroeconomic shocks. This pro-cyclical pattern can build up the financial instability in the economy.

Anundsen and Jansen (2013) highlighted the role that financial deregulation played in the Norwegian banking crisis erupting in 1988. The housing market was relatively stable trough out the 1970s.[3] During this time period, regulation was holding back growth in housing prices and credit. When the housing market and credit regulations were lifted in 1982[4], housing prices increased by about 20 percent between 1984 – 1988 (Anundsen & Jansen, 2013). The deregulation of credit market allowed banks to expand their mortgage lending – resulting in a boom in the real estate market. The Norwegian Banking Crisis started in 1988 and ended the booming developments in housing prices. At this time, Norwegian banks started to experience increased losses on loans, leading to net losses, followed by a market collapse. As a consequence of the crisis, the government needed to take ownership of some of the largest banks and they were forced to close down (Krogh, 2010). The bank crisis lasted until 1993.

In the ensuing period, Norwegian housing pieces grew rapidly until the financial crisis of mid-2008. That said, the drop in housing prices during the financial crisis was more modest than during the banking crisis of the late 1980s, see Figure 2.1a. One reason for this may be Norges Bank’s extraordinary measures to secure liquidity in the banking sector, in addition, the Norwegian banking sector had little exposure to sub-prime mortgages in the US (Krogh, 2010). The period after the financial crisis has involved expansionary monetary policy – which have boosted housing prices growths and credit growth in Norway, see Figure 2.1 b.

## 2.2 The Role Centrality Plays in the Norwegian Housing Market

About 90 percent of the Norway population lives in urban areas. Also, most of the economic activity is in the central regions (Kommunal- og moderniseringsdepartementet, 2018). Therefore, a fall in housing prices in the most central areas would have a large impact on total household wealth in Norway.

The growth of households is highest in the central areas, whereas population growth is declining in the rural municipalities (Syse, 2018). This can be related to the migration

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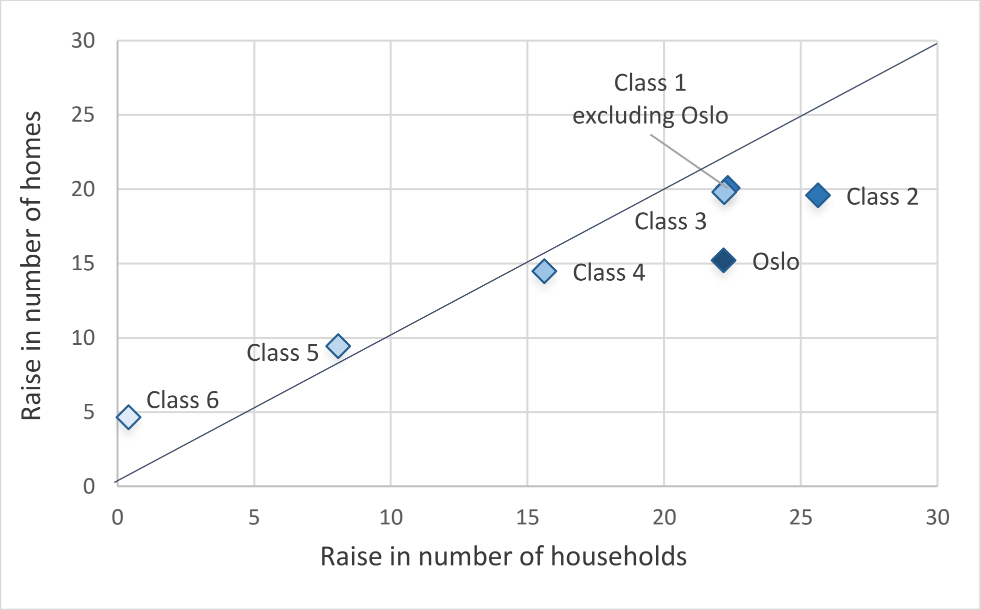
[3] The housing market were mostly stable in the 1970s, except from 1978 and 1979 when the after-tax interest being negative.

[4] The credit market where deregulated the whole period of the 1980s.

patterns the last years. For this reason, the cities are still growing. Figure 2.2 illustrates the growth in the number of households relative to the growth in the number of housing units. The relative growth in the most central areas is much higher compared to the districts, especially Oslo. This may be indicative of a scarce housing supply in the cities, relative to non-central areas.

Figure 2.2: Rise in number of households and houses, sorted by centrality classes[5]



Sources: Norges Bank[6] and Statistics Norway.

Figure 2.3 illustrates the evolution of the debt level[7] per household relative to Statistics Norway centrality index[8]. The debt level is clearly higher in the most central areas, compared to the districts. This is in line with Anundsen and Mæhlum (2017), who show that debt-to-income ratios are higher in the cities, and it means that households in the most central areas spend more of their income on housing. Therefore, households in the most central areas are

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[5] Statistics Norway centrality index where municipalities is ranged after centrality. Centrality is measured by the distance to working places, daily basis needs like stores and services. The index can take value from 0 to 1000 where a high number indicate a central area. The centrality index is explained more in detailed in Section 3.

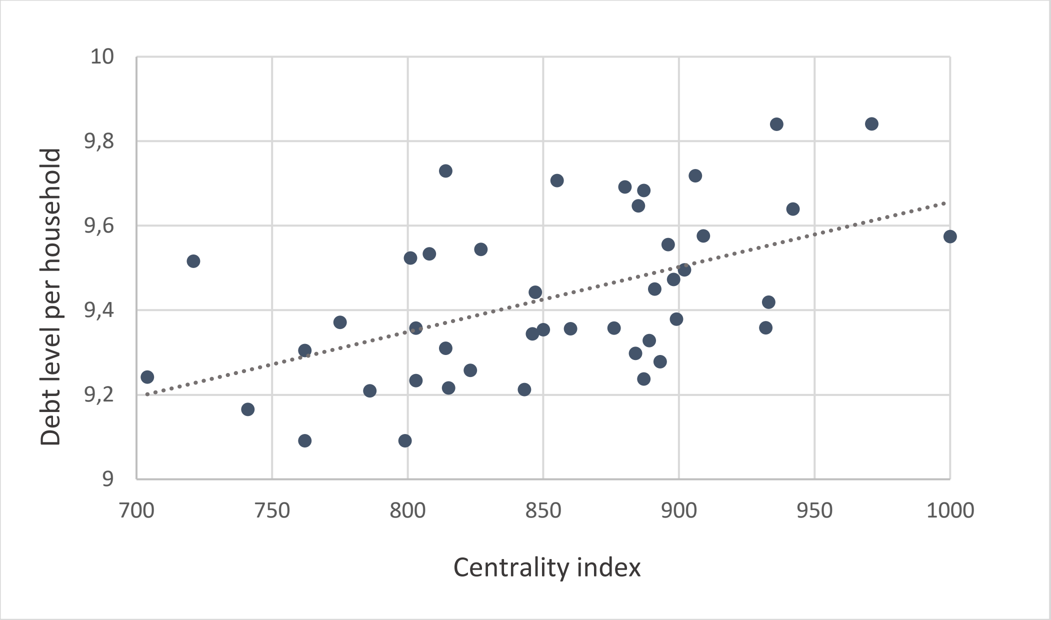
[6] Figure 3.3.1 is taken form Norges Bank (2019).

[7] The data on average debt collected from Norges Bank is received from Statistics Norway. The debt level is per household in logarithmic scale and inflation adjusted.

[8] Same centrality index as in Figure 3.3.1. Statistics Norway centrality index where municipalities is ranged after centrality, where 0 is the least central and 1000 is the most central.

more vulnerable to interest rate and income shocks. If household’s willingness-to-pay is related to their ability to pay, households in more central areas are expected to respond stronger to a given change in the key interest rate than households living in districts. Thus, there are reasons to believe that centrality plays a role in the response of housing prices to monetary policy changes.

Figure 2.3 Debt level per household and centrality index. 2017 Q4



Sources: Norges Bank and Statistics Norway

# 3. Theoretical Motivation

Why should one believe that the functioning of the housing market differ from one region to another? The answers are in the underlying mechanisms working on the supply and the demand side of the housing market. In this section, I will consider a simple demand-supply model for house price determination. The housing market is heterogeneous and differs in size, location, quality etc. These attributes will affect the value of a house. The attributes are "cleaned out" in the house price index used in my analysis, and can therefore be interpreted as the price development as a whole.[9] Then, supply and demand mechanism will be essential in analyzing the driving factors of housing prices. Also, I will present the model by Anundsen and Jansen (2013), explaining how housing demand and supply is determined.

## 3.1 Housing Demand

According to Jacobsen and Naug (2004), household demand is either for investment purposes or consumption purposes. In addition, there are two ways to consume housing services – either renting or owning. In Norway, demand for housing is mostly related to home purchases (NOU 2002: 2).

Following Jacobsen and Naug (2005) and Anundsen and Jansen (2013), I take as a starting point the commonly used life-cycle model for housing to represent the demand side of the housing market, see, Muellbauer and Murphy (1997, 2008) and Meen (2001, 2002). Several papers, see e.g. Anundsen and Jansen (2013), Meen (1990), or Meen and Andrew (1998), capture the presence of credit constraints. Solving the optimization problem implied by the life-cycle model of housing, the marginal rate of substitution (MRS) between consumption of housing and consumption of other goods can be expressed as:

$$MRS = \frac{U_H}{U_C} = PH_t[(1-\tau_t)i_t - \pi_t + \delta_t - \frac{\dot{PH}_t^e}{PH_t} + \frac{\lambda_t}{\mu_c}] \qquad (3.1)$$

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[9] The house price index from Eiendom Norge is estimated by using a hedonic regression model. They include attributes like size, location, number of floors etc.

Where $PH_t$ is real housing prices, $\tau_t$ is the marginal tax rate on equity income, $\pi_t$ is the annual CPI-inflation rate, $i_t$ is the nominal interest rate, $\delta_t$ is the depreciation rate and $\frac{\dot{PH}_t^e}{PH_t}$ is the expected real rate of housing price appreciation. $\mu_c$ is the marginal utility of consumption and $\lambda_t$ is the shadow price of the credit constraint. The interpretation of equation 3.1 is what a household is willing to give up of consumption of other goods in order to consume one more unit of housing, should be equal to what it costs. According to the specification, a change in the interest rate affects consumption of housing negatively.

Furthermore, an efficient market implies that there are no arbitrage opportunities. That means; the user cost of owning a house should be equal to the cost of renting a house. According to Anundsen and Jansen (2013), the following no-arbitrage relationship holds:

$$PH_t = \frac{Q_t}{(1-\tau_t)i_t-\pi_t+\delta_t-\frac{\dot{PH}_e}{PH_t}+\frac{\lambda_t}{\mu_c}} \qquad (3.2)$$

Where $Q_t$ represents the real imputed rental price for housing services. Equation 3.2 can be interpreted as an inverted housing stock demand function, see Meen (2002). From now, I will assume a constant depreciation rate. Following Anundsen and Jansen (2013), $Q_t$ is assumed to be a function of real disposable income for the household sector (excluding dividends) $YH_t$, in addition the stock of houses $H_t$. The inverted demand function can be expressed:

$$PH_t = f^*(H_t, YH_t, R_t, \frac{\dot{PH}_t^e}{PH_t}, \frac{\lambda_t}{\mu_c}) \qquad (3.3)$$

Where $R_t$ is the after tax interest rate.

The determination of a long-run equilibrium level of real housing prices at an aggregate level will be the following specification:

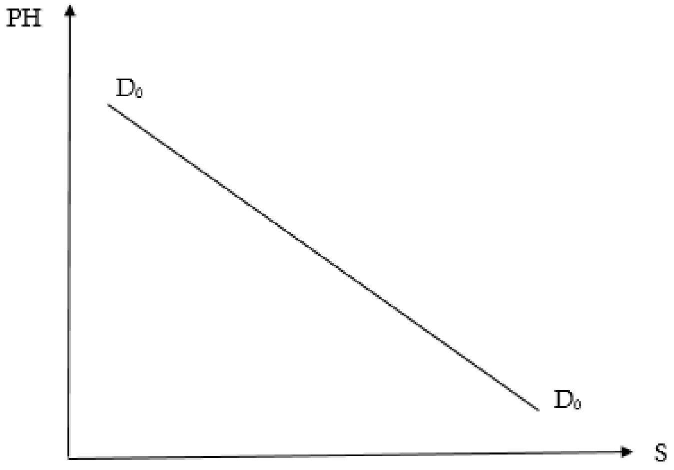
$$PH_t = f(H_t, YH_t, R_t, D_t) \qquad (3.4)$$

Where $D_t$ is real household debt and the partial derivatives[10]: $\frac{\partial f}{\partial H} < 0, \frac{\partial f}{\partial YH} > 0, \frac{\partial f}{\partial R} < 0, \frac{\partial f}{\partial D} > 0$. Equation 4.4 show the market clearing condition for any given level of housing stock.

## 3.2 Housing Demand Function

As the price of a house decreases, the quantity demanded increases. It is reasonable to assume that housing is an ordinary good.[11] This indicates that as the price of the good decreases, more individuals would like to buy a positive quantity. This means that either more people will buy the good, or that individuals choose to buy a larger amount of the good. Furthermore, I will assume that housing is a normal good, meaning that the demand of the good increases with household disposable income (Snyder, Nicholson & Steward, 2015).

Figure 3.1: Housing demand function



**Note**: $D_0$ is the demand curve. The quantum is measured along the horizontal axes (S), and the housing price on the vertical axis (PH).

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[10] The sign of the partial derivative of the interest rate is ambiguous in Anundsen and Jensen (2013). The reason is because the interest rate work through disposable income and household's loan. So the remaining effect only is the substitution effect. Since the shock series used in the models is exogenous, the income effect is still relevant. The relation of interest rate and the housing demand is no longer ambiguous, but negative, given all other assumptions.

[11] A good where demand increases as price of the good fall, likewise, the demand falls as the price of the good increase. The opposite as a Giffen good (Snyder et al., 2015).

Figure 3.1 illustrates the demand function for the housing market. The demand curve is downward sloping, so the quantity demanded decreases when the price increases. This reflects the assumption of housing as an ordinary good.

A shift in the demand function is associated with a change in quantity demanded for a given price. A negative shift in the demand curve can be due to increased interest rates on mortgages, induced e.g., by an increase in the Central Bank policy rate. These factors affect the household interest burden and then reduce the demand for housing, given the assumption that housing is a normal good.

