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# House Prices and Household Debt in Norway: An Econometric Analysis



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## Abstract

It is commonly acknowledged that historically high levels of house prices and household debt pose risks for macroeconomic and financial stability in Norway. This thesis is aimed at understanding what are the driving forces behind the development in house prices and household debt in Norway since the 1980s. By surveying the empirical literature, the study by Anundsen and Jansen (2013) is found to be of particular interest. Their model of the interaction between house prices and household credit in Norway is studied in detail and re-estimated over an extended sample. Following this, a re-specification of the long-run relationships of their model that seems to better match the extended data sample is introduced.

Next, by building on Anundsen and Jansen (2013), a new model for the housing market and household debt is developed. Specifically, the econometric modelling is focused on challenging two assumptions made by Anundsen and Jansen (2013): First, that it is valid to condition on the supply of housing when modelling house prices and household borrowing. Second, that none of the variables in the information set are integrated of an order higher than one. Regarding the first assumption, the results suggest that it is valid to condition on the *flow* of new dwellings when estimating long-run relationships for house prices and household debt. Regarding the second assumption, two variables of interest in the analysis, real household debt and the housing stock, are found to be  $I(2)$  variables. A simple solution is suggested to ensure that all unit roots are accounted for in the econometric analysis.

Like Anundsen and Jansen (2013), it is found to be of importance to account for mutual dependence between house prices and household borrowing when modelling the housing market. Both house prices and household borrowing are found to depend positively on disposable income and negatively on interest rates. Housing supply is found to depend on a proxy for the profitability of supplying new dwellings. Dynamic simulation of the model shows that shocks are amplified by self-reinforcing effects between house prices and credit. Over time, the supply of housing responds to changes in prices and dampen the credit and house-price cycles.



## Preface

This thesis represents the end of my studies at the University of Oslo.

I would like to thank my supervisors Roger Hammersland at Statistics Norway and Ragnar Nymoen at the University of Oslo for excellent supervision. It has been a privilege to be guided by and learn from such experienced and accomplished researchers.

I would also like to thank the research-group for macroeconomics at the research department of Statistics Norway for including me in an inspiring work environment. Thanks to Thomas von Brasch for teaching me Eviews and Pål Boug for interesting discussions.

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Any mistakes or shortages are solely my responsibility.

Oslo, May 2019

Magnus Åstebøl



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# Chapter 1

## Introduction

House prices and household debt levels in Norway have been trending upwards ever since the deregulation of housing and credit markets in the 1980s and the subsequent Norwegian Banking Crisis. This thesis seeks to answer the following question: *What are the driving forces behind the development in house prices and household debt in Norway since the 1980s?*

Why is this important to study? First and foremost, there is widespread agreement that historically high levels of house prices and household debt pose risks for macroeconomic and financial stability in Norway (Lindquist and Riiser, 2018). A growing empirical literature is focused on how rapid growth in house prices and credit can lay the foundation for future instability (Borio and Drehmann, 2009; Cerutti et al. 2017; Jorda et al. 2013, 2015a, 2015b; Anundsen et al. 2016). Studies such as Borio (2014), Claessens, Kose, and Terrones (2011), Cerutti et al. (2017) find that cycles in credit and house prices tend to be tightly linked. Borio (2014) argues that for most industrialized countries, it is not possible to understand business fluctuations and the corresponding policy challenges over the last three decades without better understanding of cycles in credit and property prices. Anundsen et al. (2016) find that the probability of a financial crisis increases when rapid growth in house prices coincides with high household leverage. Based on a cross-country study (including Norway), Jorda et al. (2016) conclude that:

”Financial stability risks have been increasingly linked to real estate lending booms which are typically followed by deeper recessions and slower recoveries. Housing finance has come to play a central role in the modern macroeconomy.”

In Norway, the development in house prices and household credit is tightly linked as mortgage credit make up the majority of households’ borrowing. Anundsen and Jansen (2013) underline the importance of taking into account credit effects when modelling housing markets in Norway.

To answer the question raised in this thesis, emphasis is put on previous empirical work. The study by Anundsen and Jansen (2013) is found to be of particular interest and their model of house prices and household credit is studied in detail. Following this, a new model for the housing market and household debt is developed, applying a systems approach inspired by

Anundsen and Jansen. The results confirm the previous finding by Anundsen and Jansen of self-reinforcing effects between house prices and household credit in Norway. Further, two assumptions made by Anundsen and Jansen are challenged: First, whether it is valid to condition on the supply of housing when modelling house prices and household borrowing. Second, that none of the variables in the information set are integrated of an order higher than one.

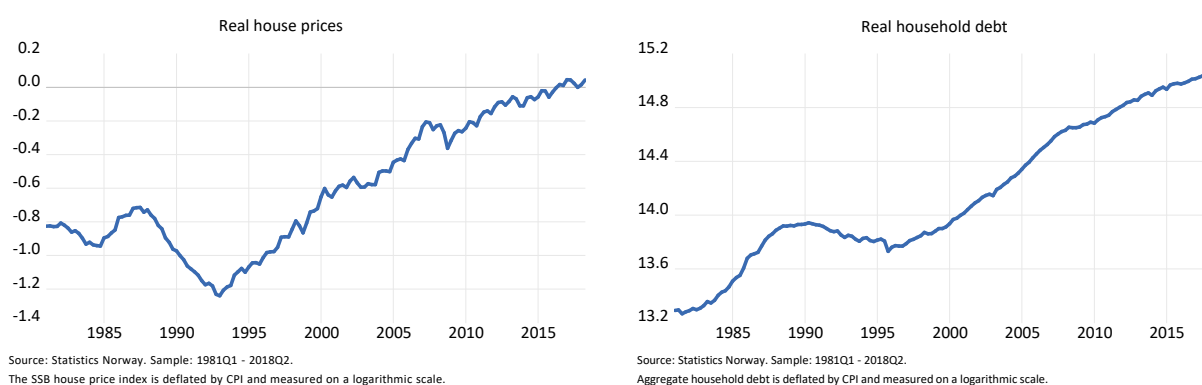
This thesis is organized as follows: The next chapter offers a brief historical account of housing and credit markets in Norway since the 1980s. The third chapter outlines the economic theory applied in the econometric analysis and chapter four summarizes concepts from time series econometrics that are applied in the analysis. Chapter five includes a survey of the empirical literature and chapter six is devoted to the study by Anundsen and Jansen (2013). Chapter seven presents information about the data set that is used for developing a new model of the housing market and household debt in chapter eight. Finally, in chapter 9, the findings are summarized and some suggestions for future research are discussed. The statistical software applied are OxMetrics 7 (with PcGive version 14) and Eviews (version 10).

## Chapter 2

# A Brief Historical Account of Housing and Credit Markets in Norway

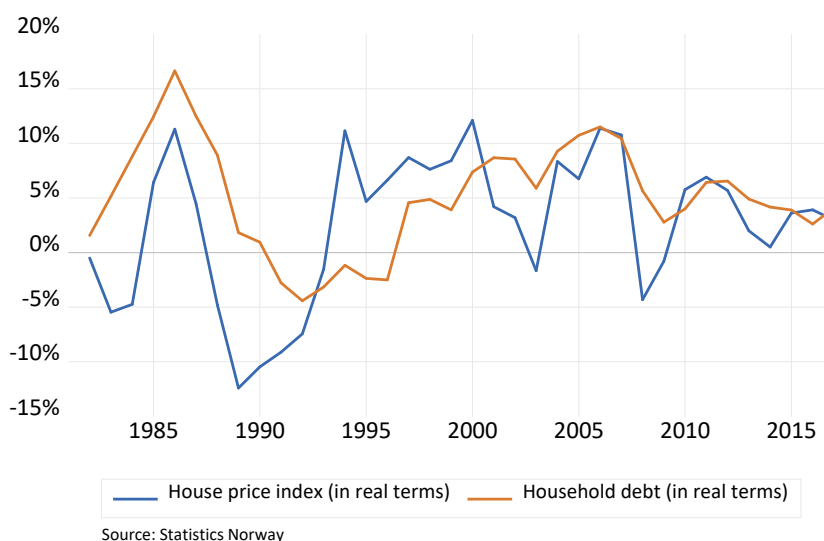
This section offers a brief historical account of housing and credit markets in Norway from the 1980s until 2018. Anundsen and Jansen (2013) summarize some important developments in Norwegian housing markets in this period and Krogh (2010) offers a detailed account of credit market regulations from 1970 to 2008. The period considered involves deregulation of housing and credit markets in the 1980s and the subsequent Norwegian Banking Crisis, followed by a longer period where real house prices and real household debt have been trending upwards, see figure 2.1. Figure 2.2 illustrates how the growth in real house prices and real household debt have been co-varying throughout the period considered.

Figure 2.1: Real house prices and real household debt (in logs)



Housing markets were heavily regulated in the decades following World War II, partly due to limited housing supply (Anundsen and Jansen, 2013). Building materials were rationed and prices and quantities in the housing market were regulated. House prices were relatively stable in the 1970s, despite the real after-tax interest being negative (except from 1978 and 1979). As Anundsen and Jansen (2013) note, credit and housing market regulations were likely to hold expansions in house prices and credit back in these years. Housing market regulations were lifted in 1982 and credit markets were deregulated throughout the 1980s. Additional reserve requirements in the banking sector, which was considered to constrain the credit supply, was

Figure 2.2: Annual growth rates, real house prices and real household debt



abolished in 1984 (Krogh, 2010). Following the changes in regulatory policy, real house prices increased by almost 20 percent from 1984 to 1988. Household debt and house prices measured relative to disposable income increased rapidly in the last part of the 1980s (see figure 2.3 and 2.4).<sup>1</sup> As pointed out by Anundsen and Jansen (2013), the deregulation enabled the banking sector to expand mortgage lending which resulted in a boom in real estate markets.

The development ended with the banking crisis starting in 1987, known as the Norwegian Banking Crisis, which lasted until 1993.<sup>2</sup> Norwegian banks started experiencing net losses in 1987 caused by increased losses on loans and a stock market collapse in October. Plummeting house prices amplified the crisis, decreasing in real terms by over 40 percent from 1988 until 1993. Several banks were forced to close down and the government had to take ownership of some of the largest banks (Krogh, 2010). The crisis also had substantial negative consequences for the real economy and is listed as one of the worlds big five banking crises in the post-war period by Reinhart and Rogoff (2008).

Following the crisis, house prices increased more or less continuously until the financial crisis of 2008-09, accompanied by expanding household debt (see figure 2.1 and 2.2). House prices measured relative to disposable income followed a similar trend (see figure 2.4).

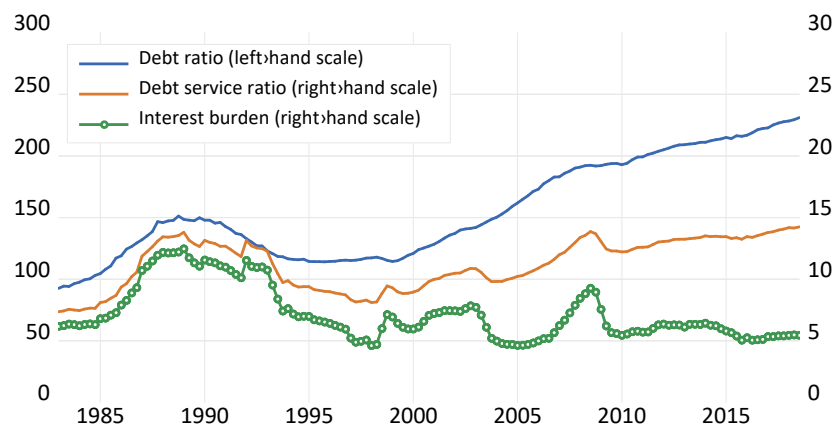
The financial crisis of 2008-09 hit the Norwegian economy as an external shock, but neither Norwegian financial markets or banks were affected that much. Real house prices fell by about 10 percent, but started increasing again already in 2009. Norwegian banks had relatively little exposure to sub-prime mortgages in the U.S and Norges Bank and the Norwegian government introduced extraordinary measures to secure liquidity in the Norwegian banking sector (Krogh, 2010). The decade following the financial crisis has involved expansionary monetary policy, household credit expansion and further growth in house prices. As figure 2.3 illustrates, debt

<sup>1</sup>Figure 2.3 and figure 2.4 are taken from Norges Bank (2018).

<sup>2</sup>Krogh (2010) includes a summary of the crisis, Gerdrup et al. (2004) offers a detailed account of the crisis and its subsequent events.



Figure 2.3: Households' debt ratios and interest expenditures (Norges Bank, 2018)



Source: Norges Bank (2018). Sample: 1983Q1 - 2018Q3.

Series are defined as in Norges Bank (2018):

\*Debt ratio is loan debt as a percentage of disposable income. Disposable income is adjusted for estimated reinvested dividend income for 2000 Q1 - 2005 Q4 and reduction of equity capital for 2006 Q1 - 2012 Q3. For 2015 Q1 - 2018 Q3, growth in disposable income excluding dividends is used.

\*\*Debt service ratio is interest expenses and estimated principal payments on an 18-year mortgage as a percentage of disposable income plus interest expenses.

\*\*\*Interest burden is interest expenses as a percentage of disposable income plus interest expenses.

ratios have increased, while the interest burden has remained stable.

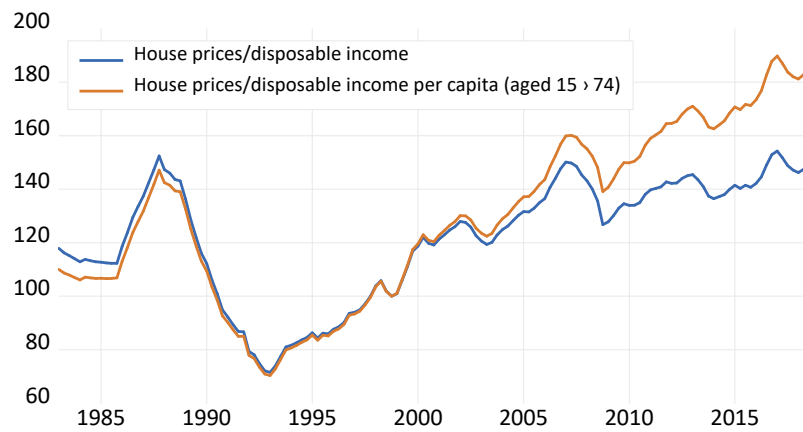
For several years there has been widespread agreement that historically high property prices and household debt levels involve risks for macroeconomic and financial stability in Norway. New macroprudential regulations have been introduced over the last decade (Lindquist & Riiser, 2018).