Figure 3.2: Shift in demand function

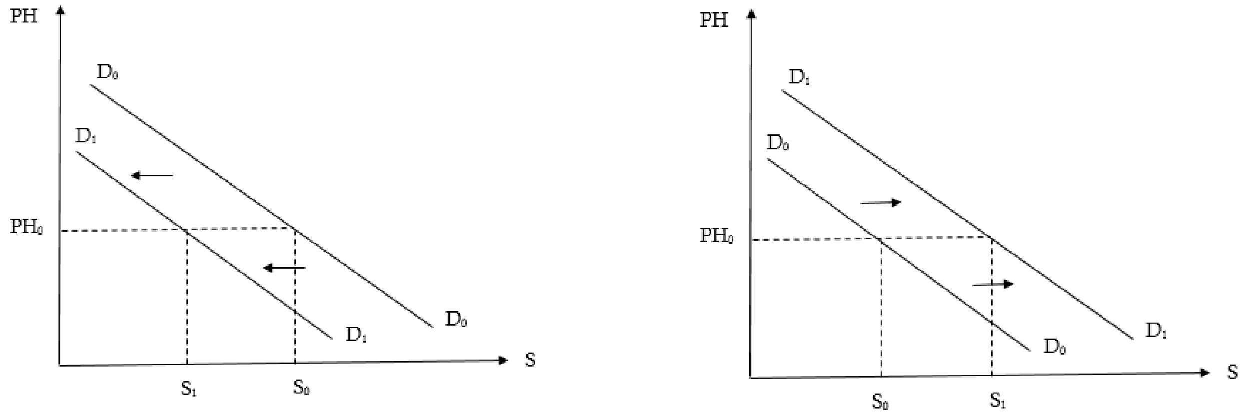


Figure 3.2a Negative shift in demand function

Figure 3.2b Positive shift in demand function

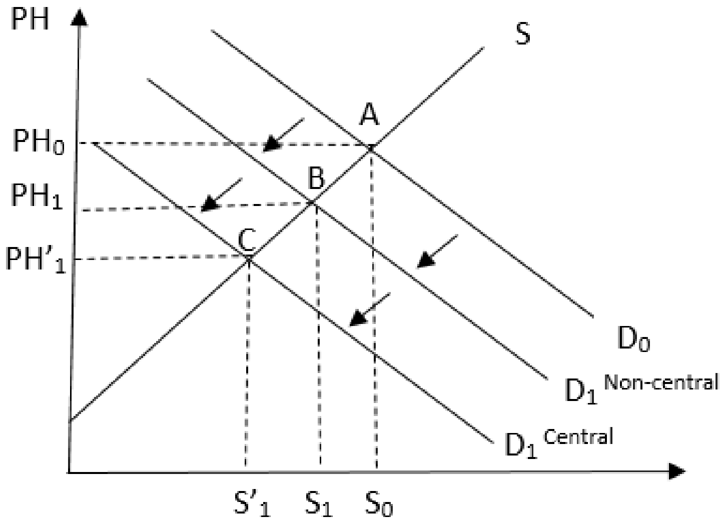
**Note:** $D_0$ is the original demand curve, while $D_1$ is the demand curve after a shift in the demand curve. The quantum demand shifts from $S_0$ to $S_1$. The price of the house is given $PH_0$.

Figure 3.2a illustrates a negative shift in the demand curve. The quantity demanded falls from $S_0$ to $S_1$. A positive shift is then when quantity demanded increases for a given price. This can be due to lower interest rates, illustrated in Figure 3.2b where the demand function shift outwards.

## Centrality and Regional Differences in how a Contractionary Monetary Policy Shock Affects Demand

Referring to the modelling framework in Anundsen and Jensen (2013); the demand for housing depend on debt and the interest rate. According to Anundsen and Mæhlum (2017), the debt-to-income level is highest in the cities. If a contractionary shock occurs, the demand for housing is expected to respond more in central areas - since the interest burden will be highest for households' higher debt.

Figure 3.3: Contractionary monetary policy shock



**Note:** $D_0$ is the original demand curve, while $D_1$ is the demand curve after a shift in the demand curve for a non-central and central area. The quantity demanded shifts from $S_0$ to $S_1$ for non-central and to $S'_1$ for a central area. The price of the house is given $PH_0$. The initial equilibrium is given by point A. New equilibrium for non-central area is point B and the central area C.

Figure 3.3 illustrates a negative shift in the demand function as a result of a positive monetary policy shock. The response of households living in central areas is expected to be higher because of the higher debt level.

## 3.3 Housing Supply

Housing supply is known to be more difficult to predict than to housing demand (Ball, Meen & Nygaard, 2010). Anundsen and Jansen (2013) estimate an equation for housing starts in square meters. The housing stock is then determined by the law of motion for capital:

$$H_t^s = (1-\delta)H_{t-1}^S + HS_t \qquad (3.5)$$

Where $H_t^s$ is the total housing stock, and $\delta$ is the depreciation of the last period houses $H_{t-1}^S$ and $HS_t$ housing starts. The long-run housing supply can be modeled based on the Tobin q-theory of investment see Sørensen and Jacobsen (2005). The theory states that one percent increase in housing prices or a one percent fall in construction costs, leads so a one percent increase in housing starts. Housing starts is then a function of housing prices, the cost of land and construction cost.

$$HS_t = g(PH_t, CC_t, LC_t) \qquad (3.6)$$

Equation 3.6 shows that housing starts $HS_t$, depend positively on the housing prices (PH), since the project is more likely to be profitable when prices are increasing, and negatively on construction and land costs $CC_t$ and $LC_t$.[12] The total supply of housing can then be characterized by inserting equation (3.6) into equation (3.5). We end up with the following equation:

$$H_t^s = (1-\delta)H_{t-1}^S + g(PH_t, CC_t, LC_t) \qquad (3.7)$$

Total housing supply depends on the depreciation rate of existing housing stock, and housing starts. In the empirical analysis, the housing start will be the variable representing the supply side. The timeline for data of housing stock is too short and will therefore not be included in the model.

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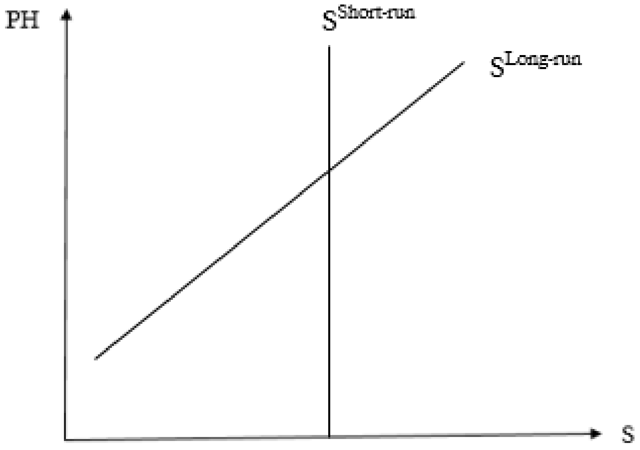
[12] Both construction and land cost are assumed to reduce the construction of new housing property Anundsen and Jansen (2013).

## 3.4 Housing Supply Function

The housing market is assumed to have increasing marginal costs, so the supply function is increasing with the price, illustrated in Figure 3.4. It is reasonable to assume that the supply of houses is fixed in the short-run,[13] while in the long-run, the supply curve is upward-sloping[14].

Figure 3.4: Housing supply in short- and long-run



**Note**: The supply function is given by S, noted with inelastic and elastic supply.

One of the largest construction companies in Norway, OBOS, operates with a time frame between 10 and 15 years on a housing project (Larsen & Sommervoll, 2004), confirming that it takes time before construction projects are finalizes. Furthermore, construction of new residential property amounts to only one percent of the total housing stock every year (NOU, 2002). Therefore, the year-by-year change in the housing stock is small. Hence, housing supply is relatively inelastic compared to other markets.

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[13] The assumption of compete inelastic supply curve where $\lim_{PH\prime(S)\to\infty} El^H = 0$ for the short-run just an approximation. A more correct would be to say that the short-term supply curve is very inelastic, but not zero.

[14] The supply elasticity say the percentage change in quantum supplied when the price of housing change with one percent.

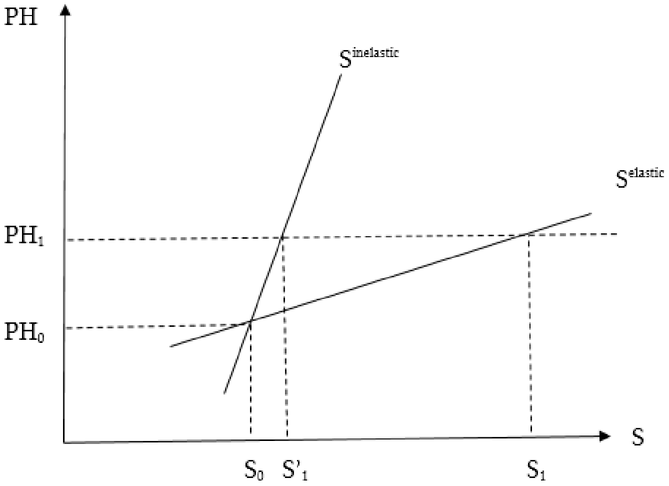
## 3.5 Supply Elasticity

The supply elasticity is the percentage change in quantity supplied when the price of housing changes with one percent (Snyder et al., 2015).The housing supply elasticity is formally given by:

$$El^H = \frac{dS(PH)}{dPH}\frac{PH}{S(PH)} \qquad (3.8)$$

Where S(PH) is quantity supplied, and PH is the price of a house unit.

Figure 3.5: Effect of a price change with elastic and inelastic supply



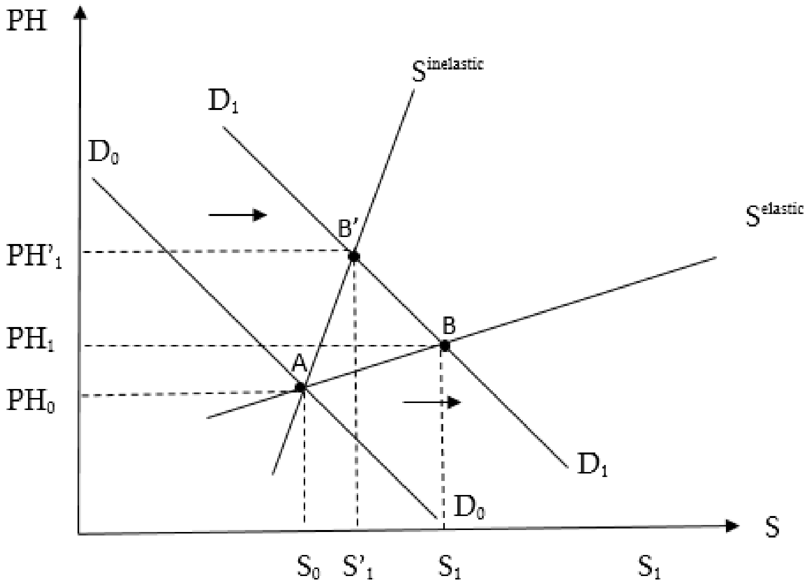
**Note**: The supply curve is given by $S^{elastic}$ for elastic supply and $S^{inelastic}$ for inelastic supply. $PH_0$ shows the original price and $PH_1$ is the new price.

Figure 3.5 illustrates an elastic and an inelastic housing supply function. When housing prices increase from $PH_0$ to $PH_1$, the inelastic supply increase from $S_0$ to $S'_1$, while the elastic supply increase from $S_0$ to $S_1$. The elasticity of housing supply is important in order to understand how demand shocks affect prices and quantity, e.g., a monetary policy shock. Therefore, in order to analyze regional differences in the transmission of monetary policy shocks to housing prices, it is important to understand the factors driving differences in housing supply elasticities. Glaeser, Gyourko and Saiz (2008) investigated the role of supply elasticities during the booms and busts in the 1990s in the US. Their findings show that cities with inelastic supply elasticities experienced a higher house price growth during the time, while cities with high housing supply elasticities experienced larger increases in quantity supplied. These results are consistent with the theoretical framework.

## 4.6 Monetary Policy Shock and the Housing Supply Elasticity

The effect of monetary policy changes on housing prices will depend on the housing supply elasticity. As illustrated in Figure 3.6, a demand shock will be absorbed in the price (from $PH_0$ to $PH_1$) if the supply function is inelastic, and in quantity (from $S_0$ to $S_1$) if the supply curve is elastic. According to Aastveit and Anundsen (2017) and Aatveit et al. (2019), supply elasticities play a significant role in how monetary policy affect housing prices in the US.

Figure 3.6: Effect of an expansionary monetary policy shock



**Note**: $D_0$ is the original demand curve, while $D_1$ is the demand curve after a monetary policy shock. The supply curve is given by $S^{elastic}$ for elastic supply and $S^{inelastic}$ for inelastic supply. The initial equilibrium is given by point A. New equilibrium for the inelastic supply is given at point B’ and the elastic B.

Figure 3.7: Effect of contractionary monetary policy shock

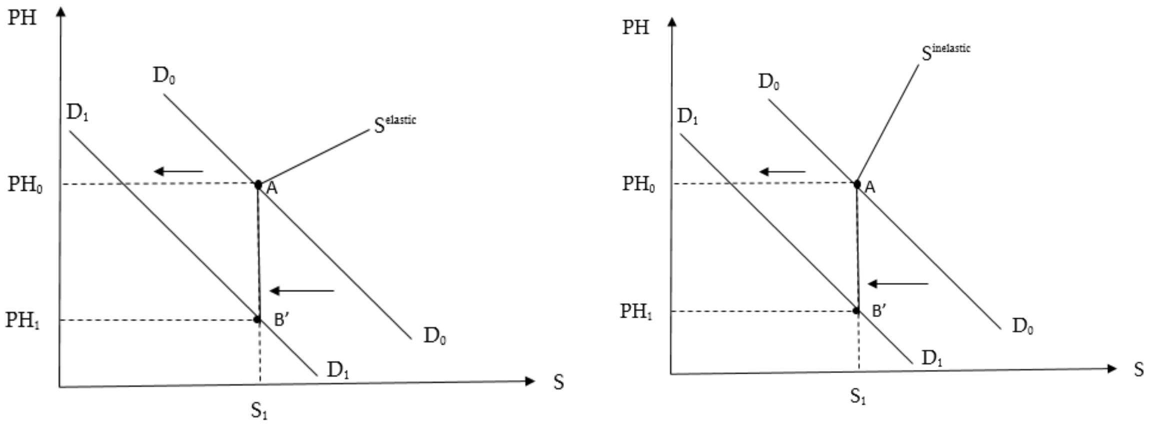


Figure a: Market with elastic supply

Figure b: Market with inelastic supply

**Note**: $D_0$ is the original demand curve, while $D_1$ is the demand curve after the interest rate increase. The supply curve is given S. The equilibrium point before the shock is at point A, while after the contractionary monetary policy shock is the equilibrium point B', for both inelastic and elastic supply.

Figure 3.7 a and b illustrates the effect of a contractionary monetary policy shock on housing prices. With both elastic and inelastic supply, the price falls with the same amount. The reason is that the housing stock remains is the same, even if the interest rate increases and the demand reduces. Compared to other goods markets, where quantity supplied in most cases decreases when demand falls.

Furthermore, several papers have shown that the effect of monetary policy on housing prices, and the real economy is asymmetric; see e.g., Aastveit and Anundsen (2017), Angrist, Jordà and Kuersteiner (2017), Tenreyro and Thwaites (2016) and Barnichon and Matthes (2018). An expansionary shock has a greater impact on housing prices in a market where is inelastic, like illustrated in Figure 3.6. While a contractionary shock is independent of the elasticity of housing supply, see Figure 3.7 (a and b). Studying potential asymmetric effects of monetary policy is outside of the scope of this thesis, but it would be an interesting extension of my analysis, which concentrates on the role of centrality in the transmission of monetary policy shocks to housing prices.

# 4. Data

## 4.1 House Price Index and Housing Starts

In my empirical analysis, I use data covering the period 2003 Q1 – 2017 Q4. The housing price data are collected from Eiendom Norge[15], in collaboration with Finn.no[16] and Eiendomsverdi[17]. The data are based on sales that where mediated by brokers and announced on finn.no. Compared to the housing price index constructed by Statistics Norway, Eiendom Norge's price statistics use turnover weights; meaning they exploit the value of all housing transactions (the flow of housing). [18] Statistics Norway base their index on housing stock weights, meaning the value of all existing houses (the stock of housing). The housing price index compiled by Eiendom Norge is therefore the most relevant index to use for the analysis, since the sample of housing sales transactions gives a more precise picture of the dynamics in the market, compared to Statistics Norway house price index. An important assumption underlying the weights used by Statistics Norway is that the price development for a house that is not for sale is the same as those that are actually transacted. This assumption is not superimposed by the weights used by Eiendomsverdi. Since the purpose of this master thesis is to analyze developments of houses that are for sale and bought by households, it is more relevant to use Eiendom Norge's price index. The index constructed by Eiendom Norge is now considered by most people and institutions to be the most reliable house price index in Norway, and used by e.g. Norges Bank in their Monetary Policy Reports[19].