### Regulatory Policy Since 2010

In 2010, the Financial Supervisory Authority of Norway (Finanstilsynet) introduced guidelines for responsible mortgage lending by banks. Further, in 2015, new regulations were introduced, involving amortization requirements and mandatory testing of households interest rate sensitivity. In addition, banks were only allowed to finance a maximum of 85 percent of a given house purchase. As house prices and household borrowing continued to increase (especially in Oslo), the regulations were extended and expanded in 2017. In addition to the previous requirements, potential buyers of a dwelling can not borrow more than five times their annual income. To target the relatively high house price growth in Oslo and limit speculative investment, special requirements regarding the purchase of secondary dwellings was also introduced (Lindquist and Riiser, 2018). Borchgrevink and Torstensen (2018) study the impact of the regulations introduced in 2017 and find that it has dampened growth in house prices and credit.

Higher capital requirements for banks has been another important component of policy reform following the financial crisis of 2007-08. Capital requirements for Norwegian banks increased substantially in 2013 as the Basel III regulations were introduced (Juelsrud and Wold, 2018). Still, house prices and household borrowing continued to grow. The requirements

Figure 2.4: House prices relative to disposable income (Norges Bank, 2018)



Source: Norges Bank (2018). Sample: 1983Q1 - 2018Q3.

Series are defined as in Norges Bank (2018):

\*Disposable income adjusted for estimated reinvested dividend income for 2000 Q1 - 2005 Q4 and reduction of equity capital for 2006 Q1 - 2012 Q3. Change in disposable income excluding dividend income is used for 2015 Q1 - 2018 Q3.

involved risk-weighted measures were mortgage credit typically have a lower risk weight than corporate credit. Recent research by Juelsrud and Wold (2018) find that Norwegian banks mainly reacted to the capital requirements by rebalancing loan portfolios, reducing corporate credit growth relative to household credit.

To summarize, there is a close relationship between house prices and household credit in Norway and the regulatory policies introduced over the last decade underline the perceived macroeconomic risks related to the record high levels of house prices and household debt. This motivates the need for understanding of the driving forces behind this development.

# Chapter 3

## Economic Theory

This section outlines the theoretical framework underlying the econometric analysis in chapter 8. It is based on the theoretical framework used in Anundsen and Jansen (2013) augmented with a more careful discussion of the supply side of the housing market.

In reality, there is not a single housing market, but several regional markets. Correspondingly, households are heterogeneous with respect to credit constraints. I will follow Anundsen and Jansen (2013) and make the simplifying assumption of viewing regional markets as one single market and study aggregate time series in the econometric analysis. Indeed, variation across regional housing markets and heterogeneous households are lost in such an information set.<sup>1</sup> The theoretical framework corresponds to these considerations.

### 3.1 A Systems Approach to House Prices and Credit

The theoretical framework of Anundsen and Jansen (2013) (from now on: "A&J (2013)") emphasizes that there can be feedback effects between house prices and credit and that a systems approach to these two variables is useful. Later on in chapter 6, we shall see that A&J (2013) found evidence such a two-way relationship studying data for Norway. These feedback effects arise from the fact that households' credit constraints can be endogenous to house prices since dwellings usually serve as collateral for mortgages. If house prices were to increase, more credit is needed to finance the purchase of a given dwelling leading to higher credit demand. At the same time, the value of the collateral that households can provide for mortgage credit (and possibly other types of credit) increases, which can further increase banks' willingness to lend. The result are self-reinforcing effects between house price and credit, which is often referred to as a financial accelerator mechanism in housing markets. It is based on the seminal studies on the relationship between asset prices and credit by Bernanke, Gertler, and Gilchrist (1999) and Kiyotaki and Moore (1997).

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<sup>1</sup>Also, regarding dwellings, none are identical but vary with size, type, location and quality. These characteristics impact the market value of a given dwelling. In the empirical analysis, a house price index that seeks to control for this is analyzed. This is a so-called hedonic price index which measures the average price per unit of housing capital.

## 3.2 Housing Demand

Housing demand can be regarded for analytical purposes as being motivated by demand for housing services and speculation for profits. Some households' behaviour in the housing market can be influenced by both motives. However, Finansdepartementet (2002) state that in Norway, most home purchases are directly related to demand for housing services and the following theory corresponds to this perspective. Hence, it is assumed that there is a close relationship between households willingness and ability to pay, such that a change in the ability to pay leads to a change in demand.

The following summarizes the theoretical derivation in A&J (2013).<sup>2</sup> A&J (2013) take the life-cycle model of house prices commonly applied (see, Meen (2001, 2002), Muellbauer and Murphy (1997, 2008) and augment it with a term capturing the presence of credit constraints (following Meen (1990, 1998)). Given a representative consumer's maximization problem, the first order conditions imply that the marginal rate of substitution (MRS) between housing and a composite consumption good is given by:

$$MRS = PH_t[(1 - \tau_t)i_t - \pi_t + \delta_t - (dph_t^e/dt)/ph_t + \lambda_t/\gamma_c] \quad (3.1)$$

The interpretation of equation (3.1) is that the consumer's marginal willingness to pay for housing in terms of other consumption goods should be equal to the cost in terms of foregone consumption. As stated by A&J (2013), the right-hand side can be interpreted as the real user cost of housing capital augmented with a term representing the credit constraint. The real user cost consists of the real after-tax interest rate  $((1 - \tau_t)i_t - \pi_t)$ , the housing depreciation rate  $(\delta_t)$ , the expected real rate of appreciation in house prices  $((dph_t^e/dt)/ph_t)$  and finally, the shadow price of the credit constraint over the marginal utility of consumption  $(\lambda_t/\gamma_c)$ .

Further, market efficiency implies that there should be no arbitrage between the cost of owning and renting a house, such that in equilibrium, the user cost of a given dwelling should be equal to the cost of renting a dwelling of similar quality (ie. the value of living in the property). The latter is usually referred to as the imputed real rental price for housing services ( $Q$ ), such that the condition is given by:

$$PH_t = Q_t/[(1 - \tau_t)i_t - \pi_t + \delta_t - (dph_t^e/dt)/ph_t + \lambda_t/\gamma_c] \quad (3.2)$$

A&J (2013) follow Meen (2002) and interpret (3.2) as an inverted demand function for the housing stock. Further it is assumed that the depreciation rate is constant and that  $Q$ , which is unobservable, is a function of real disposable income for the household sector (excluding dividends),  $YH$ , and the stock of dwellings,  $H$ . Due to these modifications, the inverted demand function is written as a more general function:

$$PH_t = f^*(H_t, YH_t, R_t, (dph_t^e/dt)/ph_t, \lambda_t/\gamma_c), \quad (3.3)$$

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<sup>2</sup>See section 4 in their paper for more information.

where  $R$  is the real after-tax interest rate. With a constant depreciation rate, the real user cost can be split into two components: the real direct user cost (measured by  $R$ ) and expected real house price appreciation. Following A&J (2013), in the econometric analysis, the real direct user cost will be the operational measure of the user cost of housing, while price expectations will be proxied by including both an expectations indicator and lagged house price growth. The stock of household debt will be used as a proxy for the theoretical credit constraint it is thereby assumed that household debt includes information about credit constraints. Finally, the long-run equilibrium level of real house prices is assumed to be given by:

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

where  $\frac{\partial f}{\partial H} < 0$ ,  $\frac{\partial f}{\partial YH} > 0$ ,  $\frac{\partial f}{\partial R} < 0$ ,  $\frac{\partial f}{\partial D} > 0$  and  $D_t$  is real household debt. Equation 3.4 can be seen as market clearing prices for a given level of the housing stock. House prices are assumed to be an increasing function of disposable income and credit to households. Increased supply of housing is assumed to put downward pressure on prices. The impact of a higher interest rate is expected to be negative.<sup>3</sup> There are relevant factors that are excluded from equation 3.4. Among these are demographic factors, such as the population growth, the size of households, urbanization and tax advantages of house ownership.<sup>4</sup>

A semi-logarithmic transformation of (3.4) will be used in the econometric analysis:

$$\ln PH_t = \beta_1 \ln H_t + \beta_2 \ln YH_t + \beta_3 R_t + \beta_4 D_t \quad (3.5)$$

### 3.3 Housing Supply

According to Ball, Meen, and Nygaard (2010) it is commonly acknowledged in the literature that housing demand is much better understood than housing supply. For example, there is little agreement over common measures such as the price responsiveness of housing supply, with a wide range of estimates in the literature.<sup>5</sup>

A&J (2013) use a relatively simple framework to account for how housing supply responds to the development in prices. The framework will be used as a guideline for empirical modelling and some possible limitations are discussed in the last part of this section.

It is common in the literature to apply Tobin's q-theory of investment to explain supply

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<sup>3</sup>Interest rates can impact housing demand in several ways. A higher interest rate increases borrowing costs and can possibly increase the amount of household being credit rationed. Also, since most mortgage loans in Norway are loans with flexible interest rates, there can also be an indirect impact through disposable income. The opportunity cost of investing in housing also increases, with possible substitution towards other assets. By intertemporal substitution, a higher interest rate may decrease consumption of all goods, including housing, and thereby also decrease the demand for mortgages.

<sup>4</sup>In the working paper version of A&J (2013), it is found that their results do not suggest any separate population effects on the levels of real house prices and real household debt, see [https://www.ssb.no/en/forskning/discussion-papers/\\_attachment/142946?ts=142fab5a6b0](https://www.ssb.no/en/forskning/discussion-papers/_attachment/142946?ts=142fab5a6b0)

<sup>5</sup>Ball et al. (2010) argue that a possible reason for this is differences in policy regimes regarding land use and zoning regulations across countries. The importance of land policies and regulations will not be emphasized in the following.

side behaviour.<sup>6</sup> That is, in its simplest case, to proxy the profitability of supplying new dwellings by assuming that investment is proportional to the relative relationship between the market value of a new dwelling and the costs related to supplying that additional dwelling (the q-ratio).

In A&J (2013) it is assumed that the q-ratio can be proxied by the price of existing dwellings relative to real construction costs. In their model, the supply side is represented by the housing stock ( $H$ ).<sup>7</sup> The housing stock is assumed to be determined by a law of motion for capital equation:

$$H_t = (1 - \delta)H_{t-1} + IH_t, \quad (3.6)$$

where  $\delta$  is the depreciation rate and  $IH$  residential investment. Further, residential investment is assumed to be given by a weighted average of housing starts ( $S$ ) over the past three years:  $IH = J$ , where  $J$  represents this weighted average. Housing starts are seen as a leading indicator for the development in residential investment, which adds to the housing stock over time. In that way, housing starts represent the economic behaviour of property developers making the choice of supplying new dwellings and it is assumed to be determined by real house prices and real construction costs ( $PJ$ ):

$$S_t = h(PH_t, PJ_t) \quad (3.7)$$

Here it would be desirable to include land prices, but due to lack of data, it is assumed that house prices depend on the same variables as land prices (Boug & Dyvi, 2008). To be clear, this implies that the housing stock is a function of house prices, construction costs and the (fixed) depreciation rate in the long-run:

$$H_t = e(h(PH_t, PJ_t); \delta) = v(PH_t, PJ_t; \delta) \quad (3.8)$$

At last, it is also assumed that house prices and construction costs have the same effect on housing starts and that a 1 percent change in either one leads to a 1 percent change in housing starts in the long-run. The relationship takes the following form in logs:

$$\ln S_t = \ln PH_t - \ln PJ_t \quad (3.9)$$

Considering the simplicity here, it is of relevance to be aware of possible limitations. Firstly, the q-ratio should include all types of costs that are taken into account by suppliers of dwellings. In addition to construction costs, this can involve land prices and financing costs. According to Corder and Roberts (2008), the price of land is a key variable when explaining residential

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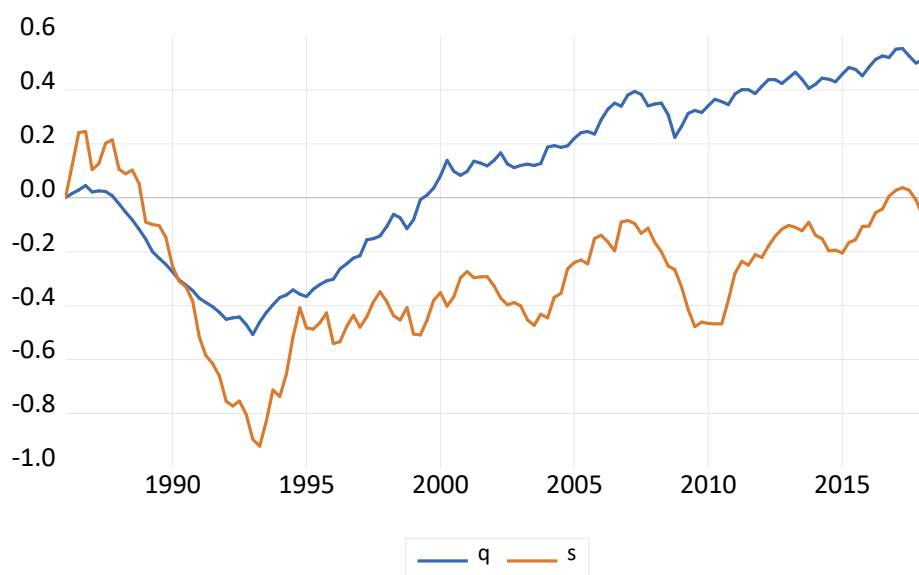
<sup>6</sup>See Jud and Winkler (2003) and Corder and Roberts (2008) for more detailed discussions of Tobin's q-theory applied to the housing market.

<sup>7</sup> $H$  is endogenized in the last part of their study, in an attempt to control for supply side effects in their model of house prices and household debt. For this they use the relations determining the supply of housing in the macroeconomic model KVARTS (see the A Appendix in their paper and Boug and Dyvi (2008) for more detailed documentation).

investment and should be captured in any measure of a  $q$ -ratio, especially for urban areas where land availability is typically a binding constraint. As argued by Grimes and Aitken (2010), the responsiveness of housing supply with respect to price changes can depend on the corresponding development in land prices. In contrast to what is implied by the supply model considered here: If increasing house prices lead to higher land prices, housing supply will not necessarily respond since the profitability of supplying new dwellings also depend on land prices.