The house price index from Eiendom Norge covers 110 different areas spanning the entire country. This includes Oslo, Bergen and Trondheim, in addition to several smaller municipalities. I will not include indexes for areas that are made up of several different

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[15] Eiendom Norge: http://eiendomnorge.no/boligprisstatistikken/

[16] Finn.no https://www.finn.no/

[17] Eiendomsverdi: https://eiendomsverdi.no/

[18] About Statistics Norway price index: https://www.ssb.no/priser-og-prisindekser/artikler-og-publikasjoner/hvorfor-spriker-boligprisindeksene-til-eiendom-norge-og-ssb-2018-7

[19] Norges Bank Monetary Reports: https://www.norges-bank.no/aktuelt/nyheter-og-hendelser/Publikasjoner/Pengepolitisk-rapport-med-vurdering-av-finansiell-stabilitet/

municipalities, such as the area Hå-Klepp-Time. The main reason for this is that the underlying municipalities have very different values of a centrality index that will be key to my analysis. For instance, Klepp have a centrality index of 854, Time of 843 and Hå of 786, and there are many municipalities between Hå and Klepp, so the range of centrality would then be wrong. In the panel data used for the analysis, I include 45 municipalities, covering most parts of Norway. I use house price data from Eiendom Norge to calculate the cumulative percentage increase in nominal housing prices for each of the regions in the period 2003 Q1 – 2017 Q4. Moreover, I include a housing stock series collected form Statistics Norway's StatBank Table 05889 - a quarterly series covering the period 2000 Q1 – 2019 Q2.

## 4.2 Macro- and microeconomic variables

I have collected data on regional unemployment rates from Statistics Norway's StatBank. The data are monthly and cover the period 1999 M1 – 2018 M11. I converted the data from monthly to quarterly frequency by taking three-month averages. Moreover, the data on disposable income and debt are collected from Norges Bank – received from Statistics Norway. The micro data used to calculate regional data for income and debt are only available at annual frequencies and I converted to a quarterly frequency using a cubic method[20]. I addition, I use demographic data such as number of households and population for each municipality. The source of the data is Statistics of Norway's StatBank Table 07459.

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[20] The annual data is transformed to quarterly data by cubic method using MatLab.

# 4.3 Centrality index

## 4.3.1 Definition of a Central Area

Centrality is about distance – how easy or difficult it is to get access to everything one needs on a daily basis, including grocery stores, working places and schools (Høydahl, 2017). The term centrality, means a geographical location that is in relation to a center where there exist functions of a higher order.[21]

## 4.3.2 The Centrality Index

In order to define the centrality of a municipal, I use Statistics Norway's centrality index.[22] The calculation of the centrality index is based on traveling time to working places and service functions from all areas, where Norway's municipalities are divided into 13 500 areas (Høydahl, 2017). The centrality index is based on two different indexes:

1) Number of working places that can be reached within a 90 minute driving distance.
2) The number of different service functions, like goods and services one can reach within 90 minutes.

The centrality index takes values from 0 to 1000. The municipalities are categorized into 6 different centrality classes. Class 1 contains the most central areas, whereas class 6 consists of the least central areas. Since Eiendom Norge only constructs house price data for a subset of the Norwegian municipalities, my data set does not cover all centrality classes, only the classes 1-4. Therefore, the least central areas like Utsira, Lurøy, Rødøy, Træna and Solund is not included in the dataset. The analysis is therefore confined to study municipalities in centrality class 1-4. Table 4.1 shows the five most and five least central areas in my panel data. Oslo is defined as the most central area in Norway according to the centrality index, followed up by Bærum and Rælingen. The least central area included in my data is Vefsn, with a centrality index of 704.

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[21] The centrality index is for municipalities in Norway in 2018. Statistics Norway. URL:https://www.ssb.no/a/metadata/conceptvariable/vardok/927/nb#

[22] The centrality index is a code with a value for every municipalityity in Norway, which gives a measure on how central the Municipalities in Norway is. Documentation on the centrality index can be found on SSB webpage. URL: https://www.ssb.no/befolkning/artikler-og-publikasjoner/ny-sentralitetsindeks-for-kommunene

Table 4.1: The 5 top and 5 bottom municipalities in the panel data

| 5 most central municipalities | | 5 least central municipalities | |
|---|---|---|---|
| 1) Oslo | *(1000)* | 1) Vefsn | *(704)* |
| 2) Bærum | *(971)* | 2) Narvik | *(711)* |
| 3) Rælingen | *(942)* | 3) Alta | *(721)* |
| 4) Asker | *(936)* | 4) Kragerø | *(741)* |
| 5) Drammen | *(933)* | 5) Notodden | *(762)* |

**Note**: Centrality index is in the brackets.

**Centrality classes:**

Class 1: 930 – 1000

Separates Oslo from Oslo's closest regions from the other large cities.

Class 2: 870 – 929

Other large cities like Bergen and Trondheim.

Class 3: 770 – 869

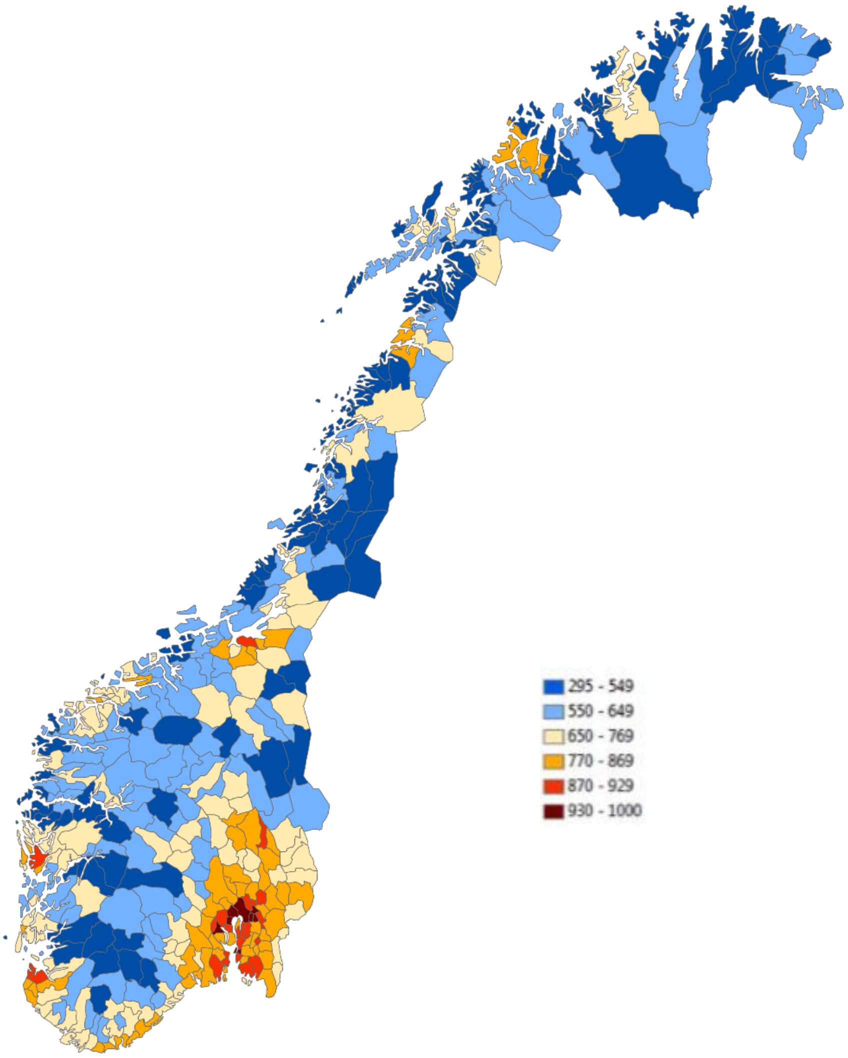
This class includes municipalities like Larvik, Ålesund and Arendal.

Class 4: 650 – 769

The least central municipalities in the panel dataset.

Figure 4.1 illustrates the municipalities in Norway and the associated values of the centrality index. The chart shows clearly that the areas around Oslo are the most central, colored with red, and the least central areas colored in blue. A list of all the municipalities used in the analysis and the corresponding centrality index is found in Table B.1 in Appendix B.

Figure 4.1: Centrality index Norway 2018[23]



Source: Statistics of Norway.

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[23] Figure 4.1 are taken from Høydahl (2017), Statistics Norway.

## 4.4 Identification of Monetary Policy Shocks

There are several methods to identify monetary policy shocks and to analyze the transmission mechanisms. One of the most commonly used methods to analyze the effect of monetary policy on the real economy is VAR models, see Del Negro and Otrok (2007) and Dokko et al. (2009). Furthermore, in order to save degrees of freedom and including more variables, several papers have used a factor vector auto regressive model (FAVAR), see e.g. Bernanke, Boivin and Eliasz (2005), Stock and Watson (2002), Bernanke and Boivin (2003) and Ellis, Mumtaz and Zabczyk (2014). They all found more or less the same results in how monetary policy affect macroeconomic variables.

Another approach is to use market based identification by utilizing forward-looking financial market data in order to isolate a monetary policy shocks. Kuttner (2001), Piazzesi and Swanson (2008) and Gürkaynak, Sack and Swanson (2005) used a market based approach in order to identify monetary policy shocks. They followed The Federal Open Market Committee (FOMC) meetings and analyzed movements in Fed Funds Futures contract prices on the announcement day.

A new identification approach was introduced by Romer and Romer (2004). They regressed the change in Fed's interest rate target for each FOMC meetings on the real-time forecast of past, current and the future inflation, unemployment rate and output growth. They used the residuals from the regression in order to identify an exogenous shock series for monetary policy. Coibion (2012) highlighted the differences in results from using the Romer and Romer (2004) narrative shock series versus shocks from VAR models. The estimated effect of monetary policy, according to the VAR models, is small in contract to the effect of Romer and Romer series which is large. The potential reasons, according to Coibion (2012), is of the lag length selected, the different contractionary impetus and because of the period of reserve targeting.

The approach used to identify monetary policy shocks, in this thesis, is the narrative identifications strategy pioneered by Romer and Romer (2004). The Romer and Romer (2004) method has been widely used and adopted in other research. Wieland and Yang (2016) created an updated version of Romer and Romer (2004). Furthermore, Champagne and Sekkel (2017) create a narrative shock series for Canada using forecast from the Bank of Canada's staff economic projections from 1974 to 2015. The narrative identification approach has gained acceptance as a measure of a monetary policy shocks, and has been widely used in order to study the transmission of monetary policy, see e.g., Coibion (2012) and Ramey (2016).

The Romer and Romer (2004) approach has recently been adopted in order to identify Norwegian monetary policy shock. First by Johansen and Bratlie (2016) in their master thesis, followed by Holm, Pascal and Tiscbirek (2019).

### 4.4.1 Monetary Policy Shock Series for Norway

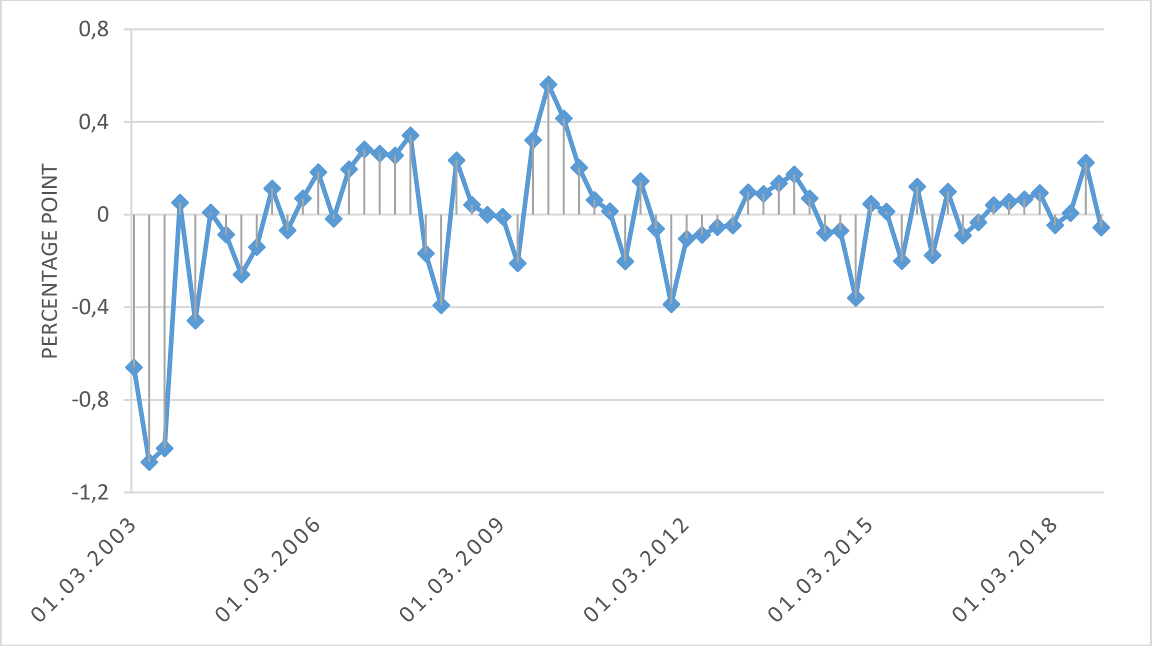
To measure exogenous changes in monetary policy in Norway, I use the narrative monetary policy shock series be Holm et al. (2019). It applies the Romer and Romer (2004) approach to identify monetary policy shocks in Norway over the period 1994 M1 – 2018 M12. The narrative approach starts by measuring changes in Norges Bank's target interest rate for each policy meeting. Then, these changes are regressed on Norges Bank's forecast of output growth, future inflation and key interest rate that were available at the time when the policy decisions were made.

The following Taylor-rule specification is estimated by ordinary-least-squares:

$$\Delta i_m = \alpha_1 + \alpha_2 i_{m,-1} + \sum_{k=0}^{1} \beta_k^{\pi} \pi_{t+k}^{m} + \sum_{k=0}^{1} \beta_k^{\Delta\pi} \Delta\pi_{t+k}^{m} + \sum_{k=0}^{1} \beta_k^{y} y_{t+k}^{m} + \sum_{k=0}^{1} \beta_k^{\Delta y} \Delta y_{t+k}^{m} + \gamma_1 ex_{m,-1} + \gamma_2 I_{IT} \cdot ex_{m,-1} + \epsilon_m^{MP} \tag{4.1}$$

Where $\Delta i_m$ is the change in the policy rate at meeting m and $i_{m,-i}$ is the level of the policy rate prior to meeting m. Meeting m takes place at time t. Similar to Romer and Romer (2004), Holm et al. (2019) also include forecasts for GDP, $y_{t+k}^{m}$, and CPI, $\pi_{t+k}^{m}$. The monetary policy shock is then measured as the residuals from equation 4.1.

Figure 4.2: Narrative shock series[1] for Norway.[2] 2003 Q1 – 2019 Q1



1) When the shock is above zero, it identifies as a contractionary monetary policy shock. Other way around, when the shock is negative, it is expansionary shock.

2) The figure illustrates Holm et al. (2019) monetary shock series, converted from basis to percentage points.

Source: Holm et al. (2019).

Figure 4.2 shows the monetary policy shock series for Norway from 2003 Q1 to 2019 Q1 constructed using the narrative approach. At the start of 2003, monetary policy was expansionary – the key interest rate was decreased more than the expected based on the forward-looking Taylor-rule. In mid-2007, monetary policy was contractionary. Since the monetary policy shock is independent of other economic variables, the narrative shock series can be included in the model as an exogenous variable.

The shock series has been shown to affect the policy rate positively, until the 12th quarter, see Figure C.1 Appendix C. After three years, the policy rate is below zero. The reason is that the central bank try to simulate the economy; since the unemployment rate increase, GDP and consumer price index falls, so the policy rate need to increase in order to maintain a flexible inflation target regime. For this reason, the horizons of interest for the analysis will only be until the third year – the peak of the impulse response to the policy rate.

# 5. Methodology

In this section, I present the different models and the methodology used in my analysis. First, I present the model used to analyze my research question, followed up by robustness and sensitivity checks. In order to analyze how monetary policy affects regional housing prices in Norway, I use a balanced panel data for 45 different municipalities covering the period 2003 Q1 – 2017 Q4.