In fact, real house prices seem to have been increasing more rapidly than real construction costs for most of the sample that will be considered in the econometric analysis. Figure 3.1 graphs, for Norway, the relative relationship between the Statistics Norway house price index and construction costs index (excluding land prices), together with housing starts. As predicted by the model above, there should be a close relationship between this measure of  $q$  and housing starts over time. Indeed, the series look correlated, but the  $q$ -ratio seems to have been growing more rapidly than housing starts since the 1990s. The development in land prices is likely to play a role here. Migration to urban areas has been a long term trend in Norway, especially since the 1980s. Land prices can be expected to have been increasing in such areas, where most of the population live today (Jacobsen, Haugland, and Solberg-Johansen, 2006). In the econometric analysis, it will be opened for the possibility of testing whether a deterministic can account for this divergence between  $q$  and housing starts.<sup>8</sup>

Figure 3.1: Housing starts ( $s$ ) and the  $q$ -ratio (both in logs)



<sup>8</sup>Another possibility is to introduce other variables that can account for land prices. Modelling residential investment in Norway, Jacobsen et al. (2006) use disposable income as a proxy for land prices, arguing that income growth is a long-term force driving housing demand and thereby land prices too. Disposable income will be part of the information set underlying the econometric analysis in chapter 8 which opens for testing this as well.

### 3.4 The Housing Market in the Short- and Long-Run

Since the supply of housing depends on house prices, the long-run equilibrium relation for house prices (equation 3.4) can be combined with equation 3.8 to get:

$$PH_t = f(v(PH_t, PJ_t; \delta), YH_t, R_t, D_t), \quad (3.10)$$

showing that the long-run equilibrium level of house prices depend on the supply side. When studying the housing market, one often distinguish between the short- and the long-run. As we shall see in the literature review in chapter 5, a common assumption when modelling house prices is to condition on a measure of the supply side and focus on variables related to the demand for housing, similar to equation 3.4. However, since I will study both long- and short-run relationships, the validity of this assumption is uncertain. The importance of taking into account mutual dependence of house prices and housing supply depends on how rapidly the supply side adjusts. As mentioned in the previous section, the supply model used by A&J (2013) assumes the housing stock to depend on housing starts over the past *three years*.

Using data on construction projects of dwellings from 2004 to 2015, Walbækken (2016) provide several interesting insights about the time dimension of the supply of new housing in Norway. The average construction project is found to be listed in the market six months until construction begins. Thus, the *speed of adjustment* of the supply side depends on when new projects are listed in the market. In that way, new supply can impact house prices well before construction projects are finished. Walbækken (2016) also show that, on average, 57 percent of the dwellings in a given project are sold before construction begins and that construction is finished over the following two years for 90 percent of the observed projects.

### 3.5 Household Debt

Mortgage credit is the most important source of financing for Norwegian households buying a property (Solheim and Vatne, 2018). In A&J (2013), the following relationship is assumed to determine real household debt in the long-run:

$$D_t = g(H_t, YH_t, R_t, PH_t, TH_t), \quad (3.11)$$

where  $\frac{\partial g}{\partial H} > 0$ ,  $\frac{\partial g}{\partial YH} > 0$ ,  $\frac{\partial g}{\partial R} < 0$ ,  $\frac{\partial g}{\partial PH} > 0$ ,  $\frac{\partial g}{\partial TH} \geq 0$  and  $TH$  is housing turnover. Eq. 3.11 is based on a similar equation for aggregate mortgage debt in Fitzpatrick and McQuinn (2007). It defines household debt as a function of the housing stock, house prices, the interest rate, disposable income and housing turnover.<sup>9</sup> Aggregate household debt is expected to be an

<sup>9</sup>A&J (2013) does not provide any motivation for why housing turnover is included in their specification. However, Jacobsen and Naug (2004) find a positive significant impact of housing turnover when studying the long-run determinants of aggregate household debt in Norway. The rationale behind this is that the number of housing transactions impacts the aggregate level of mortgage debt. A&J expect aggregate debt to be an increasing function of turnover. However, this depends on the composition of debt between buyer and seller involved in a given transaction. The purchase of a dwelling by a first-time buyer can be expected to be financed mostly by debt. If the individual purchases a new dwelling, then the change in aggregate mortgage debt can be



increasing function of the housing stock, house prices and disposable income. For the latter, higher income is expected to impact households ability to service debt positively.<sup>10</sup>

A semi-logarithmic transformation of equation 3.11 yields the following equation to be implemented in the econometric analysis:

$$\ln D_t = \gamma_1 \ln H_t + \gamma_2 \ln YH_t + \gamma_3 R_t + \gamma_4 PH_t + \gamma_5 TH_t \quad (3.12)$$

The theoretical foundation underlying equation 3.11 is somewhat loose, but the purpose is to endogenize household debt in relation to the housing market. Equation 3.11 does not distinguish between the supply and demand for credit. Regarding the supply of credit, banks' behaviour related to credit risk, underwriting standards and public regulation is likely to be relevant in this setting, but is neglected here.<sup>11</sup>

A&J's sample cover the period 1986Q2 - 2008Q4 and emphasize that the period can broadly be seen as a "post-regulation" sample following deregulating reforms implemented in the 1980s (see chapter 2). Thereby, they do not control for any policy changes. As explained in chapter 2, new regulations targeting house prices and mortgage lending has been introduced, making policy changes somewhat more relevant for my sample (1987Q2 - 2018Q2). This is addressed briefly in the last part of chapter 8.

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expected to be closely related to the price of the dwelling. If the dwelling is bought in the secondary market, then the change in aggregate debt is still positive if the buyer takes on more debt than what is repaid by the seller. If a transaction involves no first-time buyers, then the total change in the aggregate level is more uncertain. See Jacobsen and Naug (2004) for a more detailed discussion.

<sup>10</sup>However, from a theoretical view, it can be argued that a decline in disposable income could lead to increased borrowing. This would be in line with the permanent income hypothesis if households experiencing a temporary decline in income would increase borrowing to smooth consumption over time.

<sup>11</sup>See for example Stiglitz and Greenwald (2003) for a theoretical discussion of bank behaviour.

# Chapter 4

## Concepts from Time Series

### Econometrics

In this section concepts from time series econometrics that will be applied in the empirical analysis are defined. To save space, the definition of the following concepts are given in Appendix A: stationarity, cointegration and unit root testing. The following is based on Nymoen (2019) and references therein.

#### 4.1 Equilibrium Correction Models

In the econometric analysis, equilibrium correction models (ECMs) will be estimated and analyzed. Such models are practical when studying non-stationary variables and open for studying both short- and long-run relationships within the same framework.

As in chapter 6.4 of Nymoen (2019), the ECM-representation of an autoregressive distributed lag (ADL) model equation including one lag of the endogenous variable and one exogenous variable is:

$$\Delta Y_t = \phi_0 + \beta_0 \Delta X_t + (\phi_1 - 1)\{Y_{t-1} - Y^*\} + \epsilon_t, \quad (4.1)$$

assuming that  $Y^*$  is a conditional equilibrium value of  $Y_t$  given  $X_t$  defined as:  $Y^* = \frac{\phi_0}{(1-\phi_1)} + \frac{(\beta_0 + \beta_1)}{(1-\phi_1)} X_t$ . In this specification, changes in the dependent variable can be explained by  $\Delta X_t$ , which refers to short-term dynamics, or an equilibrium correction effect arising from  $Y$  deviating from the conditional equilibrium in the previous period. The equilibrium correction effect will only be present if  $\{Y_{t-1} - Y^*\}$  represents a cointegrated relationship between  $Y$  and  $X$ . The equilibrium correcting effect in the current period will be given by  $(\phi_1 - 1)$ . This one-dimensional example generally holds for higher dimensions.

## 4.2 Mis-Specification Testing

The models developed in the econometric analysis will be aimed at representing underlying data generating processes (DGPs). Following Nymoen (2019, chp.2.8), the issue of model specification will be focused on whether a given model produces residuals that satisfy the classical assumptions of homoskedasticity, non-autocorrelation and normality. This is of importance since residual mis-specification matters for the statistical inference theory applied. Specifically, when estimating multiple equation models, mis-specification will be addressed by relying on the systems versions of the tests for respectively residual normality, heteroskedasticity and autocorrelation that is automatically reported in OxMetrics 7, PcGive version 14 (see Hendry and Doornik (2013), chp. 15).

## 4.3 The Johansen Procedure

The Johansen procedure to cointegration will be applied to test for cointegration and formulate vector equilibrium correction models (VECM), following Johansen (1988) and Nymoen (2019, chp. 10.5). The procedure outlined in the following is also inspired by the methodology applied in studies such as A&J (2013), Hammersland and Jacobsen (2008) and Hammersland and Tr ae (2014). Specifically, it involves the following steps: Firstly, a VAR model will be specified including the endogenous, exogenous and deterministic variables that are relevant for the analysis.<sup>1</sup> The residual diagnostics of the estimated VAR model will be inspected, involving testing for autocorrelation, heteroskedasticity and normality. Next, given that the model is well-specified, the Johansen test will be applied to determine the number of cointegrated relationships. Consider the following VECM-formulation, which is a reparameterization of the general form of a VAR model given in Appendix A, equation (A.4):<sup>2</sup>

$$\Delta Y_t = \Pi Y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta Y_{t-i} + \Phi D_t + \varepsilon_t, \quad t = 1, 2, \dots, T \quad (4.2)$$

Where we have that:  $\Pi = \sum_{i=1}^p \Pi_i - I$  and  $\Gamma_i = -\sum_{j=i+1}^p \Pi_j$  and  $\Pi_i$  is the VAR coefficient matrix belonging to the  $i$ -th lag. The Johansen test is applied to determine the rank of the coefficient matrix  $\Pi$ , which corresponds to the number of independent linear combinations between the variables (in levels) that are stationary<sup>3</sup>, given that none of the variables entering the cointegration space are integrated of an order higher than one.

Further, if evidence of cointegration is found, normalizations and just identifying restrictions will be imposed in  $\Pi$ . Overidentifying restrictions will be considered based on significance

<sup>1</sup>See Appendix A for the general form of a VAR model.

<sup>2</sup>A conditional VECM will be formulated in the econometric analysis of chapter 8, see Appendix A for the general form of a conditional VECM.

<sup>3</sup> $\Pi$  is defined in the conventional way:  $\Pi = \alpha\beta'$ , where  $\beta$  is a  $(n+k+1) \times r$  matrix representing the cointegrating parameters and  $\alpha$  is a  $n \times r$  matrix representing the loading parameters (also known as adjustment coefficients). Here,  $n$  refer to the number of endogenous variables,  $k+1$  is the number of exogenous variables and a deterministic trend.  $r$ , which is determined by the test, refer to the rank of  $\beta$ .

levels of the estimated parameters and economic theory. The validity of the restrictions is tested by likelihood ratio tests. Finally, by imposing the results of the cointegration analysis in the VECM leads to a stationary dynamic model, where the long-run part of the model is identified.

In addition, a simultaneous structure will be allowed for in the VECM. To reach a parsimonious representation of the corresponding simultaneous VECM, overidentifying restrictions will be tested for following a general to specific procedure, more on this in chapter 8).

# Chapter 5

## Literature Review

This chapter is aimed at reviewing the empirical literature on house prices and household debt. The most relevant literature would be studies that model both demand and supply of housing and household borrowing in a joint framework. However, to my knowledge, there exist few examples of this and I, therefore, take a broader view at the literature. This section is organized along the following lines: First, some studies that analyze either house prices or household debt separately are summarized. Second, studies focused on the interaction between house prices and credit are reviewed. Finally, I turn to studies of the supply of housing, focusing on studies modelling house prices and housing supply jointly. A&J (2013) is a study of particular interest and is the point of departure for my econometric analysis. The following chapter (6) is therefore devoted to A&J (2013).

I aim at being short and concise in this section. For more extensive surveys of the literature see Girouard, Kennedy, Van Den Noord, and André (2006) on house prices and A&J (2013) for studies focused on the nexus of house prices and credit. Ball et al. (2010) provides an informative review of the empirical literature on housing supply.

### 5.1 House Prices

Hendry (1984) is often cited as an early work modelling house prices in terms of an inverted demand function for housing, conditional on a measure of the supply of housing. Several studies have followed a similar procedure (Muellbauer and Murphy, 1997, Malpezzi, 1999). Malpezzi (1999) estimates an equilibrium correction model (ECM) equation for house prices in U.S. cities and conclude that income, interest rates and population growth are important determinants. Jacobsen and Naug (2005) estimate an ECM-equation for house prices in Norway based on quarterly data from 1990 to 2004. They identify a cointegrated relationship between house prices, interest rates, a measure for unemployment in Norway, disposable income and the aggregate housing stock. In the short-run, income, interest rates and a measure for Norwegian households' expectations about their private economy and the Norwegian economy, are found to be relevant. Household borrowing is not found to have a significant impact in neither the long- nor the short-run. In a more recent study, Duca, Muellbauer, and Murphy (2011) model

U.S. house prices from 1980 to 2007 and conclude that it is of importance to include measures of credit conditions, especially in the years leading up to the financial crisis of 2008. Anundsen (2015) lend support to this view, studying U.S. data from 1975 to 2010.

## 5.2 Household Debt

Jacobsen and Naug (2004) study which variables can explain the development in aggregate household debt in Norway from 1985 to 2004. In particular, they investigate to what extent the value of the housing stock (as collateral for mortgages) and households debt service ability can explain borrowing. Estimating an ECM-equation, they find that the housing stock and the interest rate are relevant determinants in the long-run. In the short-run, the housing stock, housing turnover and the unemployment rate enter with significant coefficients. A significant relationship between household borrowing and disposable income is not found.

Borgersen and Hungnes (2009) study the relative importance of collateral value and households' debt service ability in explaining the development in Norwegian households' borrowing from 1987 to 2008. They find that in periods when house price growth exceeds the interest rate level by 4.5 percentage points, disposable income seems to be irrelevant for explaining household borrowing. Based on this, they argue that when banks experience rapidly growing house prices, they put more emphasis on the value of the collateral compared to the respective borrowers ability to service debt when issuing mortgage loans. In addition, they show that the identified regime can help explain why Norwegian households' debt continued to increase from an already record high level in the period 2004-07. This finding relates to the decade following the financial crisis of 2007-08, as house prices and household debt have grown substantially in a low-interest rate regime. This further motivates the importance of taking into account credit constraints when modelling housing markets.

## 5.3 The Nexus of House Prices and Credit

As A&J (2013) points out, papers that study house prices or credit in a single equation set-up does not necessarily take into account the possible interaction between house prices and borrowing. Their study adds to the literature focused on accounting for such two-way interactions. In these studies, both house prices and some measure of household debt are treated as endogenous variables. The following is based on the literature review of A&J (2013).

Goodhart and Hofmann (2008) document a two-way relation between house prices and credit to the private sector for a panel of 17 industrialized countries (including Norway). Their results indicate that there are self-reinforcing effects which tend to be stronger when house prices are booming. Brissimis and Vlassopoulos (2009) study quarterly data for Greece from 1993 to 2005 and find a single cointegrating vector which is interpreted as a long-run equation for mortgage credit given by house prices, interest rates and a measure of income. The significance levels of the loading parameters lead them to conclude that house prices are weakly exogenous

with respect to the long-run parameters. This is further interpreted as supporting the view that causation runs from house prices to mortgage debt.

Studying house prices and household borrowing in Finland with quarterly data from 1975 to 2006, Oikarinen (2009) find evidence of a two-way interaction after the financial liberalization in the late 1980s. Applying the Johansen method to cointegration, Oikarinen finds evidence of one cointegrated relationship and interpret it as a house price equation. Further, the direction of causation is found to run from household borrowing to housing prices, both in the long-run and in the short-run.

Fitzpatrick and McQuinn (2007) find evidence of mutual dependence in the long-run between house prices and mortgage credit in Ireland, studying the period 1981-1999. In the long-run house prices are found to depend on income, mortgage loans, the housing stock and a demographic measure. Mortgage credit is found to depend on income, interest rates and house prices. Studying data for Spain, Gimeno and Martinez-Carrascal (2010) employ the Johansen method to cointegration and find evidence of mutual dependence between house prices and mortgage credit in the long-run, conditional on interest rates and income. A&J (2013) use a similar econometric approach as Gimeno and Martinez-Carrascal (2010) and find evidence of a two-way relationship between house prices and household debt in Norway. This point is further discussed in chapter 6. With the exception of Goodhart and Hofmann (2008), the studies mentioned above are single country studies. Differences in results can therefore also be a result of country-specific factors. As pointed out by A&J (2013), institutional differences across countries is a relevant candidate.

### 5.3.1 More Recent Studies

There is a growing empirical literature on linkages between housing and credit markets. Recently, some studies have exploited regional variation and applied instrumental variables methodology to disentangle the direction of causality between housing and mortgage markets. Mian and Sufi (2011, 2015) and Basten and Koch (2015) lend support to the view that causality runs in both directions. Mian and Sufi document how the U.S. subprime bubble was triggered by an increase in the supply of mortgages and that higher house prices accelerated mortgage credit growth through collateral effects. Studying micro-data for Switzerland, Basten and Koch (2015) also document two-way causality and that higher house prices mainly drive up the demand for mortgage credit.

Another strand of this literature is more focused on house prices and credit in relation to financial stability, see for example Borio and Drehmann (2009), Cerutti, Dagher, and Dell'Ariccia (2017), Anundsen et al. (2016), Jordà, Schularick, and Taylor (2015a), Borio (2014), Claessens et al. (2011), and references therein. Among other things, Borio (2014) and Claessens et al. (2011) show how house prices and credit tend to co-vary across countries and that movements in these variables are characterized by long lasting cycles. These studies emphasize the importance of understanding such cycles in order to gain a better understanding of business

fluctuations in more recent decades.<sup>1</sup> Based on a sample of industrialized countries since the 1960s, Drehmann, Borio, and Tsatsaronis (2012) estimate the length of such cycles to average as much as 16 years and emphasize the importance of taking this into account in empirical work.

### 5.3.2 Supply of Housing

While it is common to assume that house prices are determined by the demand for housing for a fixed housing stock, the supply of housing is often modelled by considering a representative enterprise earning income from selling completed dwellings. Further, the profitability of investing in new construction projects is often proxied by a Tobin's-q ratio, as we saw an example of in chapter 3 (see also Jacobsen et al. (2006) and Corder and Roberts (2008)).

Grytten (2009) measures the development in q (house prices relative to construction costs, excluding land prices) for the Norwegian housing market from 1978 to 2009. Grytten shows that the relationship between construction costs and house prices have become weaker since the 90s as house prices have grown more rapidly than construction costs. Madsen (2011) uses Norwegian agricultural land prices as a proxy for land value and find that it helps explain the increasing gap between construction costs and housing prices. Madsen also finds that land prices and construction costs are important determinants for house prices in the long-run.<sup>2</sup> Corder and Roberts (2008) study residential investment in the UK and argue that the development in land prices seems to be more important than construction costs when explaining the development in house prices. Thus, when studying housing supply in Norway, accounting for land value poses a problem as data for it is practically unavailable. To work around this issue, Jacobsen et al. (2006), assumes that factors driving housing demand can account for the development in land prices. The same is done in the supply model used by A&J (2013) (see section 3).

Studying Norwegian data from 1990 to 2005, Jacobsen et al. (2006) find residential investment to depend on house prices, construction costs, the real interest rate, the housing stock, households' disposable income (as a proxy for land prices). They find that residential investment responds relatively quickly to house price shocks. In the first year following a one percent change in prices, almost 80 percent of the response in residential investment occur. Jacobsen et al. acknowledge that in a long term analysis of the housing market, reciprocal interaction between house prices and investment should be taken into account. However, they find it valid to condition on house prices both in the short- and the long-run.

In a cross-country analysis, Kohlscheen, Mehrotra, and Mihaljek (2018) find residential investment to depend on real house price growth, net migration inflows and the size of the existing housing stock. Another cross-country study by Caldera and Johansson (2013), identifies house prices, construction costs and population growth as relevant variables for explaining

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<sup>1</sup>Specifically, these papers develop the idea of what they call *the financial cycle*. The financial cycle involves how credit conditions can vary over time, leading to self-reinforcing effects between asset prices and credit. Borio (2014) argues that the financial cycle is best characterized by co-movements of property prices and credit.

<sup>2</sup>The land prices used by Madsen is based on transactions of agricultural land in Norway from the 1800s until 1975, which is outside the sample period that will be studied in this thesis.



residential investment in the long-run. For Norway, the impact of house prices is also found to be significant in the short-run. Caldera and Johansson conclude that the price responsiveness of housing supply seems to be larger for Nordic countries compared to the UK and continental European countries.

Fitzpatrick and McQuinn (2007) and A&J (2013) try to account for supply-side effects in their respective models of house prices and household borrowing and find that this is of importance. Fitzpatrick and McQuinn (2007) find that housing completions depend on indexes for prices of new dwellings, construction costs and land prices. More on the findings of A&J (2013) in the next chapter.

# Chapter 6

## The Anundsen and Jansen (2013) Model

In this part, the study by Anundsen and Jansen (2013) is summarized and the model is re-estimated. Based on re-estimation over an extended sample, a re-specification of the long-run part of their model is introduced in the last part of this chapter.

### 6.1 Summary

A&J (2013) is closely related to the studies mentioned in section 5.3. A&J model house prices and household debt in a joint framework to study whether there exists evidence of a financial accelerator mechanism in the Norwegian housing market. They emphasize the importance of a systems approach because of possible two-way causation between house prices and credit and their results establish a two-way relationship between house prices and household credit.

Their econometric analysis consists of cointegration analysis before developing a structural vector error correction model (SVECM) to study short-run dynamics.<sup>1</sup> The starting point is a VAR model in real house prices, real household debt and real disposable income conditional on the housing stock, the real after-tax interest rate and housing turnover.

By applying the Johansen method to cointegration, two cointegrating vectors are identified, one for house prices and one for household debt. House prices are found to be a function of household debt, disposable income and the housing stock. Household debt is found to be a function of house prices, the real after-tax interest rate and the housing stock. Hence, their results imply mutual dependence between house prices and household debt in the long-run.

The SVECM is formulated based on the results of the cointegration analysis and a final parsimonious model representation is specified, applying a joint general-to-specific reduction procedure. The results imply that the long-run relations between house prices and credit are of importance also in the short-run. The contemporaneous change in household debt is significant for house prices, but not vice versa. House prices are found to only impact household debt through the long-run part of the final model.

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<sup>1</sup>The procedure is more or less equal to the one outlined in section 4.3

Simulation of dynamic responses to shocks further illustrates the existence of self-reinforcing effects between house prices and credit (see section 7 in their paper). Also, in this part, their baseline model is augmented with the model for the supply side of the housing market that was examined in chapter 3.3.<sup>2</sup> Simulation of the extended model indicates that supply side adjustments dampen the estimated self-reinforcing effects between house prices and credit considerably. A&J conclude by underlining the importance of also taking into account supply side of the housing market.

A&J (2013) contribute to the literature with their systems approach to modelling the nexus of house prices and credit. As they emphasize, none of the other studies they relate to perform both a multivariate cointegration analysis and follow a systems-based approach when designing and estimating a final dynamic model. The other systems-based studies reviewed in chapter 5.3 use a single-equation approach to model reduction and most of them estimate their final model equation by equation using OLS. A&J refer to Hammersland and Jacobsen (2008) and argue that if the variables in the system are thought to be jointly determined in the first place, one should take into account the impact on the whole system when reducing the respective model to a final parsimonious model representation.

## 6.2 Re-Estimation Results

In this part, the model of A&J (2013) is re-estimated over the same sample (1986Q2 - 2008Q4) and over an extended sample( 1986Q2 - 2018Q2). Re-estimation refers to performing the same procedure as A&J using my dataset, which consists of the same variables as in A&J. Due to revisions and certain changes in how some of the series are defined and calculated by Statistics Norway, my results differ to some extent from A&J. Overall, the results indicate that the cointegration analysis of A&J (2013) is robust to extending the data sample. This does not seem to be the case for the SVECM. However, direct comparison involves some uncertainty due to the differences between the datasets.

### Cointegration Analysis

Table 6.1 show the long-run relations of (1) A&J (2013) together with the results of (2) re-estimation over the same sample and (3) re-estimation over the extended sample.<sup>3</sup> To reach the final long-run relations, a number of overidentifying restrictions are imposed (see section 5 in their paper). The cointegration analysis of A&J is replicated to produce the re-estimation results. The corresponding adjustment parameters are reported in Appendix E. Variables noted by lower case letters are measured on a logarithmic scale.

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<sup>2</sup>See Appendix A in their paper. The equations are taken from the macroeconomic model KVARTS (Boug & Dyvi, 2008)

<sup>3</sup>As mentioned above a VAR model in real house prices, real household debt and real disposable income conditional on housing turnover, the real after-tax interest rate and the housing stock is the starting point of A&J (2013). When re-estimating, an impulse dummy for 1995Q4 is included to account for a change in how Statistics Norway calculate aggregate household debt.

Re-estimation over the same sample yield similar results to A&J with some differences with respect to the magnitudes of the coefficients. Also, the result of the likelihood ratio (LR) test of the overidentifying restrictions differ. Overall, these differences are likely to be caused by the differences between the data sets. Keeping this in mind, extending the sample yield similar results as A&J. Again there are some differences with respect to the magnitudes of the coefficients. Overall, the final long-run relations of A&J seem robust to extending the sample with 38 observations. The two-way interaction between house prices and credit is more or less unchanged. However, the test of the overidentifying restrictions suggests that the final equations are not a valid representation of the data. There can be several reasons for this (with differences between the datasets as one likely candidate) and this is addressed more closely in the last section of this chapter.

Table 6.1: Long-run relations: cointegrating parameters<sup>1</sup>

	(1) Anundsen og Jansen 1986Q2-2008Q4		(2) Re-estimation 1986Q2-2008Q4		(3) Extended sample 1986Q2-2018Q2	
	<i>Cointegrated vectors normalized on:</i>					
	(1) ph	(1) d	(2) ph	(2) d	(3) ph	(3) d
House prices (ph)		0.76 (-)		0.66 (-)		0.64 (-)
Household debt (d)	0.98 (0.19)		1.31 (0.27)		0.94 (0.18)	
Housing stock(h)	-3.03 (1.15)	0.76 (0.16)	-5.05 (1.55)	0.66 (0.19)	-1.99 (0.92)	0.64 (-)
Disposable income (ydp)	1.69 (0.63)		2.56 (0.77)		1.18 (0.52)	
Real after-tax interest rate (R)		-2.74 (1.79)		-1.20 (1.98)		-3.79 (1.34)
Housing turnover (th)		0.28 (0.15)		0.43 (0.19)		0.27 (0.10)
LR-test <sup>2</sup>	$\chi^2(7) = 8.44[0.30]$		$\chi^2(7) = 15.56[0.03]^*$		$\chi^2(7) = 20.76[0.00]**$	
Log-likelihood	840.53		862.92		1172.00	
<b>Diagnostics of VECM<sup>3</sup></b>						
<i>Vector AR 1-5 test<sup>4</sup></i>	$F(45, 146) = 1.06[0.39]$		-		-	
<i>Vector normality test</i>	$\chi^2(6) = 7.78[0.26]$		$\chi^2(6) = 5.81[0.44]$		$\chi^2(6) = 13.73[0.03]^*$	
<i>Vector hetero test</i>	$F(270, 247) = 1.03[0.42]$		$F(270, 241) = 1.06[0.32]$		$F(270, 473) = 1.17[0.07]$	

<sup>1</sup> Absolute value of standard errors in brackets.

<sup>2</sup> LR-test refer to the likelihood ratio test of the overidentifying restrictions.

<sup>3</sup> Estimation method is FIML.

<sup>4</sup> For an unknown reason, PcGive version 14 was not able to calculate the vector AR 1-5 test when re-estimating the model.

### Short-run Dynamics

Re-estimation results for the final parsimonious SVECM reported in A&J (2013) are given in table 6.2.<sup>4</sup> In this part, A&J introduce a measure for households expectations ( $E$ ) about their private economy and the economy as a whole to serve as a proxy for the expected rate of appreciation in house prices.

Again, re-estimation over the same sample yield differences with respect to the magnitudes of the coefficients. The estimated coefficients have the same signs as A&J, except for the equilibrium correction term of household debt in the house price equation, which is insignificant. Again the LR-test of the overidentifying restrictions is highly significant in my case, keeping in mind the difference between the datasets. There are notable differences when extending the sample. In the house price equation, the contemporaneous effect of household debt on house prices is no longer significant. The same goes for the equilibrium correction term of household debt. In the debt equation, only the equilibrium correction term enters significantly. Again, the test of the overidentifying restrictions rejects that the equations are a valid representation of the data. Overall, A&J's parsimonious model for the short-term dynamics does not seem robust to extending the sample.

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<sup>4</sup>To identify the system, the contemporaneous effect of housing turnover is excluded from the house price equation and the contemporaneous effect of the expectations measure is excluded from the debt equation.