## 5.1 Stationarity

In time series econometrics, the assumption that disturbances follows a stationary process is an important requirement. Stationarity is a characteristic of the linear properties of the process, i.e., that is expectation, variance and autocovariance (Nymoen, 2019). The term refers to the concept of both weak stationarity and covariance stationarity.

For a time series process $\{y_t; t = 0, \pm 1, \pm 2, \pm 3, \ldots\}$, the requirements is formally expressed as:

1. $E(y_t) = E(y_{t-s}) = \mu \quad \forall_s$
2. $Var(y_t) = Var(y_{t-s}) = \sigma^2 \quad \forall_s$
3. $Cov(y_t, y_{t-s}) = Cov(y_{y-j}, y_{t-j-s}) \ = \gamma_s \, , \ \forall_s$

A variable is stationary if the expectation and variance is constant with time, and the covariance just depends on the timing between the two observations. According to Granger and Newbold (1974), if two variables are non-stationary, and do not share a common stochastic trend, spurious relationship may occur. Spurious relationship may appear to be significant, but do not make economic sense (e.g., birds flying over a park in Oslo predicting GDP growth in Guatamala). If a variable is time-dependent and non-stationary, hypothesis testing using a t-test, F-tests and $R^2$ will be invalid (Enders, 2008).

To illustrate the concept of stationarity in a little more detail, consider a simple AR(1) process:

$$x_t = \rho x_{t-1} + e_t \text{ where } e_i \sim iid\ N(0, \sigma^2)$$

Recursive substitution gives:

$$x_t = \rho^2 x_{t-2} + \rho e_{t-1} + e_t$$
$$x_t = \rho^3 x_{t-3} + \rho^2 e_{t-2} + \rho e_{t-1} + e_t$$
$$\vdots$$
$$x_t = \rho^k x_{t-k} + \sum_{j=0}^{k-1} \rho^j e_{t-j}$$

Assuming that $-1 < \rho < 1$ and $k \rightarrow \infty$, then we get:

$$x_t = \sum_{j=0}^{\infty} \rho^k e_{t-j}$$
$$E(x_t) = 0$$

In which case we find that:

$$Var(x_t) = var\left(\sum_{j=0}^{\infty} \rho^j\, e_{t-j}\right) = \sum_{j=0}^{\infty} \rho^2 var(\, e_{t-j}) = \frac{\sigma^2}{1-\rho^2}$$

As illustrated, both the expectation and the variance are time-independent as $k \rightarrow \infty$. The process is therefore stationary if $\rho < |1|$.

If the variable $x_t$ follows a random walk, and $x_0$ are assumed constant, recursive substitution gives:

$$x_t = x_0 + \sum_{j=0}^{k-1} e_{t-j}$$

In which:

$$E(x_t) = x_0$$

$$var(x_t) = var(\sum_{j=0}^{k-1} e_{t-j}) = \sum_{j=0}^{k-1} var(e_{t-j}) = k\sigma^2$$

When $x_t$ is a random walk, the variable contain a unit root - the variance of $x_t$ increases with time, in addition, when $k \rightarrow \infty$ it approaches infinity. When a variable contain a unit root, the series is non-stationary.

### 5.1.1 Order of Integration

If a series is non-stationary and contains a unit root, but becomes a stationary after being differenced once, the non-stationary variable is integrated of order one I(1). If $\rho = 1$, the series is still not stationary, but the series $x_t$ become stationary by differencing once:

$$\Delta x_t = x_t - x_{t-1} = e_t$$
$$E(\Delta x_t) = 0$$
$$var(\Delta x_t) = var(e_t) = \sigma^2$$

The order of integration I(d) of a time series refers to the minimum number of times it is needs to be differenced (d) to become stationary. If a series is stationary, without differencing, the series is I(0).

## 5.2 Testing for Non-Stationarity

At the beginning of this subsection, I argued that stationary is an important property for valid inference in time series models. There are several ways to test for stationarity. The test I will use for this purpose, Harris-Tzavalis (1999), originated from the traditional Dickey-Fuller (Dickey & Fuller, 1979) test, see Appendix A.1 for description.

The Dickey-Fuller test is not suited for panel data, therefore, I use a test for panel data developed by Harris-Tzavalis (1999).This test is particularly well suited for panel data with large numbers of panels (large N) and relatively few time periods (small T), compared to alterative panel data tests for unit roots, such as Levin-Lin-Chu (2002). The Harris-Tzavalis (1999) test compute bias adjustments to the estimated coefficient and the residual, and use the corrected estimated to construct a test for unit root. The test assumes that the number of panels tends to infinity while the number of periods is fixed. Of this reason, the asymptotic of normality ($N \rightarrow \infty$) holds.

The estimated model for the test is:

$$y_{i,t} = \propto_i + u_{i,t} \qquad u_{i,t} = \rho u_{i,t-1} + \varepsilon_{it}$$

$$\varepsilon_{i,t} \sim N(0, \sigma^2)$$

The null hypothesis is $\rho = 1$. If the null hypothesis is rejected, the series is stationary. Results from testing the different variables employed for unit root can be found in Table A.1 in Appendix A.2. The test gives significant results at a one percent level. Therefore, I can conclude that the variables I include in my models are stationary.

## 5.3 Econometric Specification

The supply-demand framework outlined in Section 2 suggests that the effect of monetary policy might differ depending on the supply elasticity. In order to investigate the empirical relevance of these conjectures, I estimate a reduced form supply-demand model, similar to Aastveit and Anundsen (2017).

In particular, I use the local projection methods developed by Jordà (2005) to calculate impulse response. Local projection methods consider a local approximation for each forecast horizon of interest. I use the framework to estimate the effect of a monetary policy shock on housing prices when h=0, 4, 8, 12. The advantage with local projection methods is that it makes it easy and possible to analyze non-linear effects of monetary policy, something that would be almost infeasible with a VAR model. The parameter of interest is the impulse response of housing prices following a one percent monetary policy shock. A VAR model would have one-step ahead predictors, while impulse responses are functions of multi-step forecast. Also, the standard errors for VAR impulse response functions are complicated; they are nonlinear functions of the estimated parameters.

My baseline specification takes the following form:

$$ph_{i,t+h} - ph_{i,t-1} = \propto_i + \beta_h MP_t + \mathbf{\Gamma}' \boldsymbol{W_{i,t}} + D_{crisis} + D_{regulation} + S_1 + S_2 + S_3 + \varepsilon_{i,t} \tag{5.1}$$

And when I group based on centrality, it takes the following form:

$$\begin{aligned} ph_{i,t+h} - ph_{i,t-1} = \propto_i + \beta_h MP_t + \beta_h^{MP,centrality} * MP_t{}^{centrality} \\ + \mathbf{\Gamma}' \boldsymbol{W_{i,t}} + D_{crisis} + D_{regulation} + S_1 + S_2 + S_3 + \varepsilon_{i,t} \end{aligned} \tag{5.2}$$

Where $ph_{i,t+h} - ph_{i,t-1}$ is the cumulative percentage change in housing prices after h quarters and $MP_t$ is the monetary policy shock. The vector $\boldsymbol{W_{i,t}}$ contains sets of control variables, including lagged percentage changes in log of housing prices, lagged percentage changes in the average debt level and lagged percentage changes in average income, lags of the logarithm of housing starts, and lags of quarterly changes in the unemployment rate. For all lagged variables, I include four lags. $\propto_i$ is area-fixed effects, $D_{crisis}$ is a dummy for the financial crisis, taking a value 1 if year equal 2008 Q3 – 2010, and zero otherwise. Similarly, $D_{regulation}$ trap dummy variable for mortgage regulations, taking a value of one starting from 2015 and two from 2016, respectively.[24] Before this, the dummy is zero. The coefficient $\beta_h$measures how a change in the key policy rate affects the housing prices after h quarters. I will estimate equation 5.1 for h=0, 4, 8 and 12. The independent variables coincide with the supply and demand factors presented in Section 3, and are similar to those employed by Jacobsen and Naug (2005) and Anundsen and Jansen (2013).

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[24] See Regjeringen.no about the regulation: https://www.regjeringen.no/no/aktuelt/regjeringen-viderefører-boliglansforskriften/id2604844/

Equation 5.1 is used to analyze the average effect of monetary policy on housing prices at different horizons. In order to analyze whether centrality plays a role in the transmission of monetary policy shock to the housing market, I group the municipalities based on the centrality index, and use the groups as an interaction term in Equation 5.2. In this way, it is possible to analyze if some regions stand out from the rest of the panel.

## 5.4 Fixed Effects Versus Random Effects

I account for heterogeneity through the intercept term by allowing for municipality-fixed effects. Some panel data approaches, like pooled OLS, have some disadvantages because it violates the OLS assumptions. Important assumptions for using pooled OLS is exogeneity, saying that the explanatory variables in each time periods are uncorrelated with the residual for each time period. In addition, it is important that the disturbances have the same variance, homoscedasticity, and that they are not related to one another over time (non-autocorrelation). However, if the individual effect of the residuals is non-zero in longitudinal data, the assumption of exogeneity and homoscedasticity can be violated. Furthermore, as discussed in Pesaran, Shin and Smith (1999) and Phillips and Moon (2000), the pooling assumption of equal slope coefficients may often be disputed.

### 5.4.1 Hausman Test

In order to ensure that there exist fixed or random effects in the data, I use the Hausman (1978) test. The Hausman specification test compares a random effect model to the alternative fixed-effects model. A simple random effect model can be expressed as following:

$$y_{it} = \beta_0 + \beta_1 \boldsymbol{x'_{it}} + \alpha_i + v_{it} \qquad v_{it} \sim IID(0, \sigma^2)$$

Where $\alpha_i, \alpha_2, \dots, \alpha_N$ are the following probability distribution:

$$\alpha_i \sim IID(0, \sigma_a^2)$$

Crucial assumptions for a random effect model is that the unobserved effect ($\propto_i$) and the explanatory variables are not correlated:

$$cov(\boldsymbol{x_{it}}, \propto_i) = 0$$

If there correlation is zero, both fixed effect model and random effect model is consistent, but the fixed effect model would be inefficient. While, if there exist a correlation – the fixed effect model is consistent, while the random effect model is inefficient. The null hypothesis of no correlation, the random effect model is preferred. If the null hypothesis is rejected, the fixed effect model is the model one should use. The following test statistic is used to test $H_0$, where $\beta_{RE}$ is the coefficient for random effect model, and $\beta_{FE}$ is the coefficient for the fixed effect model:

Since the random effect coefficient is efficient under the null hypothesis, it holds that:

$$V(\hat{\beta}_{FE} - \hat{\beta}_{RE}) = V\left(\hat{\beta}_{FE}\right) - V\left(\hat{\beta}_{RE}\right)$$

The null hypothesis under the Hausman statistics is:

$$H_0\colon\ W = (\hat{\beta}_{FE} - \hat{\beta}_{RE})'\left[\hat{V}\left(\hat{\beta}_{FE}\right) - \hat{V}\left(\hat{\beta}_{RE}\right)\right]^{-1}(\hat{\beta}_{FE} - \hat{\beta}_{RE}) \sim \chi^2(k)$$

If the null hypothesis is rejected, the fixed effect model is the best fit.

Table A.3 Appendix A shows the results. These results demonstrate that there are fixed effects at all horizons greater that zero. Therefore, a fixed effect model is the most appropriate to use for the analysis. A fixed effects model examines individual differences in intercepts, assuming constant variance across areas. The individual specific effect is time invariant and considered as a part of the intercept.

## 5.5 Statistical Tests for Valid Estimates

For valid inference, it is important to test the assumption of residual normality. I test for normality by using a new method by Alejo, Galvao, Montes-Rojas, Sosa-Escudero (2015). The test is based on resent results of Galvao, Montes-Rojas, Sosa-Escuedero and Wang (2013) and is an extension of the classical Jarque-Bera (1980) normality test for the case of a linear model from panel data.

Considering the following panel data model:

$$y_{i,t} = x_{i,t}b + u_i + e_{i,t}, \quad i = 1, \dots, N \; t = 1, \dots., T$$

b is a p-vector of parameters, $x_{i,t}$, $e_{it}$ and $u_i$ are copies of a random variable u, e and x. The residuals, $u_i$ and $e_{i,t}$ refers to the individual-specific component and the error component, respectively.

To test normality of residuals, each component´s skewness and kurtosis is in interest.

$$s_u = \frac{E(u^3)}{\{E(u^2)\}^{\frac{3}{2}}} \quad \text{and} \quad s_e = \frac{E(e^3)}{\{E(e^2)\}^{\frac{3}{2}}}$$

$$k_u = \frac{E(u^4)}{\{E(u^2)\}^2} \quad \text{and} \quad k_e = \frac{E(e^4)}{\{E(e^2)\}^2}$$

The construction of testing for skewness and kurtosis in the individual-specific and the remainder components, jointly and separately, is constructed by Galvao et al. (2013). If the underlying distribution of the residual is normal, the null hypotheses are given by

$$H_0^{s_u \& k_u} : \quad s_u = 0 \quad \text{and } k_u = 3$$

$$H_0^{s_e \& k_e} : \quad s_e = 0 \quad \text{and } k_e = 3$$

The normality test is shown together with other results in Section 6. In Appendix A, the residuals for the baseline model is illustrated in a histogram and a Q-Q plot. The figures shows that the residuals at all the horizons, close to being normally distributed. According to Brooks (2008), it is still desirable to use OLS even in the presence of non-normality.

In order to ensure valid statistical inference, I use Driscoll and Kraay (1998) standard errors in order to avoid cross-sectional dependence. The standard error estimated are also robust to disturbances being heteroscedastic autocorrelated. The residuals are controlled for autocorrelation up to four lags.

# 6. Empirical Analysis: The Transmission of Monetary Policy to Norwegian Housing Prices

An important contribution of this thesis is to investigate the role centrality plays in the transmission of a monetary policy shocks to housing prices. In order to investigate this, I estimate several versions of Equation 5.2, as presented in Section 5. In Section 1, I argued that the effect of monetary policy shocks on regional housing prices might depend on centrality. The theoretical framework outlined in Section 3 suggest that one reason for this could be if housing supply elasticities differ across regions. In addition, the debt-to-income is typically higher in the cities (Anundsen & Mæhlum, 2017), see Section 2. Therefore, it is reasonable to believe that monetary policy shocks have a greater impact on more indebted households. For these reasons, housing prices in central areas are expected to be more responsive to monetary policy shocks than non-central areas.

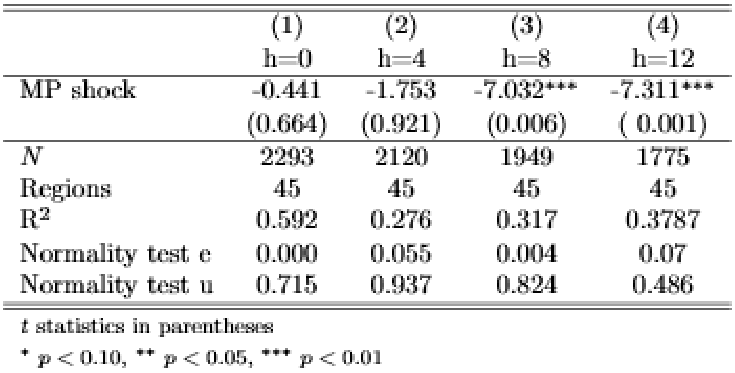
In the first part of this section, I present results for the whole panel, followed up by the results for the most central areas and groups based on centrality.

## 6.1 Results for the Whole Panel

In order to understand how monetary policy shocks affect housing prices on average, I estimate Equation 5.1 from previous section.