Table 6.2: Short-run dynamics, re-estimation<sup>1</sup>

	(1) Anundsen og Jansen		(2) Re-estimation		(3) Extended sample	
	1986Q2-2008Q4		1986Q2-2008Q4		1986Q2-2018Q2	
	(1) $\Delta ph_t$	(1) $\Delta d_t$	(2) $\Delta ph_t$	(2) $\Delta d_t$	(3) $\Delta ph_t$	(3) $\Delta d_t$
Constant	1.54*** (0.20)	0.05*** (0.01)	4.36*** (0.54)	0.04*** (0.01)	1.35 (2.48)	0.17*** (0.01)
$\Delta d_t$	0.86** (0.38)	-	1.63*** (0.58)		- 6.10 (14.32)	
$\Delta d_{t-1}$		0.17* (0.09)		0.23** (0.10)		0.01 (0.03)
$\Delta d_{t-3}$	0.31** (0.13)		0.31** (0.15)		0.26* 0.13	
$\Delta ph_{t-4}$	0.39*** (0.08)		0.40 (0.09)		0.28*** 0.08	
$\Delta y_{t-3}$		0.20** (0.06)		0.09 (0.05)		0.01 (0.02)
$\Delta E_t$	0.09*** (0.02)		0.08*** (0.02)		0.08*** (0.02)	
$\Delta E_{t-1}$	0.10*** (0.02)		0.06** (0.02)		0.04** 0.02	
$\Delta E_{t-2}$	0.05*** (0.02)		0.03 (0.02)		0.01 (0.02)	
$\Delta R_{t-4}$		0.26** (0.12)		-0.16 (0.11)		0.04 (0.10)
$ECM_{t-1}^{ph}$	-0.17*** (0.02)		-0.20*** (0.02)		-0.15*** 0.02	
$ECM_{t-1}^d$	-0.06*** (0.03)	-0.05*** (0.03)	-0.01 (0.03)	-0.04*** (0.01)	0.51*** (0.92)	-0.06*** 0.01
Dummy, Q1	0.02 (0.01)	0.004 (0.003)	0.02 (0.01)		0.04 (0.04)	0
Dummy, Q2	0.02 (0.01)	0	0.01 (0.01)	0.01 (0.00)	0.14 (0.24)	0.02 (0.002)
Dummy, Q3	0.01 (0.01)	0	0.03 (0.01)	0.01 (0.00)	0.01 (0.03)	0
SE of regression	0.01	0.01	0.02	0.01	0.07	0.01
Estimation method	FIML		FIML		FIML	
LR-test <sup>a</sup>	$\chi^2(46) = 55.79 [0.15]$		$\chi^2(46) = 100.86 [0.00]**$		$\chi^2(46) = 128.26 [0.00]***$	
Log-likelihood	560.26		543.50		765.81	
Diagnostics:						
Vector AR 1-5 test <sup>2</sup>	F(20,140)=0.90 [0.59]		F(20,138)=1.81 [0.03]*		-	
Vector normality test	$\chi^2(4)=5.34 [0.25]$		$\chi^2(4) = 6.73 [0.15]$		$\chi^2(4) = 5.72 [0.22]$	
Vector hetero test	F(183,81)=0.88 [0.76]		F(183,78) = 0.88 [0.76]		F(183,95)= 1.33 [0.03]*	

<sup>1</sup> Absolute value of standard errors in brackets. \*  $p$ -value < 0.1, \*\*  $p$ -value < 0.05, \*\*\*  $p$ -value < 0.01, where  $p$ -value refer to the significance of the estimated coefficients or the significance of a given test.

<sup>2</sup> For an unknown reason, PcGive version 14 was not able to calculate the vector AR 1-5 test when re-estimating the model.

## 6.3 A Re-specification of A&J (2013)

Re-estimation over an extended sample resulted in long-run relationships that are similar to that of A&J, but the test of the overidentifying restrictions indicated that the long-run relations are not a valid representation of the data. In this section, a simple solution to this is introduced before I proceed to formulate a new model in the following chapter.

In addition to differences between the data sets, there may be other reasons for the significance of the test for the overidentifying restrictions. Clearly, the test indicates that one or more of the restrictions imposed are not valid. Also, when extending the sample, the Johansen test yield evidence of three cointegrating vectors (full rank). Thus, restricting the model to two cointegrating vectors is likely to be rejected by the joint test of the restrictions. Based on this, I perform the following procedure to produce long-run relations that better match the extended data sample. Firstly, as A&J emphasize, house prices and credit are the variables of interest, not disposable income. By this, I change the starting point to a fifth order VAR in real house prices and real household debt conditional on disposable income, in addition to the same variables as earlier.<sup>5</sup> Performing the Johansen test yields evidence of two cointegrating vectors (full rank).<sup>6</sup> Next, the same normalizations and just identifying restrictions as A&J are imposed. Regarding over-identifying restrictions, the real after-tax interest rate is *not* excluded from the house price vector and it is not imposed that there is *no effect of disequilibrium house prices on household debt*.<sup>7</sup> The final long-run relationships are given in table 6.3, together with the matrix representing the (reduced form) loading parameters. Comparing to the theoretical relations outlined in chapter 3, the signs of the cointegrating parameters are as expected. The joint test of the restrictions indicates that the system is a valid representation of the data.

Interestingly, the (reduced form) loading parameters imply that household borrowing will in fact increase when house prices are above the level predicted by the fundamentals. This differs from A&J's results, which imposes the restriction  $\alpha_{1,(d)} = 0$ . Based on these results a new dynamic model could be specified, but I choose to proceed in order to address more features of the A&J (2013) model in chapter 8.

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<sup>5</sup>That is, conditional on real disposable income, the real after-tax interest rate, the housing stock and housing turnover. Following A&J, a deterministic trend is included. I also introduce a dummy to control for the external shock of the financial crisis of 2007-08. The dummy is equal to one in 2008Q3-Q4. There is some indication of serial correlation in the residuals. See Appendix F for the diagnostic tests.

<sup>6</sup>See Appendix F for the results of the Johansen test.

<sup>7</sup>The latter is a restriction on the matrix of loading parameters. See Table 4 in A&J (2013) for an overview of the restrictions they impose.

Table 6.3: Alternative long-run relations\*

Sample: 1986Q2-2018Q2

$$\begin{aligned}
 ph &= 0.39d - 3.49R + 2.03yh + 1.97h \\
 &\quad (0.20) \quad (1.21) \quad (0.54) \quad (0.95) \\
 d &= 0.50ph - 6.18R + 0.50h + 0.98th \\
 &\quad (-) \quad (2.52) \quad (0.33) \quad (0.12)
 \end{aligned}$$

*Reduced form loading parameters:*

$$\begin{pmatrix}
 \alpha_{1,ph} = -0.10 & \alpha_{2,ph} = -0.02 \\
 (0.02) & (0.01) \\
 \alpha_{1,d} = 0.02 & \alpha_{2,d} = -0.03 \\
 (0.01) & (0.01)
 \end{pmatrix}$$

LogL=805.10, LR-test of overidentifying restrictions:  $\chi^2(3)=4.58[0.21]$ 

\* Absolute value of standard errors in brackets.



# Chapter 7

## The Dataset

The information set underlying the empirical analysis consists of the same variables as in A&J (2013). That is: real house prices ( $ph$ ), real household debt ( $d$ ), the aggregate stock of housing ( $h$ ), real after-tax interest rate ( $R$ ), real disposable income ( $yh$ ), real construction costs ( $pj$ ), housing starts ( $s$ ), housing turnover ( $th$ ) and an expectations indicator ( $E$ ). The data are quarterly and measured on a logarithmic scale (except the expectations indicator,  $E$ , and the real after-tax interest rate,  $R$ ). Real variables are deflated by the consumption deflator from the National Accounts.<sup>1</sup> Based on inspection of data plots and Augmented Dickey-Fuller tests, all variables are assumed to be  $I(1)$  except for the real after-tax interest rate ( $R$ ), the expectations indicator ( $E$ ), the housing stock ( $h$ ) and real household debt ( $d$ ).  $R$  and  $E$  are taken as  $I(0)$ , while  $d$  and  $h$  show signs of being  $I(2)$ . Following is a closer description of the latter. See the appendix for more information about the data, plots of the series and the results of the ADF-tests.

### Real Household Debt

Real household debt enters as the total amount of outstanding gross household debt deflated by the consumption deflator. It is challenging to determine the order of integration of this variable, but it shows clear signs of being  $I(2)$ . In levels, it is clearly trending. In first differences, it is more uncertain whether it is stationary. Graphically, it does not look to have a constant mean.<sup>2</sup> Indeed, much of the volatility in this series can be related to the period involving the Norwegian Banking Crisis. Following the crisis, household borrowing recovered over time as the growth rate looks to have been trending upwards in the late 1990s. In the 2000s, the growth rate show clearer indications of being stationary, but with indications of fluctuating around lower levels in the more recent years. Unit root testing indicates that the variable is  $I(2)$ , as the existence of a unit root is neither rejected in levels nor in first differences, but is rejected for second-order differences. Indeed, there is uncertainty related to this testing. The unit root testing performed by A&J (2013) also indicates that this variable may be  $I(2)$ , but they assumed it to be  $I(1)$ . I will open for this variable being  $I(2)$ .

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<sup>1</sup>See <https://www.ssb.no/en/knr>

<sup>2</sup>See the data plot in Appendix C.

## Real housing stock

The stock of existing dwellings enters as the aggregate housing stock measured in fixed prices. In levels, the series is clearly trending and it seems to follow a relatively smooth pattern. Descriptively, in first differences it does not show clear indications of having a constant mean (see the data plot in Appendix C). In first differences, the series was relatively volatile before the Norwegian Banking crisis and the growth rate fell rapidly from a high level during the crisis period. Following this, the housing stock accelerated throughout the 1990s and the early 2000s, before growth slowed down in the wake of the financial crisis of 2007-08. More recently, the growth rate seems to have stabilized around a higher level (about 0.6 percent quarterly growth). ADF-tests indicate that the series is  $I(2)$ . This is similar to the results of Anundsen and Jansen (2013), but which assumed it to be  $I(1)$ . I will open for this variable being  $I(2)$ .

# Chapter 8

## A New Model for the Housing Market and Household Debt

In this chapter, a new model of house prices, housing starts and household debt is developed by building on A&J (2013). Firstly, two features of A&J's model are discussed: how the supply of housing enter their model and a possible unit root problem. Based on the discussion, I outline my empirical strategy before proceeding to the cointegration analysis. Next, a structural vector error correction model (SVECM) is specified and estimated. The properties of the SVECM are analyzed by studying dynamic multipliers. Finally, possible implications arising from changes in macroprudential policy in recent years are discussed briefly.

### 8.1 Two Puzzles in the A&J (2013) Model: Accounting for an Extra Unit Root and the Supply of Housing

#### Housing Supply

As we have seen above, A&J developed their baseline model under the assumption that the supply of housing is exogenous since it adjusts *slowly*. At the same time, they aim at modelling both short- and long-run relationships. They acknowledge that the exogeneity assumption can have implications for the model results and find that this is the case when endogenizing the supply of housing in the last part of their paper.<sup>1</sup> The supply model adopted by A&J assumes that the change in the housing stock is given by the depreciation of the existing stock and a weighted average of new construction over the past three years. Given this assumed time dimension, A&J's simulation of dynamic multipliers demonstrate significant differences between their extended model with endogenous housing supply and their baseline model. For example, in their baseline model, a shock to credit growth of 1 percentage point predicts house prices to increase by approximately 20 percent after four years and to stabilize at a level 40 percent higher than the initial level in the long-run (see figure 4 in their paper). Thus, the estimated feedback mechanism between house prices and credit seems to be very strong. Considering

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<sup>1</sup>Which makes up their extended model, see chapter 6.

the same shock in their extended model, the response in house prices is more or less equal for the first four years as in their baseline model. Following this, the impact of increased supply dominates and house prices decline with the financial accelerator mechanism going to reverse for several years. In the long-run, house prices stabilize at a level of just above the initial level (approximately 1 percent). Simulation of shocks in other variables illustrate the same differences between their baseline model and their extended model, see section 7 in A&J (2013). Thus, there is not much difference between their baseline model and their extended model in the (approximately) first four years following a given shock. In the medium/long-run there are notable differences between the two model specifications.

Further, the implications of their extended model depend on two implicit assumptions: firstly, the supply model is not fully incorporated into the joint structure of their baseline model, as it is estimated separately, not taking into account a possible simultaneity with respect to the rest of the model. There is reason to believe that joint design and estimation of their extended model could have resulted in different parameter estimates. Secondly, the dynamics implied by their model seem to depend on the assumed speed of adjustment of the supply side, as the difference between their baseline model and extended model consistently show up after about four years. Different assumptions about the speed of adjustment could have lead to different results.

Based on these arguments, I will augment A&J's analysis by seeking to incorporate the supply side endogenously from the outset of the econometric modelling. In addition, I will not make any assumption about the speed of adjustment of the housing stock. This can lead to a more comprehensive model of the housing market and household debt, and it can open for studying what such a modelling approach implies for the estimated feedback mechanism between house prices and credit, both in the short- and the long-run. The empirical strategy is outlined in more detail in section 8.2.

### A Unit Root Problem?

The discussion of the order of integration in chapter 7 suggested that real household debt and the housing stock are  $I(2)$  variables. The unit root tests carried out in A&J (2013) indicate the same, but they make the assumption that neither variable is integrated of an order higher than one. The existence of  $I(2)$  variable(s) in their model could have represented a threat to the validity of the inference about the relationships between the variables. Indeed, the final dynamic model reported in A&J (2013) seems to produce stationary residuals and it can be argued that the issue is limited in their case.<sup>2</sup> In my case, it is uncertain whether the same will be achieved in the econometric analysis and I, therefore, choose to address this possible problem in more detail. The very purpose is to make sure that all of the unit roots contained in the variables being analyzed are accounted for.

In theory, a linear combination of  $I(1)$  and  $I(2)$  variables would *not* be expected to be

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<sup>2</sup>This is addressed explicitly by A&J in their working paper version, as they test for unit roots in the structural residuals of their final model. See: [https://www.ssb.no/en/forskning/discussion-papers/\\_attachment/142946](https://www.ssb.no/en/forskning/discussion-papers/_attachment/142946)

stationary unless there are more than one I(2) variables entering the linear combination that cointegrate down to I(1) or I(0). Given that there are indications of two variables being I(2) in the information set, these two variables may cointegrate down to I(1) and that relationship may further be cointegrated with the other I(1) variables to arrive at stationary relationships (see Haldrup (1998) and Johansen (1995)). Hence, if there is evidence of real household debt and the housing stock being cointegrated, there will not be any terms that are I(2) entering the econometric analysis in the continuing, which should help accomplish stationarity.

To address this, I will simply test whether there is evidence of household debt relative to the housing stock,<sup>3</sup>  $(d - h)$ , representing a cointegrated relationship.<sup>4</sup> At first hand, the plot of this relationship (in levels) is clearly trending and look less smooth than the plots of the two variables separately (see the data plot in Appendix C). The first difference of the relative relationship,  $\Delta(d - h)$ , look more like a stationary series. At the same time, it is descriptively similar to the plot of the change in real household debt. The reason for this may be that the growth rate of the housing stock is relatively less volatile and usually smaller than the growth in household debt throughout the sample. The quarterly growth rate of the housing stock is seldom above 1 percent, while the corresponding change in real household debt varies (mostly) between 4 and minus 2 percent.