The results obtained from estimating (5.1) are reported in Table 6.1. The table shows that changes in monetary policy have significant effects on housing prices at horizon 8 and 12 – being significant at the five and one percent level, respectively. The contemporaneous effect and the effect after four quarters are less precisely estimated. One reason for this result can be that the effect of a monetary policy shock differs more between regions in the short-run, as I will discuss in more detail later. Although the contemporaneous and four-quarter effect on housing prices following a monetary policy shock may appear small, this may be hiding large underlying heterogeneities between different regions. For instance, the effect may be positive in some regions and negative in other regions, so the average effect is small, or close to zero. In the long-run, the effect of a monetary policy shock is negative and highly significant.

Table 6.1: The effect of monetary policy shock to the whole panel



| | (1)<br>h=0 | (2)<br>h=4 | (3)<br>h=8 | (4)<br>h=12 |
|---|---|---|---|---|
| MP shock | -0.441 | -1.753 | -7.032*** | -7.311*** |
| | (0.664) | (0.921) | (0.006) | ( 0.001) |
| $N$ | 2293 | 2120 | 1949 | 1775 |
| Regions | 45 | 45 | 45 | 45 |
| $R^2$ | 0.592 | 0.276 | 0.317 | 0.3787 |
| Normality test e | 0.000 | 0.055 | 0.004 | 0.07 |
| Normality test u | 0.715 | 0.937 | 0.824 | 0.486 |

$t$ statistics in parentheses

$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

**Note**: The table shows the effect on housing prices of a monetary policy shock. The dependent variable is the cumulative log change in the housing price index at a horizon h = 0, 4, 8 and 12. The results are based on the estimating equation (5.1) using fixed effect estimator and the data covering 45 municipalities in Norway from the period 2003 Q1 – 2017 Q4. The brackets report the p value, and the statistical tests of normality from Alejo et al. (2015), see Section 5.

These findings are in line with previous research. According to a survey conducted by Williams (2015), a one-percentage point increase in the short-term interest rate leads to a 6 percent decline – on average across studies – in housing prices after two years, which fits the results from my panel data analysis. Similar results are found in Aastveit and Anundsen (2017), where housing prices in the US, on average, are found to drop by 3.53 percent following a contractionary monetary policy shock, whereas an expansionary monetary policy shock – on average – increases housing prices by 7.8 percent after two years.

## 6.2 Analysis of the Most Central Areas

### 6.2.1 Interpretation of the Interacted Coefficient With One Area

If there is only one area of interest, for instance Oslo, the dummy variable D$_i$ will be one for Oslo, and zero for all the other areas. $\beta_h^{MP,centrality}$ , from the specification in equation 5.2, will then measure the additional effect of monetary policy on housing prices in Oslo.
In this particular case, the specification of interest, will take the following form:

$$
\begin{gathered}
ph_{i,t+h} - ph_{i,t-1} = \propto_i + \beta_h MP_t + \beta_{Oslo,h}^{MP} * MP_t^{Region=Oslo} \qquad (6.1) \\
+\boldsymbol{\Gamma}'\boldsymbol{W_{i,t}} + D_{Crisis} + D_{regulation} + S_1 + S_2 + S_3 + \varepsilon_{i,t}
\end{gathered}
$$

Given the OLS assumption $E\left(\varepsilon_{i,t} \middle| MP_t, MP_t^{Region=Oslo}, \boldsymbol{W_{i,t}}\right) = 0$. A one unit change in $MP_t$ will give the following expected change in the housing prices in Oslo:

$$
\frac{\partial E\left((ph_{i,t+h} - ph_{i,t-1}) \mid \boldsymbol{W_{i,t}}, MP_t, MP_t^{Region=Oslo}\right)}{\partial MP_t} = \beta_h + \beta_{Oslo,h}^{MP}
$$

In all other areas, it will be given by:

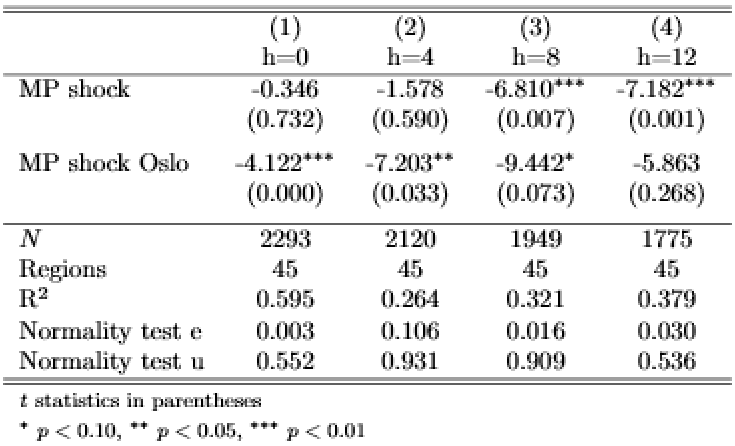
$$
\Delta E\left(ph_{i,t+h} - ph_{i,t-1}\right) = \beta_h
$$

Therefore, one can interpret $\beta_{Oslo,h}^{MP}$ as the additional effect a monetary policy shock has on the housing prices in Oslo. Housing prices in Oslo is more sensitive to a monetary policy shock, compared to the rest of the municipalities in the panel if the coefficient $\beta_{Oslo,h}^{MP}$ is negative and statistically significant.

### 6.2.2 Results for Oslo

Oslo is defined, according to Statistics Norway centrality index, as the most central municipality in Norway. Oslo stands out from all the other municipalities in at least two ways; it is the most populated municipality[25] and it has limited building opportunities due to “Marka loven”[26]. According to the theoretical motivation in Section 3, the effect of monetary policy on housing prices  in areas with less elastic supply elasticity should be greater effect than in areas with elastic supply. Consistent with theory, Table 6.2 shows that the additional effect on housing prices in Oslo following a monetary policy shock is substantial and significant at all horizons, except 12.

Table 6.2: Results of panel regression, Oslo interacted with shock



|  | (1)<br>h=0 | (2)<br>h=4 | (3)<br>h=8 | (4)<br>h=12 |
|---|---|---|---|---|
| MP shock | -0.346 | -1.578 | -6.810*** | -7.182*** |
|  | (0.732) | (0.590) | (0.007) | (0.001) |
| MP shock Oslo | -4.122*** | -7.203** | -9.442* | -5.863 |
|  | (0.000) | (0.033) | (0.073) | (0.268) |
| *N* | 2293 | 2120 | 1949 | 1775 |
| Regions | 45 | 45 | 45 | 45 |
| $R^2$ | 0.595 | 0.264 | 0.321 | 0.379 |
| Normality test e | 0.003 | 0.106 | 0.016 | 0.030 |
| Normality test u | 0.552 | 0.931 | 0.909 | 0.536 |

*t* statistics in parentheses

$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

**Note**: The table shows the effect on housing prices followed by a monetary policy shock when using Oslo as an interaction term. The dependent variable is the cumulative log change in the housing price index at a horizon h = 0, 4, 8 and 12. The results are based on the estimating equation (6.1) using fixed effect estimator and the data covering 45 municipalities in Norway from the period 2003 Q1 – 2017 Q4. The brackets report the p value, and the statistical tests of normality from Alejo et al. (2015), see Section 5.

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[25] In 2018, the population in Oslo approximately 673 469 people according to Statistics Norway StatBank table 07459.

[26] See Regjeringen web page about “Markaloven”: https://www.regjeringen.no/no/dokumenter/prop.-11-l-20182019/id2618254/sec1

The additional impact on housing prices, compared to the rest of the panel, is about 7 percent after one year. This means that an apartment, or a detached house with a value of four million NOK, will fall an additionally 280 000 NOK after one year if the key interest rate unexpectedly increases by with one percent percentage point. This is a considerable effect compared to other municipalities in the panel, where the effect is almost absent. After two years, housing prices in Oslo is estimated to fall by 16.25 percent, whereas the rest of the panel 6.81 percent. This corresponded to a fall in value of 650 000 NOK for an apartment worth 4 million NOK. For the other municipalities, a four million apartment would fall by 272 400 NOK. A fall in housing prices in Oslo could therefore have a large consumption wealth effect compared to other municipalities – a potential concern for both macroeconomics and financial stability.

My analysis does not take potential asymmetric effect of monetary policy into account. Therefore, one cannot say for sure if the large Oslo-effect is dominated by contractionary or expansionary monetary policy shocks, or if the effect is indeed symmetric. I leave this question open for future research.

### Potential reasons of the large Oslo-effect

1. Higher investment speculations in Oslo

According to Ambita rapport (2019), Oslo is the municipality with most secondary dwellings.[27] When the key policy rate is low, speculations in the housing market would be more profitable compared to alternative investments, such as the shock market. Similarly, if the interest rate is high, it would be more profitable to invest in stocks and other alternative investments instead of dwellings. Changes in the policy rate is therefore likely to affect investment in second home purchases, and especially so in a liquid market, such as Oslo.

2. Higher debt level

Oslo is one of the municipalities with the highest debt level compared to the rest of the panel, see the scatter plot Figure 2.3 Section 2. A contractionary monetary policy shock will therefore push households closer to their constraints. This weakens their ability to purchase a

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[27] Secondary dwellings as a share of total housing stock, is relatively equal across municipalities.

new home. Also, some people might move to an area where housing is more affordable in order to maintain the same consumption level. For this reason, demand for housing may fall, leading to a drop in housing prices.

3. Inelastic supply

As mentioned in Section 2, the growth in households relative to the growth in the number of houses is greatest in Oslo. One reason can be legislation like “Marka loven”, which prevents for housing constructions, and can therefore lead to scarce supply. The conjectures in Section 4 suggest that more inelastic supply of housing would lead to an even greater effect of monetary policy to housing prices. The result confirms these conjectures.

### 6.2.3 Results for Bærum and Rælingen

It is important to analyze the most central municipalities individually in order to see if the results are consistent. Bærum and Rælingen are the most central areas in the panel data after Oslo. Table 6.3 a and b shows results when I allow an additional effect of monetary policy on housing prices in Bærum and Rælingen, respectively. The “extra” effect of a monetary policy shock after one quarter is about -1.8 for Bærum and -2 for Rælingen. These results are significant at a one and five percent level, respectively. Compared to Oslo, the additional effect of monetary policy is much smaller.

When comparing Bærum and Rælingen, there are some important factors that need to be considered. The average gross income in Bærum in 2017 was 634 400 NOK compared 473 700 NOK in Rælingen.[28] The debt-to-income ratio in Bærum was 1.73, while it was 1.92 in Rælingen.[29] In the short run, a monetary policy shock will push households in Rælingen closer to the constraints than in Bærum. Consistent with this, results in Table 6.3 a and b, shows that the effect is greater for Rælingen compared to Bærum in the short-run.

After two years, the additional effect of a shock in Rælingen is actually positive, but not significant. Considering the statement in the previous section; if households in Oslo move

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[28] Statistics Norway StatBank table 03068. URL: https://www.ssb.no/statbank/table/03068/

[29] Statistics Norway StatBank table 05854. URL: https://www.ssb.no/statbank/table/05854/

outside of the city center in order to maintain the same level of consumption of goods as before the interest rates increase, then they have a choice to move to areas within commuting distance to Oslo. Comparing Bærum and Rælingen; housing prices are approximately at the same level in Bærum as Oslo (approximately 55 000 NOK per square meter), whereas the square meter price in Rælingen is about 40 000 NOK. [30] Therefore, it is possible that some households in Oslo move to Rælingen. If this is the case, then the demand for houses in Rælingen increases as a result of re-location. Therefore, housing prices in Rælingen fall less than the other municipalities

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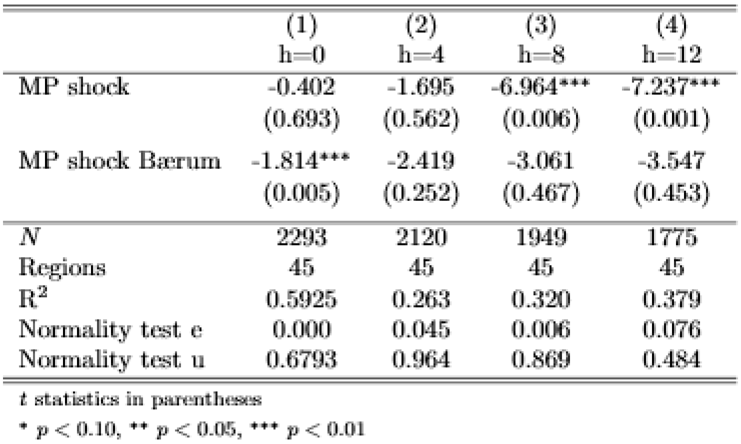
[30] Statistics Norway StatBank table 06696: URL: https://www.ssb.no/statbank/table/06696/. See also a comparison of notional and regional price statistics on the house price level on Krongsveen webpage. URL: https://www.krogsveen.no/prisstatistikk also URL: https://www.smartepenger.no/boligokonomi/3113-kvadratmeterpriser-pa-boliger-i-kommunene

Table 6.3: Results of panel regression

a) Bærum interacted with monetary policy shock

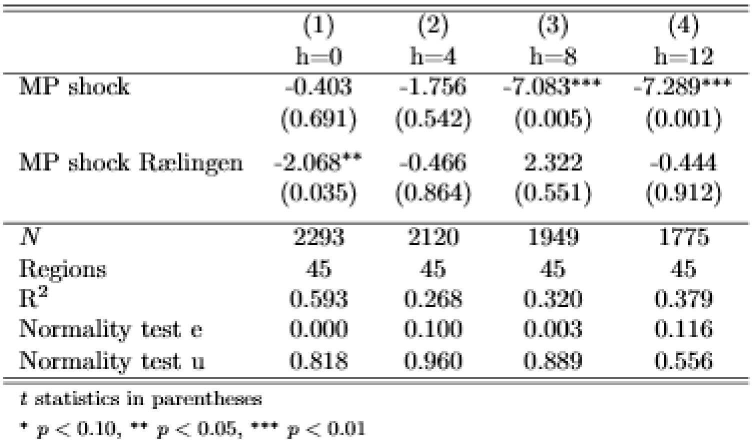


| | (1)<br>h=0 | (2)<br>h=4 | (3)<br>h=8 | (4)<br>h=12 |
|---|---|---|---|---|
| MP shock | -0.402 | -1.695 | -6.964*** | -7.237*** |
| | (0.693) | (0.562) | (0.006) | (0.001) |
| MP shock Bærum | -1.814*** | -2.419 | -3.061 | -3.547 |
| | (0.005) | (0.252) | (0.467) | (0.453) |
| *N* | 2293 | 2120 | 1949 | 1775 |
| Regions | 45 | 45 | 45 | 45 |
| $R^2$ | 0.5925 | 0.263 | 0.320 | 0.379 |
| Normality test e | 0.000 | 0.045 | 0.006 | 0.076 |
| Normality test u | 0.6793 | 0.964 | 0.869 | 0.484 |

*t* statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

b) Rælingen interacted with monetary policy shock



| | (1)<br>h=0 | (2)<br>h=4 | (3)<br>h=8 | (4)<br>h=12 |
|---|---|---|---|---|
| MP shock | -0.403 | -1.756 | -7.083*** | -7.289*** |
| | (0.691) | (0.542) | (0.005) | (0.001) |
| MP shock Rælingen | -2.068** | -0.466 | 2.322 | -0.444 |
| | (0.035) | (0.864) | (0.551) | (0.912) |
| *N* | 2293 | 2120 | 1949 | 1775 |
| Regions | 45 | 45 | 45 | 45 |
| $R^2$ | 0.593 | 0.268 | 0.320 | 0.379 |
| Normality test e | 0.000 | 0.100 | 0.003 | 0.116 |
| Normality test u | 0.818 | 0.960 | 0.889 | 0.556 |

*t* statistics in parentheses

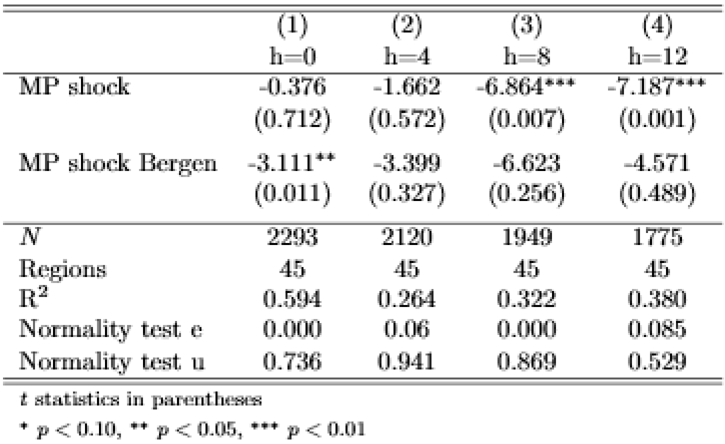
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

**Note**: The table shows the effect on housing prices of a monetary policy shock when using Bærum and Rælingen as an interaction term. The dependent variable is the cumulative log change in the housing price index at a horizon h = 0, 4, 8 and 12. The results are based on the estimating equation (6.1) using fixed effect estimator and the data covering 45 municipalities in Norway from the period 2003 Q1 – 2017 Q4. The brackets report the p value, and the statistical tests of normality from Alejo et al. (2015), see Section 5.