As table A.1 in the Appendix D shows, the ADF-test of the change in debt relative to the housing stock,  $\Delta(d - h)$ , has a higher critical value than real household debt, but is not significant at the 5 percent level. However, in this case, the conclusion of the test depends on the method used for choosing the lag length. According to Aikaike information criterion (AIC), an additional lag should be included in the Dickey-Fuller regression and in that case, the test statistic is significant at the five percent level. The test of the second-order difference of the relative relationship is highly significant.

Further, this is investigated in a multivariate setting applying the Johansen test on a VAR in real house prices, real household debt, the housing stock and housing starts.<sup>5</sup> The procedure indicates that  $d$  and  $h$  cointegrate from I(2) down to I(1) and that the relationship can be represented by  $(d - h)$ . Further, the results indicate that  $(d - h)$  can be cointegrated with the other I(1) variables, which would lead to stationary relationships. See Appendix G for a detailed description of the procedure. To summarize, given that it is desirable to make sure that none of the variables that enter the econometric modelling are integrated of an order higher than one, combining the two I(2) variables by looking at the relative relationship between household debt and the housing stock can serve as a solution.

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<sup>3</sup> $(d - h)$ , since the variables are in logs.

<sup>4</sup>Which implies that the cointegrating parameter is set to 1.

<sup>5</sup>Conditional on real disposable income (yh), real after after-tax interest rate (R), housing turnover (th) and construction costs (pj).

## 8.2 Empirical Strategy

In the following, I will build on A&J (2013) and follow a procedure that incorporates the two points of emphasis discussed in the previous section. Since A&J found that it is important to account for supply side dynamics, I will treat the supply of housing as endogenous from the outset of the econometric analysis. Incorporating the supply side into the joint modelling procedure, i.e both in the long- and the short-run structure of a model may lead to different results than that of A&J.

Since the very aim is to model the housing market and household debt in a joint framework, starting off with a VAR model treating housing supply as an endogenous variable, in addition to house prices and household debt, seems more intuitive compared to the starting point of A&J. Although their analysis might be more focused on the demand of housing, they provide no motivation or theoretical arguments for why their starting point is a VAR with real disposable income as an endogenous variable (in addition to real house prices and real household debt). Also, my starting point will open for the possibility of formally testing the exogeneity assumption of the supply side.

As in the extended model of A&J, housing starts will be considered as the variable representing the economic behaviour of agents choosing to supply new dwellings that eventually add to the housing stock. Thus, regarding housing supply, housing starts will be the variable of interest in the econometric analysis.<sup>6</sup> The relationship between housing starts and the housing stock is assumed to be a technical relationship (of the "law of motion" type). As already mentioned, I will not make any assumption about the speed of adjustment of the housing stock.

The VAR model underlying the Johansen test above (section 8.1) could be an intuitive starting point, as it treats real house prices ( $ph$ ), real household debt ( $d$ ), housing starts ( $s$ ) and the housing stock ( $h$ ) as endogenous variables. This would involve joint modelling of the same endogenous variables as in the extended model of A&J (2013). However, as Appendix G shows, the Johansen test for cointegration in that particular VAR model yielded evidence of four cointegrated vectors. Working with four dimensions would make the problem of identification particularly challenging.<sup>7</sup> In addition, I want to make sure that there are no variables in the model that are integrated of an order higher than one. Since it was found that the relative relationship between real household debt and the housing stock can be treated as a linear combination that is  $I(1)$ , I choose to operate with  $(d - h)$  as a single  $I(1)$  variable and treat real house prices, ( $ph$ ), real household debt relative to the housing stock  $(d - h)$  and housing starts ( $s$ ) as endogenous variables. For practical reasons,  $(d - h)$  will be referred to as *debt to housing stock* or, *the debt ratio* in the following. In sum, this yields a model in three dimensions that should make the issue of identification more manageable. At the same time, the proposed

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<sup>6</sup>At this point, it was considered whether it could be better to model housing investment instead of housing starts, inspired by the study of Jacobsen et al. (2006) However, it was decided to stick to housing starts to be able to relate directly to A&J (2013).

<sup>7</sup>The cointegrated vectors constitute a simultaneous system. The order condition, which is a necessary condition for identification of a simultaneous system, would require each equation to exclude at least three variables that are included in the system.

solution to the unit root problem is incorporated from the outset.

Indeed, working with the relationship  $(d-h)$  will have consequences for the interpretation of the model developed in the following. It may be argued that the ratio of household debt to the housing stock is not the most intuitive relationship to analyze compared to, for example, a debt to income ratio. On the other hand, since mortgage debt makes up the majority of household debt in Norway, there is a close relationship between the level of household debt and the housing stock. Moreover, I choose to focus on this as a solution to the possible unit root problem.

Due to the non-stationarities of the variables in the data set, I start off by studying the long-run determinants of house prices, household debt (relative to the housing stock) and housing starts, following the procedure outlined in section 4.3. Depending on the cointegration analysis, a dynamic model is formulated. Throughout the analysis, the sample will be 1987Q2 - 2018Q2.

### 8.2.1 Cointegration Analysis

The starting point is a fifth order VAR in real house prices ( $ph$ ), the debt ratio ( $d-h$ ) and housing starts ( $s$ ), conditional on real disposable income ( $yh$ ), real after-tax interest rate ( $R$ ), housing turnover ( $th$ ) and real construction costs ( $pj$ ).<sup>8</sup> A deterministic trend is also included, as well as two impulse dummies. The first dummy is equal to one in the third and fourth quarter of 2008 to control for the external shock of the financial crisis. The second dummy is equal to one in the last quarter of 1995 to control for the change in how the series for aggregate household debt is calculated.<sup>9</sup> The initial VAR model is quite large in terms of the number of parameters. By the use of information criteria and F-tests, five lags in the endogenous variables and one lag in the exogenous variables are found to be appropriate (see Appendix H).

Finding evidence of cointegration implies that the VAR model can be formulated as a vector equilibrium correction model (VECM), where the results of the cointegration analysis will represent the long-run structure of the model. To test for cointegration, the trace test is applied (Johansen, 1988). I find evidence of three cointegrated vectors, meaning that there are three linear combinations between the variables that are stationary. According to residual diagnostics, the model looks well specified, meaning that the residuals are neither autocorrelated nor heteroskedastic and normality is not rejected (see table 8.1).

The cointegrated relationships takes the following form, where  $\Pi = \alpha\beta'$  in the VECM-representation of the VAR<sup>10</sup>:

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<sup>8</sup>See section 4.3 for the general form of a VAR model.

<sup>9</sup>See Appendix B.

<sup>10</sup>See Appendix A for the general form of a conditional VECM.

Table 8.1: Johansen test for cointegration<sup>a</sup>

<i>Eigenvalue: <math>\lambda_i</math></i>	$H_o$	$H_A$	$\lambda_{trace}$	p-value
0.39	$r = 0$	$r \geq 1$	107.07	[0.000]***
0.19	$r \leq 1$	$r \geq 2$	45.81	[0.000]***
0.15	$r \leq 2$	$r \geq 3$	19.88	[0.002]***
Diagonistics	Test Statistic	Value [p-value]		
Vector AR 1-5 test:	F(45, 232)	1.32[0.096]		
Vector Normality test:	$\chi^2(6)$	3.36 [0.762]		
Vector Hetero test:	F(312,402)	1.07[0.250]		
Estimation period:	1987Q2 - 2018Q2			

<sup>a</sup> Endogenous variables: Real house prices ( $ph$ ), real household debt relative to housing stock ( $d - h$ ) and housing starts ( $s$ ). Restricted variables: Real after-tax interest rate ( $R$ ), housing turnover ( $th$ ), real disposable income ( $yh$ ), real construction costs ( $pj$ ) and a trend ( $t$ ). Unrestricted variables: Constant, centered seasonal dummies for the first three quarters and two impulse dummies, one for 1995Q4 and one for 2008Q3-Q4.

$$\alpha\beta'y = \begin{pmatrix} \alpha_{1,ph} & \alpha_{2,ph} & \alpha_{3,ph} \\ \alpha_{1,(d-h)} & \alpha_{2,(d-h)} & \alpha_{3,(d-h)} \\ \alpha_{1,s} & \alpha_{2,s} & \alpha_{3,s} \end{pmatrix} \begin{pmatrix} \beta_{1,ph} & \beta_{1,(d-h)} & \beta_{1,s} & \beta_{1,yh} & \beta_{1,R} & \beta_{1,th} & \beta_{1,pj} & \beta_{1,trend} \\ \beta_{2,ph} & \beta_{2,(d-h)} & \beta_{2,s} & \beta_{2,yh} & \beta_{2,R} & \beta_{2,th} & \beta_{2,pj} & \beta_{2,trend} \\ \beta_{3,ph} & \beta_{3,(d-h)} & \beta_{3,s} & \beta_{3,yh} & \beta_{3,R} & \beta_{3,th} & \beta_{3,pj} & \beta_{3,trend} \end{pmatrix} \begin{pmatrix} ph \\ d - h \\ s \\ yh \\ R \\ th \\ pj \\ trend \end{pmatrix}$$

The first vector is normalized on real house prices, the second on the debt ratio and the third on housing starts. The cointegrating vectors constitute a simultaneous system that must be identified to be able to estimate a unique set of cointegrating parameters. By the order condition, each vector must exclude two variables that appear in the system to achieve exact identification.<sup>11</sup> The just identifying restrictions are as follows: Housing starts and turnover is excluded from the house prices vector. Based on A&J (2013) and Jacobsen and Naug (2004), housing turnover has been found to be relevant for explaining aggregate household debt in Norway, and as in A&J (2013) it is assumed to not impact house prices directly. Regarding housings starts, it is assumed that it does not have a direct effect on house prices, but rather impact house prices through the housing stock as new dwellings add to the existing supply. For the debt to housing stock vector, construction costs and the trend are excluded.<sup>12</sup> For the housing starts vector, the same q-theory of investment as in KVARTS (Boug & Dyvi, 2008) and A&J (2013), namely a one-to-one relationship between housing starts, house prices and construction costs is imposed.<sup>13</sup> The just identified system of cointegrating relations take the

<sup>11</sup>Or equivalent in this case, two restrictions must be imposed in each vector.

<sup>12</sup>It was checked whether the trend was significant when imposing other just identifying restrictions, which was not the case.

<sup>13</sup>Which was also explained in chapter 3.3.



following structure:

$$\begin{aligned}
 ph &= \beta_{1,(d-h)}(d-h) + \beta_{1,yh}yh + \beta_{1,R}R + \beta_{1,pj}pj + \beta_{1,t}trend \\
 (d-h) &= \beta_{2,ph}ph + \beta_{2,s}s + \beta_{2,yh}yh + \beta_{2,R}R + \beta_{2,th}th \\
 s &= ph - pj + \beta_{3,(d-h)}(d-h) + \beta_{3,yh}yh + \beta_{3,R}R + \beta_{3,th}th + \beta_{3,t}trend
 \end{aligned}$$

### Overidentifying Restrictions

In the following, overidentifying restrictions are tested. The restrictions are motivated by theory and the significance levels of the respective estimated coefficients. At each step, the validity of the restrictions is tested. At the same time, it must be made sure that the order condition is satisfied at each step such that identification is not lost.<sup>14</sup> The results of this process are given in table 8.2, where panel 8 represents the final long-run structure.

First, the trend is excluded from the house prices vector. The trend is not excluded from the housing starts vector by the theoretical argument that it can possibly account for land prices and according to its significance level, it seems to be relevant.<sup>15</sup> Second, in panel 2, housing turnover is excluded from the housing starts vector as it is assumed to only be relevant for explaining household debt. In panel 3, debt to housing stock is excluded from the housing starts vector, assuming that suppliers of dwellings mainly respond to price signals and that the debt ratio impact housing starts indirectly *through* house prices, but not directly. In panel 4, there is no direct effect of the real after-tax interest rate on house prices, assuming that the interest rate impact house prices indirectly through household borrowing.<sup>16</sup> In panel 5, disposable income is excluded from the housing starts vector and in panel 6 there is no direct effect of the real after-tax interest rate on housing starts. Again, it is assumed that suppliers of dwellings mainly respond to price signals and that disposable income and the real interest rate paid by households impact housing starts *indirectly* through house prices. Indeed, in the housing starts vector, the coefficient of the interest rate is highly significant and interest rates may very well be important for explaining the behaviour of housing suppliers, as argued by Jacobsen et al. (2006).<sup>17</sup> However, the interest rate included here proxies the average interest rate paid by households and is not directly linked to the external financing costs of housing suppliers housing. On the other hand, interest rates may very well be correlated across sector. Still, the restriction is not rejected by the joint test of the restrictions, which indicates that the system of long-run relations is still a valid representation of the data.

In panel 7, two more restrictions are imposed. Firstly, it is assumed that construction costs is mainly relevant for explaining supply side behaviour and that it impacts house prices indirectly through housing starts. This leads to the house prices vector being identified in terms of variables mostly related to the demand side. However, identification is lost when imposing

<sup>14</sup>As mentioned earlier, the order condition implies in this case that each vector must exclude at least two variables that are in the system.

<sup>15</sup>As was discussed in chp. 3.3.

<sup>16</sup>A&J (2013) impose the same restriction.

<sup>17</sup>The test of the restriction suggests the same with a p-value of 2 percent.

$\beta_{1,pj} = 0$ , since the order condition is violated for the vector normalized on debt to housing stock. To keep the system identified, disposable income is excluded from the debt to housing stock vector. Although disposable income is relevant for explaining borrowing, it is restricted to enter through the house prices vector, which is the same restriction imposed by A&J (2013).

Finally, in panel 8 weak exogeneity of housing starts is tested. The estimated loading parameters at each step are reported in Appendix I, which indicates that both  $\alpha_{1,s}$  and  $\alpha_{2,s}$  have low significance levels and are close to zero (in absolute value). The restrictions are not rejected by data, which implies that consistent estimates of the long-run coefficients in the first two vectors can be achieved without modelling housing starts explicitly. Panel 8 represents the final long-run relations together with the (reduced-form) adjustment coefficients.

Table 8.2: Testing overidentifying restrictions

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Panel 1: No trend in the house prices vector ( $\beta_{1,trend} = 0$ )

$$\begin{aligned} ph &= \underset{(0.29)}{0.75}(d-h) + \underset{(1.54)}{0.28}R + \underset{(0.21)}{0.07}yh + \underset{(0.68)}{1.62}pj \\ (d-h) &= \underset{(0.30)}{2.25}ph + \underset{(0.19)}{0.71}s + \underset{(2.20)}{0.21}R - \underset{(0.52)}{1.84}yh + \underset{(0.20)}{0.11}th \\ s &= (ph - pj) + \underset{(0.35)}{0.03}(d-h) - \underset{(2.26)}{6.42}R + \underset{(1.52)}{1.13}yh + \underset{(0.30)}{0.45}th + \underset{(0.01)}{0.02}trend \end{aligned}$$

$$LogL = 1112.55, \quad \chi^2(1) = 0.63[0.43]$$


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Panel 2: No effect of housing turnover on housing starts ( $\beta_{3,th} = 0$ )

$$\begin{aligned} ph &= \underset{(0.27)}{0.74}(d-h) - \underset{(1.47)}{0.06}R + \underset{(0.20)}{0.18}yh + \underset{(0.60)}{1.31}pj \\ (d-h) &= \underset{(0.38)}{2.95}ph - \underset{(0.23)}{1.01}s + \underset{(3.10)}{1.41}R - \underset{(0.63)}{2.34}yh - \underset{(0.23)}{0.44}th \\ s &= (ph - pj) + \underset{(0.29)}{0.33}(d-h) - \underset{(2.22)}{4.10}R + \underset{(1.18)}{0.73}yh + \underset{(0.01)}{0.01}trend \end{aligned}$$

$$LogL = 1111.58, \quad \chi^2(1) = 1.94[0.16], \quad \chi^2(2) = 2.57[0.28]$$


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Panel 3: No effect of the debt ratio on housing starts ( $\beta_{3,(d-h)} = 0$ )

$$\begin{aligned} ph &= \underset{(0.26)}{0.70}(d-h) + \underset{(1.48)}{0.05}R + \underset{(0.19)}{0.16}yh + \underset{(0.64)}{1.51}pj \\ (d-h) &= \underset{(0.31)}{2.44}ph - \underset{(0.19)}{0.82}s + \underset{(2.48)}{0.67}R - \underset{(0.53)}{1.78}yh - \underset{(0.18)}{0.34}th \\ s &= (ph - pj) - \underset{(2.08)}{5.10}R + \underset{(1.07)}{1.27}yh + \underset{(0.01)}{0.02}trend \end{aligned}$$

$$LogL = 1111.45, \quad \chi^2(1) = 0.27[0.61], \quad \chi^2(3) = 2.83[0.42]$$


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Panel 4: No effect of real after-tax interest rate on house prices ( $\beta_{1,R} = 0$ )

$$\begin{aligned}
ph &= \underset{(0.26)}{0.70}(d-h) + \underset{(0.18)}{0.17}yh + \underset{(0.63)}{1.48}pj \\
(d-h) &= \underset{(0.31)}{2.44}ph - \underset{(0.19)}{0.82}s + \underset{(1.90)}{0.70}R - \underset{(0.52)}{1.78}yh - \underset{(0.19)}{0.34}th \\
s &= (ph - pj) - \underset{(2.03)}{5.07}R + \underset{(1.06)}{1.25}yh + \underset{(0.01)}{0.02}trend
\end{aligned}$$

$$LogL = 1111.45, \quad \chi^2(1) = 0.27[0.88], \quad \chi^2(4) = 2.83[0.42]$$


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Panel 5: No effect real disposable income on housing starts ( $\beta_{3,yh} = 0$ )

$$\begin{aligned}
ph &= \underset{(0.30)}{0.73}(d-h) + \underset{(0.20)}{0.17}yh + \underset{(0.73)}{1.38}pj \\
(d-h) &= \underset{(0.39)}{3.59}ph - \underset{(0.25)}{1.96}s - \underset{(3.78)}{3.95}R - \underset{(0.68)}{3.19}yh - \underset{(0.25)}{0.44}th \\
s &= (ph - pj) - \underset{(2.06)}{5.33}R + \underset{(0.001)}{0.02}trend
\end{aligned}$$

$$LogL = 1110.97, \quad \chi^2(1) = 0.97[0.32], \quad \chi^2(5) = 3.81[0.58]$$


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Panel 6: No effect of real after-tax interest rate on housing starts ( $\beta_{3,R} = 0$ )

$$\begin{aligned}
ph &= \underset{(0.07)}{0.71}(d-h) + \underset{(0.08)}{0.77}yh - \underset{(0.16)}{0.13}pj \\
(d-h) &= \underset{(0.08)}{0.98}ph + \underset{(0.04)}{0.40}s - \underset{(0.33)}{0.85}R - \underset{(0.17)}{0.66}yh - \underset{(0.04)}{0.08}th \\
s &= (ph - pj) - \underset{(0.0008)}{0.005}trend
\end{aligned}$$

$$LogL = 1108.01, \quad \chi^2(1) = 5.91[0.02], \quad \chi^2(6) = 9.72[0.14]$$


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Panel 7: Restrictions on construction costs and disposable income ( $\beta_{1,pj} = 0, \beta_{2,yh} = 0$ )

$$\begin{aligned}
ph &= \underset{(0.08)}{0.70}(d-h) + \underset{(0.10)}{0.73}yh \\
(d-h) &= \underset{(0.11)}{0.26}ph + \underset{(0.07)}{1.03}s - \underset{(0.62)}{1.82}R - \underset{(0.08)}{0.17}th \\
s &= (ph - pj) - \underset{(0.0006)}{0.005}trend
\end{aligned}$$

$$LogL = 1108.01, \quad \chi^2(2) = 0.33[0.85], \quad \chi^2(8) = 10.05[0.26]$$


---

Panel 8: Testing weak exogeneity of housing starts ( $\alpha_{1,s} = 0, \alpha_{2,s} = 0$ )

$$\begin{aligned}
ph &= \underset{(0.07)}{0.77}(d-h) + \underset{(0.09)}{0.63}yh \\
(d-h) &= \underset{(0.09)}{0.38}ph + \underset{(0.06)}{0.82}s - \underset{(0.50)}{1.53}R - \underset{(0.06)}{0.14}th \\
s &= (ph - pj) - \underset{(0.0007)}{0.005}trend
\end{aligned}$$

$$\text{Log}L = 1107.58, \quad \chi^2(1) = 0.54[0.76], \quad \chi^2(10) = 10.10[0.39]$$

$$\begin{pmatrix} \alpha_{1,ph} = -0.36_{(0.05)} & \alpha_{2,ph} = -0.25_{(0.04)} & \alpha_{3,ph} = -0.19_{(0.03)} \\ \alpha_{1,(d-h)} = -0.07_{(0.02)} & \alpha_{2,(d-h)} = -0.09_{(0.02)} & \alpha_{3,(d-h)} = -0.08_{(0.01)} \\ \alpha_{1,s} = 0.00 & \alpha_{2,s} = 0.00 & \alpha_{3,s} = -0.10_{(0.03)} \end{pmatrix}$$


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The system of long-run relations constitutes an estimated steady state for house prices, household debt relative to the housing stock and the flow of new dwellings (housing starts). All variables are significant at conventional levels, and overall, the system can be related to economic theory.

One advantage of the method used is that one can observe exactly how each restriction affects the remaining estimated coefficients in the system. Throughout this reduction process, it is evident that some of the estimated parameters vary with the restrictions imposed. Particularly for the debt to housing stock vector, this seems to be the case. Comparing panel 5 and 6 shows that there is an impact on this vector when excluding the real after-tax interest rate from the housing starts vector. The coefficient of the interest rate is highly significant in panel 5, which may help explain the impact on the debt to housing stock vector. Despite this, the restriction is kept from a theoretical standpoint, as argued above.

Interestingly, there are similarities with the long-run relations of A&J (2013), while keeping in mind that care must be taken when comparing since household debt and housing stock does not enter separately here, but as a ratio. Still, I find a mutual relationship between house prices and credit, similar to that of A&J. The estimated elasticity of the debt ratio with respect to house prices is 0.38, and vice versa, the estimated elasticity is 0.77. This two-way relationship is weaker than that of A&J, which may be intuitive, considering that supply side effects should be accounted for to a larger degree here.

House prices are found to depend positively on the debt ratio and disposable income, which have coefficients of approximately the same magnitude. Since the right-hand side variables are related to demand for housing, the equation may be interpreted as an inverted demand function, as was derived in section 3. The equation consists of the same variables as in A&J (2013), but the magnitudes of the coefficients are smaller.

Housing starts are a function of the  $q$  (house prices relative to construction costs) and the deterministic trend. The coefficient of the trend is negative and of small size, but highly significant. This may indicate that it accounts for other relevant variables that are not part of the information set, with land prices as a likely candidate. The right-hand side of the equation can be interpreted as a (rough) proxy for the profitability of supplying new dwellings, predicting that new construction will take place when prices exceed costs.

The equation for debt to housing stock is somewhat more difficult to interpret in light of

theory. It is found to depend on real house prices, housing starts, the real after-tax interest rate and housing turnover. The interpretation of the impact of housing starts in this equation is somewhat uncertain. Indeed, a relationship between the level of housing starts and the housing stock should be expected. The coefficient implies that a one percent increase in housing starts is associated with a 0.82 percent increase in the level of household debt relative to the housing stock. The coefficient should be seen in relation to the third equation. By inserting for  $s$  one get that house prices would have a direct effect on debt relative to the housing stock of 1.20 ( $=0.38+0.82$ ). This indicates a stronger impact of house prices on household borrowing than what was found by A&J (2013).<sup>18</sup> The coefficient of housing turnover confirms what A&J (2013) and Jacobsen and Naug (2004) have found, that household debt is positively related to housing turnover.

The reduced form adjustment coefficients indicate how departures from estimated steady state levels impact the changes in the endogenous variables. The results imply that both house prices and the debt ratio equilibrium correct when either one depart from it's predicted long-run level. The reason for this may (partly) be that households are less willing to invest in housing and banks might tighten credit conditions when house prices and/or debt exceed the level(s) predicted by fundamentals. Equilibrium correction in the debt ratio may also be a result of the housing stock responding to house prices departing from fundamentals, but this is seen as less likely since the adjustment coefficients relate to short-run dynamics. Moreover, real house prices are predicted to adjust more rapidly to equilibrium than the debt ratio, which is similar to the results of A&J (2013).

Further, the results indicate a one-way relationship between respectively house prices and the debt ratio, and housing starts, as the latter was found to be weakly exogenous with respect to the long-run parameters. This implies that housing starts are not found to respond when neither house prices nor the debt ratio depart from the estimated steady state levels. Regarding the discussed *time dimension of the supply side*, this is interesting as it indicates that there is no short-run response in housing starts when house prices depart from the level predicted by fundamentals. Possibly, this can be related to the fact that construction projects take time and might not be easily adjusted because due to irreversible costs. This lends some support to the approach of A&J (2013) of not taking into account housing starts when estimating long-run relationships for house prices and household debt. However, for this model specification, it does not necessarily imply that it is valid to condition on the supply of housing, which is represented by the housing stock. The housing stock enters as an endogenous variable here through the relationship  $d - h$ .

Since we have that  $\alpha_{3,s} = -0.10$ , housing starts are found to equilibrium correct when house prices depart from construction costs and other factors accounted for by the deterministic trend. Thus, housing starts are found to react to profitability, rather than disequilibrium in the housing market.

Finally, the results indicate equilibrium correction in house prices and the debt ratio when

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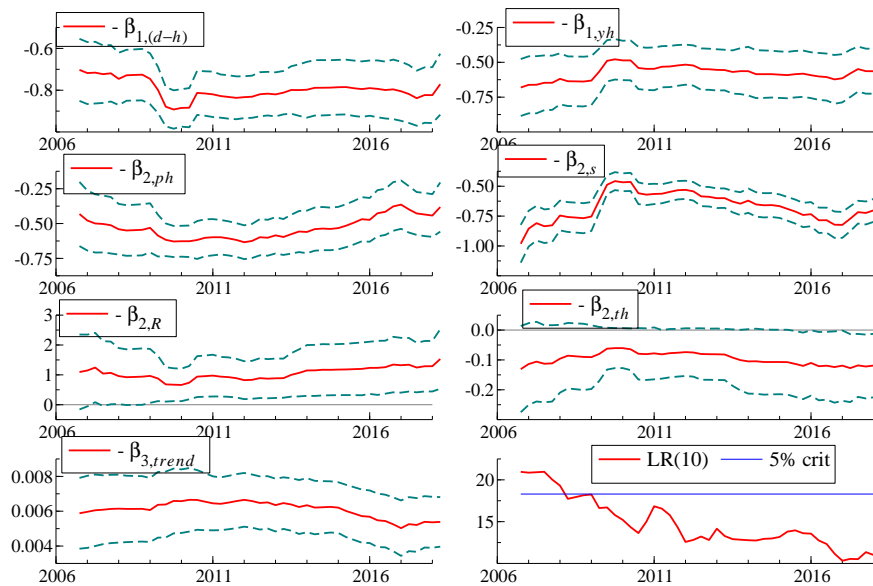
<sup>18</sup>In A&J (2013), the coefficient of house prices in the long-run equation for household debt is 0.76. In my respecification of their long-run relations, the same coefficient is estimated to 0.50, see chapter 6.

housing starts depart from its estimated steady state level. A similar interpretation as earlier may apply here, as households can be thought to postpone investment if a high level of new construction projects is expected to put downward pressure on prices in the future. Regarding banks' behaviour, the same may be true as banks can be thought to tighten credit supply to manage exposure towards property prices. On the contrary, the long-run relation for debt to housing stock indicates that it is positively related to the flow of new dwellings in the long-run.

### Recursive Estimates of Long-Run Coefficients

To investigate the recursive stability of the long-run coefficients, the model is estimated quarter-by-quarter over the period 2006Q1-2018Q2. The recursive estimates are given in figure 8.1 (note that the coefficients are graphed with the opposite signs compared to the representation in table 8.2). The plots indicate some parameter instability in the wake of the financial crisis of 2008 when house prices dropped by almost 10 percent in the last part of 2008 before turning upwards again in 2009. This is particularly true for the coefficients of debt to housing stock ( $\beta_{1,(d-h)}$ ) and income ( $\beta_{1,yh}$ ) in the house price equation, as well as the coefficient of housing starts ( $\beta_{2,s}$ ) in the debt to housing stock equation. The graph down to the right plots the likelihood ratio test statistic recursively. The plot indicates that the overidentifying restrictions are not accepted recursively at the 5% level from 2006 to 2009.