### 6.2.4 Results for Bergen

Following the municipalities around Oslo, like Bærum and Rælingen, Bergen is the most central area in my dataset. Table 6.4 shows results when I add an interaction term for Bergen.

Table 6.4: Results of panel regression for Bergen



| | (1) h=0 | (2) h=4 | (3) h=8 | (4) h=12 |
|---|---|---|---|---|
| MP shock | -0.376 | -1.662 | -6.864*** | -7.187*** |
| | (0.712) | (0.572) | (0.007) | (0.001) |
| MP shock Bergen | -3.111** | -3.399 | -6.623 | -4.571 |
| | (0.011) | (0.327) | (0.256) | (0.489) |
| $N$ | 2293 | 2120 | 1949 | 1775 |
| Regions | 45 | 45 | 45 | 45 |
| $R^2$ | 0.594 | 0.264 | 0.322 | 0.380 |
| Normality test e | 0.000 | 0.06 | 0.000 | 0.085 |
| Normality test u | 0.736 | 0.941 | 0.869 | 0.529 |

$t$ statistics in parentheses

$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

**Note**: The table shows the effect on housing prices of a monetary policy shock when using Bergen as an interaction term. The dependent variable is the cumulative log change in the housing price index at a horizon h = 0, 4, 8 and 12. The results are based on the estimating equation (6.1) using fixed effect estimator and the data covering 45 municipalities in Norway from the period 2003 Q1 – 2017 Q4. The brackets report the p value, and the statistical tests of normality from Alejo et al. (2015), see Section 5.

For Bergen, the additional effect of a monetary policy shock the first quarter is 3 percent at a 5 percent significance level. After two years, the interaction effect is about -6.6 percent, although not significant. Housing prices in Bergen are more affected by a monetary policy shock than Rælingen and Bærum. One reason could be that the housing prices in Bergen is among the highest in Hordaland,[31] and therefore, most people move from Bergen following an contractionary monetary policy shock. It should be noted that the additional effects estimated for Bærum, Rælingen and Bergen are less precisely estimated than what in the case for Oslo.

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[31] Statistics Norway StatBank table 06696: URL: https://www.ssb.no/statbank/table/06696/.

# 6.3 Regression Analysis for Group of Areas Based on Centrality

## 6.3.1 Defining Centrality Groups Based on the Panel Data

Statistics Norway centrality index is calculated based on driving distance to goods and service one need in a daily basis. Therefore, the most central areas in Norway are not necessarily the largest cities, see Table 2.B in Appendix B. Statistics Norway have divided the areas in different centrality classes based on their centrality index, see Section 4.3.2, for all the municipalities in Norway. I will group the municipalities in my sample into five groups depending on their measure of the centrality index. I let Oslo be a separate group, whereas the other areas are partitioned into (almost) equally sized groups. Four of the municipalities in my data set have the same centrality index, which is why some groups consist of more municipalities than others. Since the panel data contains only 45 municipalities out of a total of 422 municipalities[32], my grouping of the municipalities will differ from Statistic Norway's centrality classes. The reason is that it will be a large difference in the number of municipalities in each centrality class, whereas as my groups are, with the exception of Group 1 (only Oslo), almost equally sized.

The top 11 most central areas in my panel data are the areas surrounding Oslo, in addition to Bergen and Trondheim. Table 6.5 summarize my grouping of municipalities based on centrality.

---

[32] SNL. URL: https://snl.no/kommune

Table 6.5: Centrality groups

| *Centrality groups* | *Range of centrality order in panel data* | *Interval in Statistics Norway centrality index rage* | *Number of Municipalities* | *Description* |
|---|---|---|---|---|
| **Group 1** | 1 | 1000 | 1 | For the first class, only Oslo is included. |
| **Group 2** | 2-11 | 898-971 | 10 | Including municipalities in the Oslo area, in addition to Trondheim and Bergen. |
| **Group 3** | 12-21 | 860- 896 | 11 | Group 3 include municipalities like Lier, Askim and Horten. |
| **Group 4** | 22-31 | 808-855 | 11 | Municipalities like Nesodden, Kongsberg and Tromsø is included in this group. |
| **Group 5** | 32-41 | 704-803 | 12 | This group is categorized as the least central group. Municipalities like Vefsn, Narvik and Alta is included in this group. |

**Note:** Group 3: Sandnes and Sarpsborg has the same centrality index (887). Group 4: Stange and Askøy has the same centrality index (814). Group 5: Arendal and Gjøvik have the same index (803) and Elverun and Notodden have the same index (762).

## 6.3.2 Centrality Groups Interacted With a Shock

To study difference across the five centrality groups, I use a specification with multiple interaction terms:

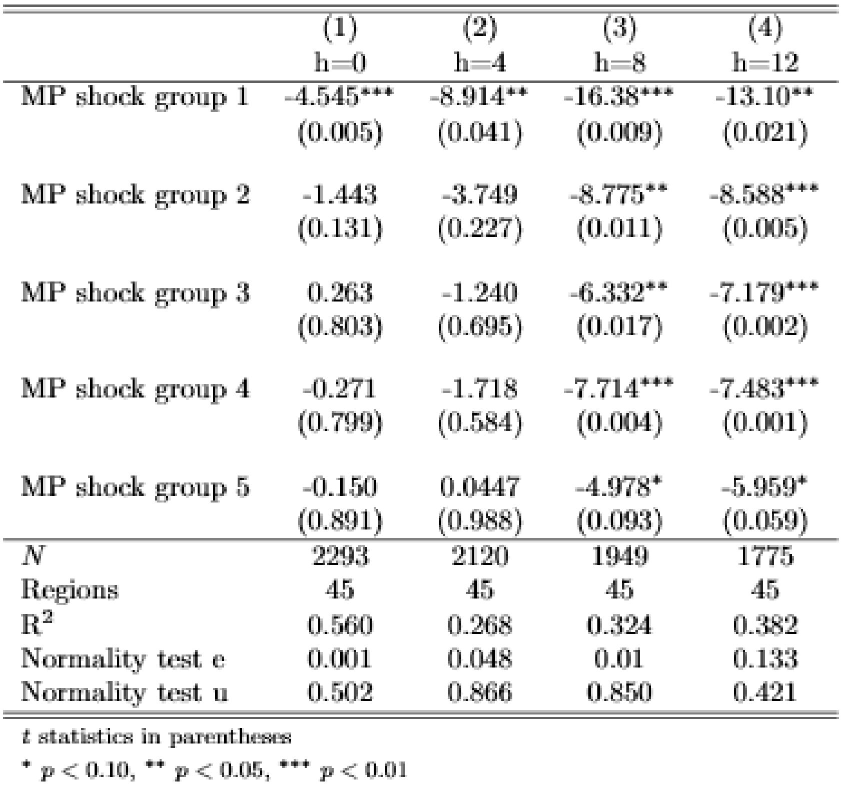
$$ph_{i,t+h} - ph_{i,t-1} = \propto_i + \beta_h^{MP,group\ 1} * {MP_t}^{group1} + \beta_h^{MP,group\ 2} * {MP_t}^{group2} + \beta_h^{MP,group3} * {MP_t}^{group,3} + \beta_h^{MP,group4} * {MP_t}^{group,4} + \beta_h^{MP,group5} * {MP_t}^{group,5} + \boldsymbol{\Gamma}'\boldsymbol{W_{i,t}} + D_{crisis} + D_{regulation} + S_1 + S_2 + S_3 + \varepsilon_{i,t} \tag{6.2}$$

A one percentage point increase in $MP_t$ in area i (i=1,…, 5) will give the following expected change in the housing prices:

$$\frac{\partial E\left((ph_{i,t+h} - ph_{i,t-1}) \mid \boldsymbol{W_{i,t}} MP_t^{group_i}\right)}{\partial MP_t^{group_i}} = \beta_h^{MP,group_i}$$

The coefficient is interpreted as the total effect of a monetary policy shock on housing prices in group i.

Table 6.6: Results of panel regrssion with centrality groups 1-5



| | (1)<br>h=0 | (2)<br>h=4 | (3)<br>h=8 | (4)<br>h=12 |
|---|---|---|---|---|
| MP shock group 1 | -4.545*** | -8.914** | -16.38*** | -13.10** |
| | (0.005) | (0.041) | (0.009) | (0.021) |
| MP shock group 2 | -1.443 | -3.749 | -8.775** | -8.588*** |
| | (0.131) | (0.227) | (0.011) | (0.005) |
| MP shock group 3 | 0.263 | -1.240 | -6.332** | -7.179*** |
| | (0.803) | (0.695) | (0.017) | (0.002) |
| MP shock group 4 | -0.271 | -1.718 | -7.714*** | -7.483*** |
| | (0.799) | (0.584) | (0.004) | (0.001) |
| MP shock group 5 | -0.150 | 0.0447 | -4.978* | -5.959* |
| | (0.891) | (0.988) | (0.093) | (0.059) |
| $N$ | 2293 | 2120 | 1949 | 1775 |
| Regions | 45 | 45 | 45 | 45 |
| $R^2$ | 0.560 | 0.268 | 0.324 | 0.382 |
| Normality test e | 0.001 | 0.048 | 0.01 | 0.133 |
| Normality test u | 0.502 | 0.866 | 0.850 | 0.421 |

$t$ statistics in parentheses

$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

**Note**: The table shows the effect on housing prices of a monetary policy shock when using group 1-5 as an interaction term. The dependent variable is the cumulative log change in the housing price index at a horizon h = 0, 4, 8 and 12. The results are based on the estimating equation (6.2) using fixed effect estimator and the data covering 45 municipalities in Norway from the period 2003 Q1 – 2017 Q4. The brackets report the p value, and the statistical tests of normality from Alejo et al. (2015), see Section 5.

Results from Table 6.6 shows that the additional effect for Oslo is, as expected, still is large and significant. The effect for the next 10 most central areas (group 2) is greater than the other municipalities, but considerably smaller than for Oslo. Besides group 3, the effect of a monetary policy shock on housing prices increase (in absolute value) with centrality at all horizons. The first quarter after the shock, the effect is smallest for group 3. Housing prices for the municipalities for group 3 might not have the same effect of a shock because of relocation, as discussed in the analysis of Rælingen.

The additional affect a shock on the housing prices for the 12 least central municipalities are positive for horizon four, but significant for at the two- and three- year horizon. Even though the results show a positive effect, is it necessary to be careful calming that the relationship of the housing prices and key interest rate is positive for the least central areas. The way Eiendom Norge's calculate their housing price index, is to estimate a weighted average of all the transaction during a time period. For the least central areas, it is not necessarily that many housing sales during a quarter. Therefore, one sale of a very expensive house could increase the average much more compared to a central area with multiple transactions. However, the differences between group 5 and 4 versus group 2 and Oslo is acknowledged.

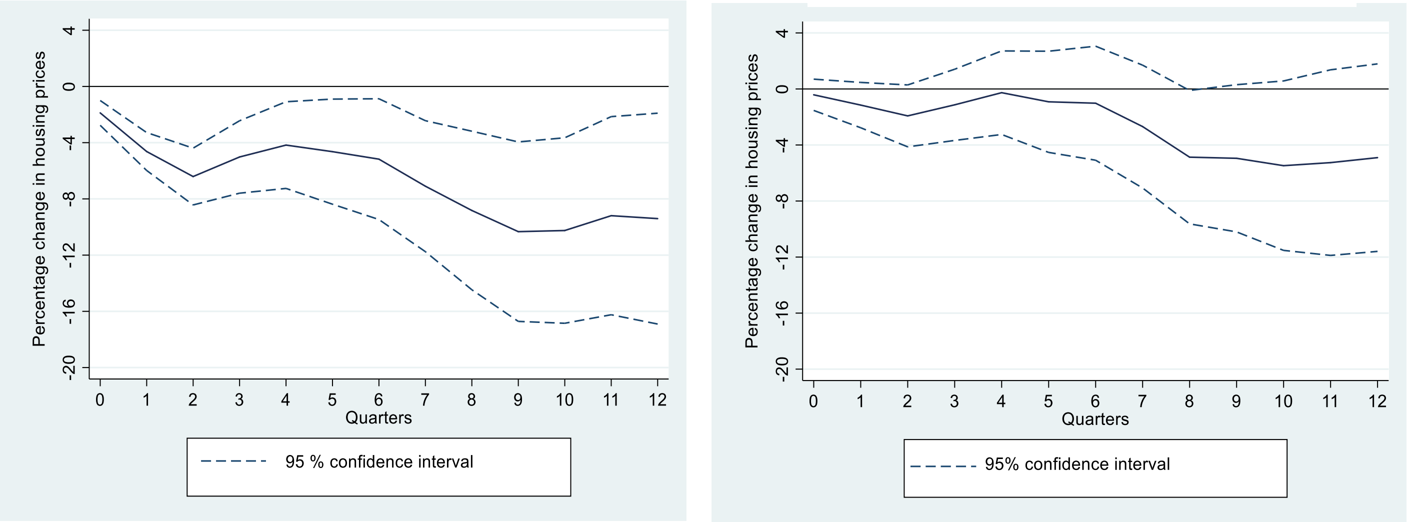
### 6.3.2 Impulse Response Functions Based on Statistics Norway Centrality Classes

The centrality classes defined by Statistics Norway are based on all the municipalities in Norway. Since the panel data only contains 45 municipalities, I created an alternative grouping, so that each group have almost the same number of municipalities. The drawback of this grouping is that the interval of centrality classes will be inconsistent across groups. It can therefore be useful to also analyze the effect of monetary policy using Statistics Norway's centrality classes. As mentioned previously, the number of municipalities is not consistent across the classes, so the uncertainty will be higher for centrality class 1 and 4. Most municipalities are classified as belonging to centrality class 2 and 3, and only 6 municipalities fall in class 1 and 4 (the most and least central areas).

Figure 6.1: The total change in housing prices for the representative centrality class followed a one percent shock in the key interest rate

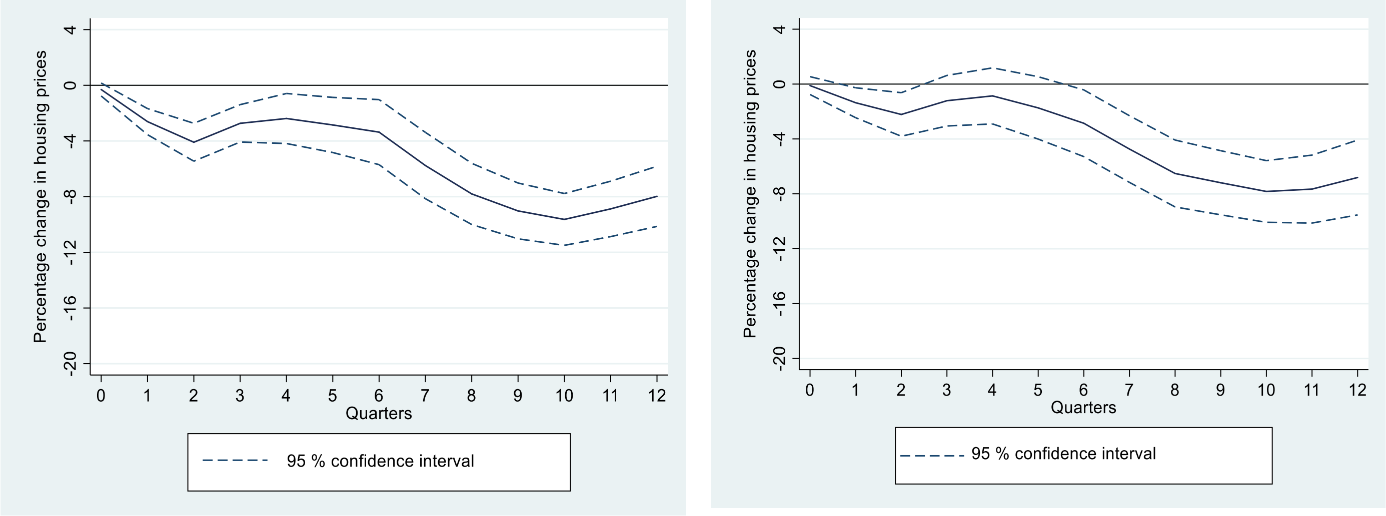
Class 1

Class 4



Class 2

Class 3



**Note**: The impulse response function shows the sum of the interaction coefficient and the constant to the total effect of the monetary policy shock. The dotted lines is the 95 percent confidence interval for the estimated interacted coefficient. The interacted term is the different centrality classes defined by Statistics Norway. The impulse response function shows the interacted effect of the cumulative log change in the housing prices after h = i when i=1, 2, 3, ... , 12 followed by a monetary policy shock.

Impulse response functions using Statistics Norway's centrality classes indicates that there is a difference in the response of housing prices to a monetary policy shock, depending on centrality. The differences between class 2 and 3 is marginal, while the differences between class 1 and 4 is large. One year after the shock, the difference in the interacted effect of centrality class 1 and 4 is about 6 percent.

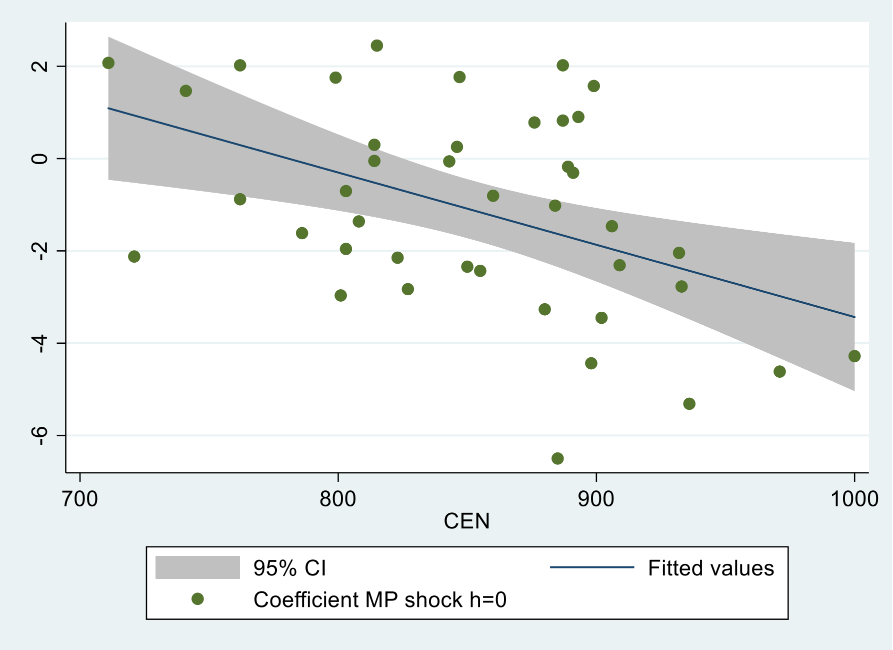
In Appendix B.1, the impulse response functions for the different groups used in the models are presented. The differences between group 2 and 3 is smaller in this case. In addition, group 2 have a smaller response to a monetary policy shock than group 3, after one year. Therefore, based on the results from the panel data, one cannot unanimously claim that increased centrality always increases the impact of monetary policy on housing prices. Still, there is a clear difference between the most and least central areas.

### 6.3.3 Area-by-area Analysis

The scatter plot illustrated in Figure 6.2 shows all the coefficients for the municipalities in the panel data, excluding outliers. The coefficients illustrates the percentage change the housing prices one and twelve quarter following a monetary policy shock. The scatter plot is estimated by interacting all municipalities in the model presented in Equation (5.2) in Section 5. This way, it is possible to separate all the estimated effect to each on the municipalities in the panel data.

In the short run, the effect of a monetary policy shock to the housing prices is clearly more negative for the most central municipalities. The coefficients for the most central areas is below -4 percent. One reason could be relocation, as mention earlier – as a result of increased debt burden. A result of contractionary monetary policy would be that people move from the cities, and expansionary that people move to the cities.

Figure 6.2: The short run effect of a monetary policy shock on housing prices



**Note:** The x-axis represents the centrality index where 700 are the least central area and 1000 is the most central. The estimated coefficients are from model 5.2 with horizon equal zero where all the areas are interacted with the monetary policy shock. Large outliers are removed from the scatter plot.

According to the impulse response functions, the housing prices in all regions is effected by the shock in the long-run. One reason could be that the response to macroeconomic variables such as GDP and unemployment is highest after three years, see Appendix C. Therefore, the ability-to-pay is lower for all household, no matter centrality.

The results confirms the development in the housing prices in Oslo the last years; where the monetary policy have been expansionary and the housing prices historically high, see Figure 2.1 Section 2. In addition, the increased number of households compared to the number of houses (especially in Oslo), indicate that housing supply might be more inelastic in the cities. The results is therefore in line with the conjectures from Section 4.

# 7. Limitations and possible extensions

In this section, I will discuss some of the limitations of my analysis of how monetary policy affects regional housing prices in Norway. In addition, I will present potential extinctions of this thesis that I would have pursued if time had allowed me to.

In Section 3, I presented Statistics Norway's centrality index, where each municipality gets a number between 0 and 1000 to describe how central the area is relative to other areas. The index is calculated on traveling distance to work, schools, shops and service. The centrality classes defined by Statistics Norway- groups all Norwegian municipalities in six different classes - where class 1 are the most central municipalities and class 6 contains the least central municipalities. In the panel data set used in this thesis, there are only municipalities in class 1-4. Therefore, the least central municipalities in Norway are excluded, which is a limitation of my analysis. My results can therefore only be used to compere the most central municipalities to municipalities with middle centrality. That said, given that I find that more central areas respond more to a monetary policy shock, one could expect the effect of a monetary policy shock to be even smaller in the least central municipalities. If this is the case, results would be stronger.

Nevertheless, it is very difficult to construct housing price indexes for the least central areas. The reason for this is that there are very few, or no transactions, in several smaller municipalities. This would make it difficult, or even impossible, to construct a housing price index. As mentioned in Section 5, the housing price indexes for municipalities in class 4 can be contaminated by very few transactions being used in the index-construction. Therefore, one very expensive, or one very inexpensive, house can drive the hedonic price index to a larger extent that in the most central areas. For this reason, an extending of the data set of include municipalities also from non-central areas could be difficult. What could be done, however, is to analyze different sub-districts within Oslo, Trondheim and Bergen, and explore if they response differently to the same shock. Furthermore, it is possible to create house price indexes for more of the municipalities in class 1-4, which would increase the sample size and therefore improve estimation efficiency.

Previous literature has shown that there are asymmetric effects of monetary policy shock on real and financial variables, see Aastveit and Anundsen (2017), Angrist et al. (2017), Tenreyro and Thwaites (2016) and Barnichon and Matthes (2018). Aastveit et al. (2019a) have shown that local differences in housing supply elasticities matter of the transmission of monetary policy shocks to housing prices. In this thesis, I did not estimate separate housing supply elasticities for the different municipalities, as the main focus has been on the role of centrality. However, a possible extinction would be to look into whether similar results hold for Norway, and in particular how they interact with differences in centrality.

In Section 4, I presented the different statistical tests. The normality test is violated for some of the models, and therefore, the t-statistics may be a crude approximation of a t-distribution variable. Because of limiting time, I could not investigate this problem further. Reasons could be high volatility in housing prices, or that micro variables for disposable income and debt level are converted with cubic methods to a quarterly frequency. In an extension it would be natural to pursue this in more detail, e.g., by using bootstrap-methods.

### Financial stability considerations and liquidity risk

Should central bank consider centrality when evaluating financial stability? According to the results in Section 5, there is a significant difference between the most and least central areas in how housing prices corresponds to a monetary policy shock. Taking into consideration that 90 percent of households in Norway live in the most central areas – it could be an argument that centrality need to be considered. Still, one caveat is that there is not “enough” statistical evidence to conclude that centrality plays a major role, since the difference between group 3 and group 4 is relatively marginal.

The large additional effect for Oslo could be something to consider. Since 673 469 people are living in Oslo (registered in 2018)[33] a fall in housing prices could have a large wealth effects

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[33] StatBank table 07459.

on consumption. As mention in Section 1, the Norwegian banking crisis in 1988-1993 developed to a liquidity crisis – mostly centered in Oslo. Furthermore – an expansionary monetary policy shock could increase housing prices considerably, and result in an increase in the debt level, which is typically seen as worrisome for financial supervisory authorities. If a contractionary monetary policy shock follows a period of debt accumulation, it could be a concern that housing prices falls so much that some households may struggle to finance their mortgages. This concern is important to consider when evaluating financial stability.

# 8. Conclusion

This thesis has aimed at understanding the role centrality plays in the transmission of monetary policy to Norwegian housing prices. To study this, I created a panel data set containing variables for 45 municipalities in Norway over the period 2003 Q1 – 2017 Q4. Collecting data for housing price indexes from Eiendom Norge, monetary policy shocks from Holm et al. (2019), centrality index from Statistics Norway, and other control variables from Norges Bank and Statistics Norway, I analyzed what role centrality plays in the transmission of monetary policy to housing prices. I applied local projection method developed by Jordà (2005), and my results show that Oslo and Bergen stand out from the rest of the panel, with significantly greater response. The additional effect for Oslo, compared to the rest of the panel, is 7 percent after one year, and 9.5 percent after two years. There are also some signs that people relocate following a monetary policy shock – mainly from the most central areas where the debt level is highest, to less central areas.

The disaggregated founding's are important in order to understand the underlying heterogeneity in the Norwegian housing market. When using the centrality index as an interaction term, results show a significant additional affect contemporaneously. When grouping the municipalities from the most central (group 1) to the least central (group 5), results show that the additional effect of monetary policy increases with centrality, with the exception group 3. Analyzing the centrality classes defined by Statistics Norway, the corresponding effect of monetary policy on the housing prices is clearly largest in the most central class - while the response is more muted in the least central areas.

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# Appendix

## Appendix A Supplement to Section 5

### A.1 The Traditional Dickey-Fuller (1976) Test for Unit Root

Consider the following specification:

$$y_t = \mu + \beta t + \sum_{i=1}^{p} \gamma_i \, y_{t-i} + \varepsilon_{it},$$

Where $\mu$ is a drift and t is the linear trend. A simple re parameterization of equation:

$$\Delta y_t = \mu + \beta t + \gamma y_{t-1} + \sum_{i=1}^{p-1} \alpha_j \, \Delta y_{t-i} + \varepsilon_t,$$

Where $\gamma = \sum_{i=1}^{p} \gamma_j - 1$ and $\alpha_j = -\sum_{k=j+1}^{p} \gamma_k$

The integration order of variable y is tested with the following hypothesis:

$$H_0 : \gamma = 0, \qquad H_A : \gamma < 0$$

If the null hypothesis is not rejected, it means that $y_t$ is integrated of the first order. If this is the case; then it is necessary to differentiate the variable one more time, and then following integration order of $\Delta y_t$ should be tested. If the null hypothesis is rejected, then the series do not contain a unit root. Under the null hypothesis, the coefficients do not follow a normally distribution, so the t-value need to be compared to the critical values from the Dickey-Fuller distribution, in order to reject $H_0$ hypothesis (Lütkepohl & Kratzing, 2004; Chapter 2).

## A.2 Harris-Tzavalis Test for Unit Root

The null hypothesis of the test is that there is a unit root, versus the alternative of a single stationary value.

The estimated model for the test is:

$$y_{i,t} = \propto_i + u_{i,t} \qquad u_{i,t} = \rho u_{i,t-1} + \varepsilon_{it}$$

$$\varepsilon_{i,t} \sim N(0, \sigma^2)$$

The null hypothesis is $\rho = 1$.

Table A.1: Harris Tzavalis unit root test

|  | Rho Statistics | Empirical probability of rejection | Deterministic trend |
|---|---|---|---|
| **In levels:** |  |  |  |
| *MP shock series* | 0.505 | 0.000 | Stationary |
| *Housing starts* | 0.154 | 0.000 | Stationary |
| **First differences:** |  |  |  |
| *Housing prices:* |  |  |  |
| *h=0* | 0.220 | 0.000 | Stationary |
| *h=4* | 0.835 | 0.000 | Stationary |
| *h=8* | 0.905 | 0.000 | Stationary |
| *h=12* | 0.917 | 0.000 | Stationary |
| *Unemployment rate* | -0.436 | 0.000 | Stationary |
| *Average debt level* | 0.640 | 0.000 | Stationary |
| *Average income* | 0.655 | 0.000 | Stationary |
| *Population* | -0.020 | 0.000 | Stationary |

## A.3 Hausman Test for Fixed Versus Random Model

The Hausman test is estimated using the command xtreg compering specification fe and re. The null hypothesis under the Hausman statistics is:

$$H_0:\ W = (\hat{\beta}_{FE} - \hat{\beta}_{RE})'\left[\hat{V}(\hat{\beta}_{FE}) - \hat{V}(\hat{\beta}_{RE})\right]^{-1}(\hat{\beta}_{FE} - \hat{\beta}_{RE}) \sim \chi^2(k)$$

If the null hypothesis is rejected, the fixed effect model is the best fit.

Table A.2: Results from Hausman tests

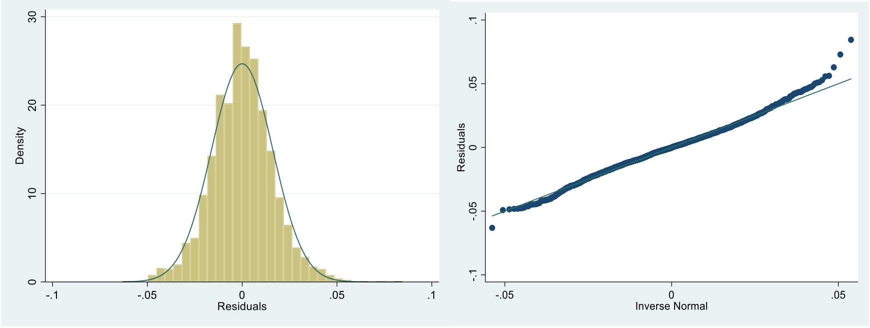
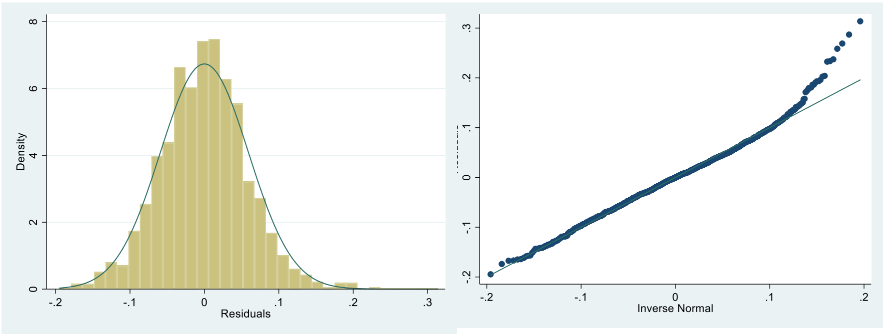
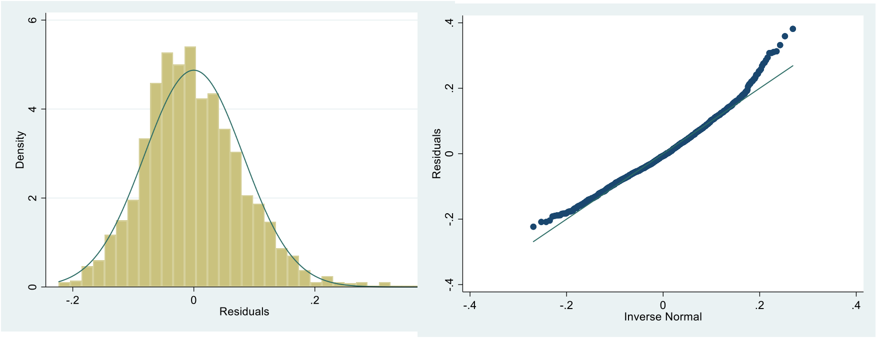
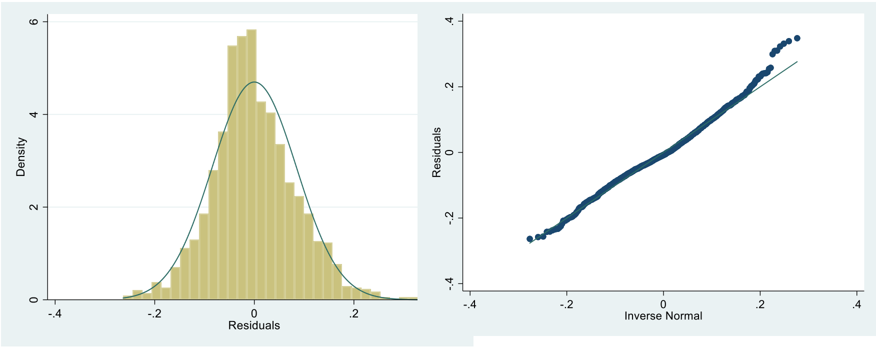
| Equation (5.1) | *Prob>chi2* |
|---|---|
| *h=0* | 0.997 |
| *h=4* | 0.001 |
| *h=8* | 0.000 |
| *h=12* | 0.000 |

| Equation (6.1) | *Prob>chi2* |
|---|---|
| *h=0* | 0.999 |
| *h=4* | 0.000 |
| *h=8* | 0.000 |
| *h=12* | 0.000 |

| Equation (6.2) | *Prob>chi2* |
|---|---|
| *h=0* | 1 |
| *h=4* | 0.000 |
| *h=8* | 0.000 |
| *h=12* | 0.987 |

**Note:** The fixed and random effect models used in the Hausman test is estimated with use of xtreg command in STATA. The models in the results is estimated with Driscoll and Kraay (1998) standard errors.

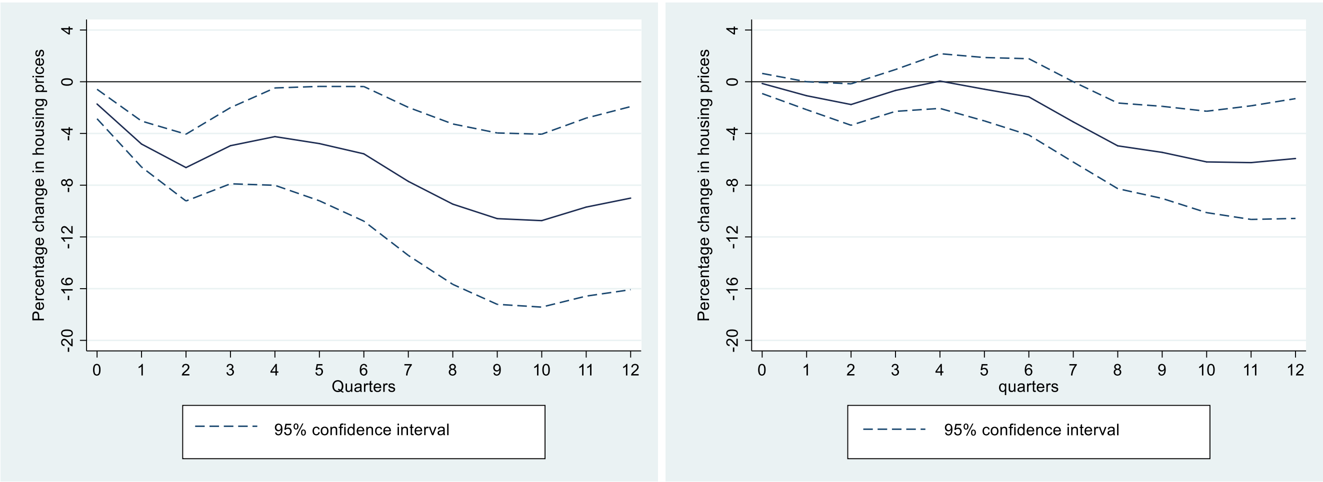
## A.4 Normality of Residuals

| *Equation (5.1)* | ***Histogram and Q-Q plot*** |
|---|---|
| *h=0* |  |
| *h=4* |  |
| *h=8* |  |
| *h=12* |  |

# Appendix B Regions in the Analysis

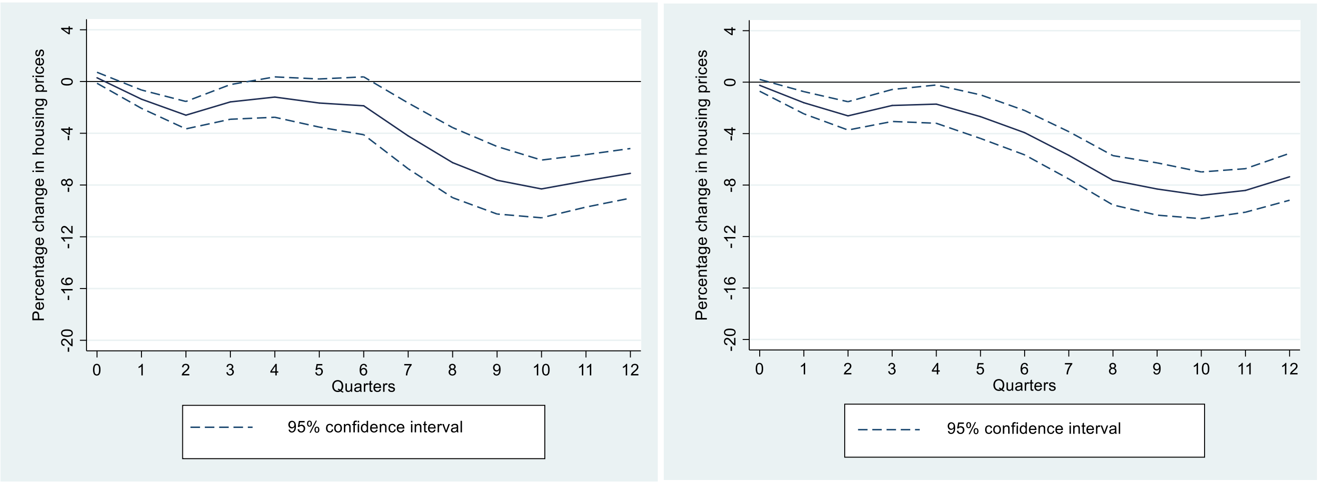
## B.1 Impulse Response Functions

Figure B.1: The total change in housing prices for the representative centrality groups followed a one percent shock in the key interest rate



Group 2 including Oslo

Group 5

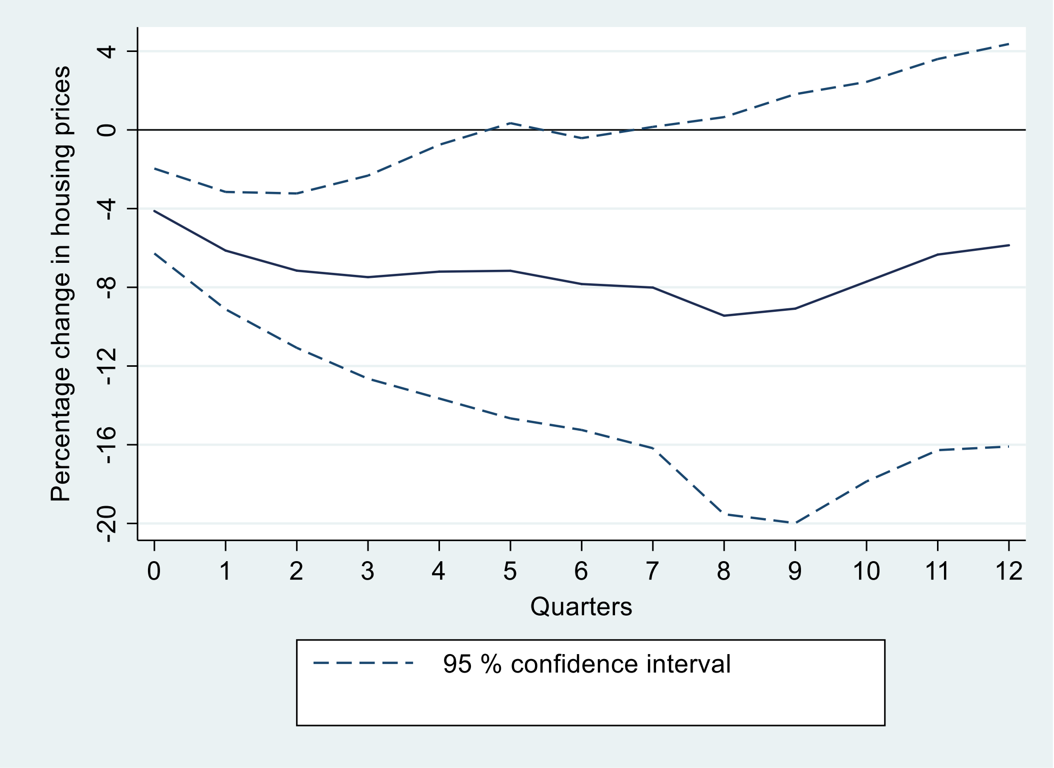


Group 3

Group 4

**Note**: The impulse response function shows the sum of the interaction coefficient and the constant to the total affect of the monetary policy shock. The doted lines is the 95 percent confidence interval for the estimated interacted coefficient. The interacted term is the different groups used in the models. The impulse response function shows the interacted effect of the cumulative log change in the housing prices after h = i when i=1, 2, 3, ... , 12 followed by a monetary policy shock.

Figure B.2 Impulse response function: the additional Oslo effect



**Note**: The impulse response function shows the interaction coefficient of Oslo from regression 6.1. The figure then shows the additional effect of the cumulative log change in the housing prices in Oslo relative to the rest of the panel followed by a monetary policy shock.

## B.2 Municipalities in Norway and the Centrality Index

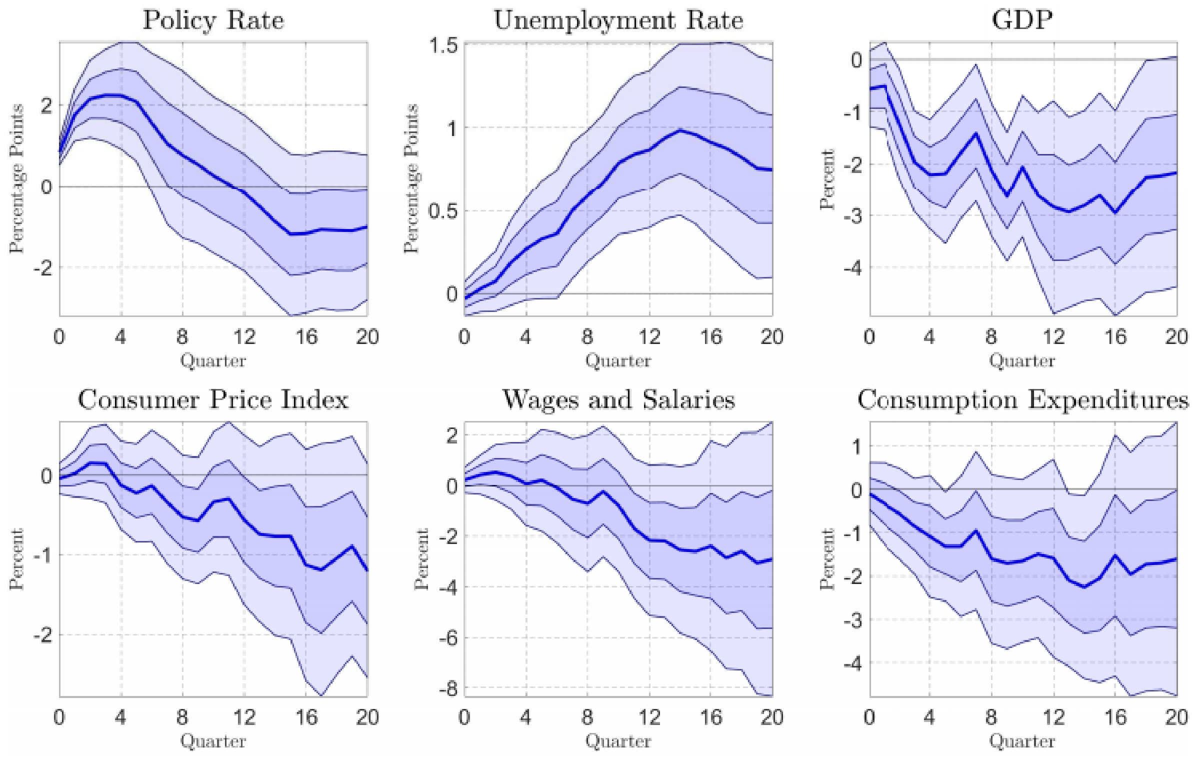
Table B.1: Municipalities used in panel data

| **Municipalities** | **Centrality index** | Nesodden | 855 |
|---|---:|---|---:|
| Oslo | 1000 | Kongsberg | 850 |
| Bærum | 971 | Eidsvoll | 847 |
| Rælingen | 942 | Skien | 846 |
| Asker | 936 | Halden | 843 |
| Drammen | 933 | Ålesund | 827 |
| Moss | 932 | Lillehammer | 823 |
| Ullensaker | 909 | Ringerike | 815 |
| Frogn | 906 | Stange | 814 |
| Bergen | 902 | Askøy | 814 |
| Ås | 899 | Tromsø | 808 |
| Trondheim | 898 | Arendal | 803 |
| Lier | 896 | Gjøvik | 803 |
| Askim | 893 | Bodø | 801 |
| Tønsberg | 891 | Kongsvinger | 799 |
| Horten | 889 | Ringsaker | 786 |
| Sandnes | 887 | Bamble | 775 |
| Sarpsborg | 887 | Elverum | 762 |
| Nittedal | 885 | Notodden | 762 |
| Fredrikstad | 884 | Kragerø | 741 |
| Vestby | 880 | Alta | 721 |
| Hamar | 876 | Narvik | 711 |
| Porsgrunn | 860 | Vefsn | 704 |

**Note**: The table shows the 45 municipalities I have included in my analysis, and the appurtenant centrality index.

# Appendix C Effect on the Macroeconomic Variable Followed a Monetary Policy Shock

Figure C.1: The effect of a monetary policy shock to the macro economy in Norway[34]



**Note**: The figures illustrates the impulse response function with quarterly frequency. A one-percentage point contractionary monetary policy shock.

Source: Holm et al. (2019).

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