Figure 8.1: Recursive estimates of long-run coefficients and the LR-test statistic



### 8.2.2 Short-Run Dynamics

In this section, short-run dynamics are addressed by specifying and estimating a structural vector equilibrium correction model (SVECM). This provides the opportunity to study the impact of short-run determinants and the long-run relations in a unified framework. A full simultaneous structure is allowed for, which involves a simultaneous specification of the VECM from the cointegration analysis (hence, a SVECM). Thus, I open for house prices, the debt ratio and housing starts to be jointly determined also in the short-run.

By pre-multiplying the conditional VECM (see equation (A.5), Appendix A) by the (non-zero) contemporaneous feedback (3x3) matrix,  $B$ , the model takes the following form:

$$B\Delta X_t = B\tilde{\Pi}\tilde{Y}_{t-1} + \sum_{i=1}^4 B\Gamma_i\Delta X_{t-i} + \sum_{i=0}^2 B\Psi_i\Delta Z_{t-i} + B\Phi D_t + B\epsilon_t \quad (8.1)$$

where  $B\tilde{\Pi} = B\alpha\beta' = \alpha * \beta'$ ,  $B\Gamma_i = \Gamma_i^*$ ,  $B\Psi_i = \Psi_i^*$ ,  $B\Phi = \Phi^*$ ,  $B\epsilon_t = \epsilon_t$ . The error terms are assumed to be independently Gaussian distributed,  $N(0, \Omega)$ , with the variance-covariance matrix defined as  $\Omega = E(\epsilon_t\epsilon_t') = BE(\epsilon_t\epsilon_t')B' = B\Sigma B'$ . The system will be estimated by FIML (full information maximum likelihood). The contemporaneous feedback matrix,  $B$ , is normalized such that it has ones along the main diagonal.  $X_t$  represent the same endogenous variables as before ( $X_t' = (ph_t, (d-h)_t, s_t)$ ). The short-run analysis is supplemented with an expectations variable,  $E_t$ , which was found to be relevant by A&J (2013). The expectations indicator measures households expectations about the future development in their personal economy and the macroeconomy.<sup>19</sup> As in A&J (2013), it is meant to serve as a proxy for the expected rate of appreciation in real house prices.  $Z_t$  include the weakly exogenous variables, defined as  $Z_t' = (R_t, yh_t, pj_t, th_t, E_t)$ . The initial VAR model included five lags of the endogenous variables and one lag of the exogenous, so the corresponding SVECM formulation would involve four lags of the endogenous variables in first differences and only contemporaneous changes in the exogenous ones. I have therefore chosen to augment the model with one lag of the change in the exogenous variables.

The simultaneous equation system will be estimated and designed simultaneously, implying that the challenge of identification must be faced once again. To achieve exact identification, the matrix representing the loading parameters,  $\alpha$ , is restricted to be diagonal. This implies that each of the structural equations of the model only includes the long-run relation of the variable normalized on in the dynamic structural specification.<sup>20</sup> Indeed, this may not be the case for the reduced form of the final model since I allow for a simultaneous contemporaneous structure.

Estimation of 8.1 yields a well specified model with respect to the residual diagnostics and is thereby taken as a starting point for a reduction process aimed at a parsimonious model representation.<sup>21</sup> The reduction process follows a general-to-specific procedure eliminating in-

<sup>19</sup>See Appendix B for more information about this variable.

<sup>20</sup>For example, the structural equation for the change in real house prices will only include the long-run equation pertaining to real house prices

<sup>21</sup>The results of diagnostic tests are as follows:

significant variables in the system step-wise, either one by one or in blocks. At each step, it is made sure that the Gaussian properties of the residuals are not lost by paying attention to the diagnostic tests and that the restrictions are not rejected by data according to the joint LR-test. This reduction process is carried out manually, since (to my knowledge) it does not exist an algorithm for automatic general-to-specific simplification of structural model representations. The final parsimonious model is reported in table.<sup>22</sup> The reduction process results in a rather big model with respect to the number of parameters. This is mostly due to the number of lags of the endogenous variables entering the respective equations. The final model produces well-behaved residuals according to the diagnostic tests, see table 8.4.

For this model representation, the LR-test of the overidentifying restrictions has a p-value below 5%. This is due to the exclusion of the second and third lag of the debt ratio from the model in the final step of the reduction process, which was motivated by the coefficients of these variables being insignificant. Still, there is an impact on the LR-test, lowering the p-value beneath the 5% level. See Appendix J for the model results without these restrictions imposed.

The simultaneous structure indicates a contemporaneous two-way relationship between house prices and credit in the short-run. No contemporaneous endogenous variables are found to be significant for the housing starts equation. This indicates that it is of importance to account for simultaneity between house prices and credit, while the same does not seem to be the case for housing starts. Further, the coefficient of the contemporaneous value of housing starts is significant in the debt ratio equation. This implies that, in the short-term, increasing growth in housing starts leads household borrowing to grow relative to the housing stock. From theory, supply side dynamics would be expected to only impact household borrowing *through* house prices and not *directly* as the results indicate. Still, this may be intuitive if new dwellings are sold in the market before or during construction, such that mortgage debt increase before construction projects are eventually finished and the housing stock increases. On the other hand, this is somewhat difficult to relate to the economic theory outlined in chapter 3. How housing starts enter the model is discussed further in the next section when addressing dynamic multipliers.

The contemporaneous effect of a change in the expectations indicator is significant for real house prices, indicating a positive relationship between households' expectations about their private economy and the macroeconomy and housing demand. At the same time, the expectations indicator enter with an unexpected negative effect in the debt ratio equation (dampened by a positive lagged impact). The estimated coefficients of the expectations indicator are small in absolute terms. This differs from A&J (2013) who found the expectations indicator to be particularly important for explaining the short-run dynamics of house prices.

The contemporaneous effect of real construction costs enters with a positive sign in the

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Vector SEM-AR 1-5 test:  $F(45,229) = 1.16$  [0.24], Vector Normality test:  $\chi^2(6) = 3.40$  [0.76], Vector Hetero test:  $F(324,397) = 1.1231$  [0.14]

<sup>22</sup>The ECM notation refer to the long-run equations as in table 8.2, panel 8. We have that:  $ECM_{t-1}^{ph} = ph_{t-1} - 0.77(d-h)_{t-1} - 0.63yh_{t-1}$ ,  $ECM_{t-1}^{d-h} = (d-h)_{t-1} - 0.38ph_{t-1} - 0.82s_{t-1} + 1.53R_{t-1} + 0.14th_{t-1}$  and  $ECM_{t-1}^s = s_{t-1} - (ph - pj) + 0.005trend_{t-1}$  8.3



housing starts equation, which is somewhat unexpected.<sup>23</sup> However, it may be reasonable to expect the growth rate of housing starts and construction costs to be positively related in the short-run. In fact, there may exist a two-way relationship between housing starts and construction costs that this model does not account for, as construction costs can be expected to depend on construction activity.

Consistent with the cointegration analysis, the estimated coefficients of the ECM-terms are significant with negative values. This confirms that the endogenous variables equilibrium correct whenever they depart from the levels predicted by the long-run relations. Comparing to the diagonal of the (reduced form) alpha matrix reported in panel 8 section 8.2.1, the size of the coefficients are all smaller (in absolute terms). Especially for  $\alpha_{1,ph}$ , which was estimated to -0.36 in the cointegration analysis, compared to an estimated value of -0.10 in this case. This may underline the importance of accounting for the contemporaneous relationships, which was not done in the cointegration analysis. Also, only  $ECM_{t-1}^s$  of the equilibrium correction terms will be present in the reduced form housing starts equation since there are no contemporaneous effects in this equation. This is consistent with the finding in the cointegration analysis, which indicated that housing starts are weakly exogenous with respect to the long-run coefficients.

Lagged changes in the endogenous variables are seen to make up a large part of the final model. Both house prices and credit is found to be related to past growth rates in both variables, which may be the result of house prices and credit cycles being slow-moving processes. Lagged changes in housing starts enter the house prices equation, indicating that supply side dynamics impact real house prices over time. However, the first lag enters with a positive coefficient, which may simply indicate that increasing construction and house prices tend to go together.

Lagged values of housing starts also enter the debt ratio equation, which may be less intuitive and somewhat more difficult to interpret and relate to theory. On the other hand, it is not surprising that the results indicate a relationship between debt relative to the housing stock and housing starts. Households' purchase of new dwellings can be expected to be mostly debt-financed and obviously,  $s$  is related to the denominator as new dwellings add to the existing stock.<sup>24</sup> Again, the impact of housing starts is discussed further in the next section.

Overall, the coefficients of the lagged explanatory variables should be interpreted carefully and I turn to analysis of dynamic multipliers in the next section to further study the properties of the model.

Figure 8.2 plot the fitted values versus the actual values of the endogenous variables. Overall, the model is able to explain much of the variation in the growth rates of real house prices and the debt ratio. The picture is different for housing starts, as the model underestimates the variation in this variable in several periods. This is not surprising, considering the simplicity of how housing starts are modelled and the fact that few variables associated with housing supply were included in the information set. In fact, the growth in housing starts is explained only in terms of lagged values, real house prices, real construction costs and the long-run relation,

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<sup>23</sup>The estimated coefficient of the lagged change in construction costs is negative, which dampens the contemporaneous impact.

<sup>24</sup>See Solheim and Vatne (2018) on Norwegian households' financing of home purchases.

Table 8.3: Final model results<sup>1</sup>

	$\Delta ph_t$	$\Delta(d-h)_t$	$\Delta s_t$
Constant	-0.740*** (0.137)	-0.34*** (0.038)	0.47*** (0.169)
$\Delta(d-h)_t$	0.929*** (0.155)		
$\Delta ph_t$		0.501*** (0.090)	
$\Delta s_t$		0.720*** (0.270)	
$\Delta ph_{t-1}$	0.288*** (0.074)	-0.489** (0.191)	0.400** (0.163)
$\Delta ph_{t-3}$		-0.402** (0.204)	0.490*** (0.171)
$\Delta ph_{t-4}$	0.216*** (0.067)		-0.174*** (0.077)
$\Delta(d-h)_{t-1}$	0.172*** (0.092)		
$\Delta(d-h)_{t-4}$		0.054* (0.032)	
$\Delta s_{t-1}$	0.172*** (0.036)	-0.339*** (0.113)	0.364*** (0.077)
$\Delta s_{t-2}$	-0.153*** (0.036)	0.270** (0.103)	-0.256*** (0.082)
$\Delta s_{t-4}$		-0.231** (0.081)	0.322*** (0.082)
$\Delta R_{t-1}$	-0.270* (0.165)	0.241** (0.099)	
$\Delta E_t$	0.064*** (0.019)	-0.035*** (0.013)	
$\Delta E_{t-1}$		0.007* (0.004)	
$\Delta pj_t$			0.472*** (0.174)
$\Delta pj_{t-1}$			-0.110* (0.063)
$ECM_{t-1}^{ph}$	-0.095*** (0.017)		
$ECM_{t-1}^{d-h}$		-0.051*** (0.005)	
$ECM_{t-1}^s$			-0.064*** (0.023)
IDUM, 1995Q4		0.017*** (0.004)	
IDUM, 2008Q3-Q4	-0.014*** (0.005)		
Dummy, Q1	0.033 (0.006)	0.001 (0.014)	-0.036 (0.011)
Dummy, Q2	0.024 (0.006)	-0.011 (0.011)	0.009 (0.013)
Dummy, Q3	0.000 (0.005)	-0.000 (0.010)	-0.007 (0.013)

<sup>1</sup> Absolute value of standard errors in brackets. \*  $p$ -value < 0.1, \*\*  $p$ -value < 0.05, \*\*\*  $p$ -value < 0.01, where  $p$ -value refer to the significance of the estimated coefficients.

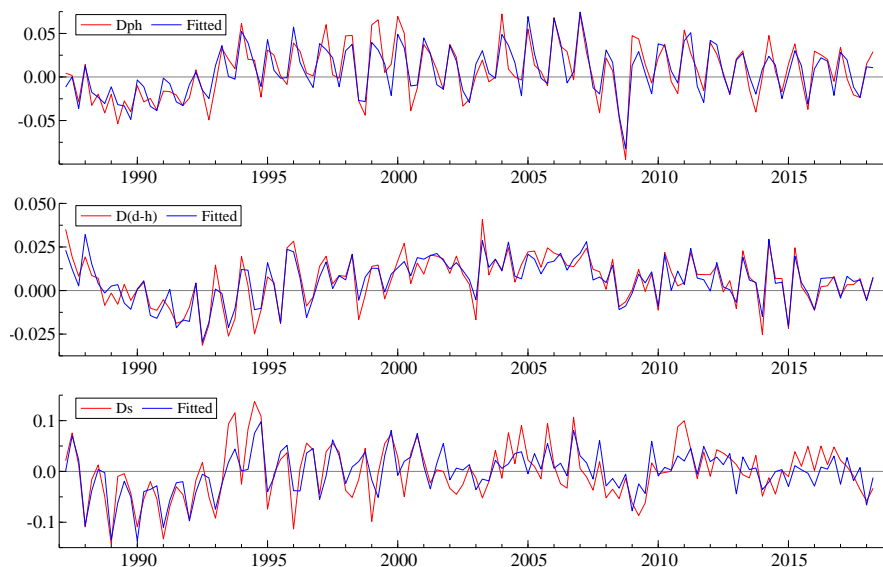
Table 8.4: Final Model: Additional information

SE of regression	0.015 0.030 0.033
Sample	1987Q2 - 2018Q2
Estimation method	FIML
LR-test, overidentifying restrictions	$\chi^2(49) = 73.03[0.02]$
Log-likelihood	1086.93
Diagnostics:	
<i>Vector SEM AR 1-5 test</i>	$F(45,280) = 1.24 [0.15]$
<i>Vector normality test</i>	$\chi^2(6) = 5.23 [0.51]$
<i>Vector hetero test</i>	$F(324,397) = 1.16 [0.07]$

which consists of the same variables (in addition to the deterministic trend).

Compared to the extended model of A&J (2013), it is evident that by allowing for an endogenous supply side from the outset of the analysis, I end up with a quite different final model. Apart from being a larger model in terms of the number of parameters, A&J do not find a contemporaneous two-way relationship in the short-run between house prices and credit. Further, in my model, housing starts enter in the house price equation, possibly indicating some short-term supply side effects, which is not allowed for by A&J. There are also differences with respect to the estimated adjustment coefficients, as the impact of the long-run relations is generally weaker in my case. Most notable is the estimated coefficient of the equilibrium correction term for housing starts. A&J estimate it to be -0.26, while it is -0.06 in my case, indicating slower adjustment towards steady state in the wake of a deviation from the estimated equilibrium level.

Figure 8.2: Final model: actuals and fitted values



### 8.3 Dynamic Multipliers

In this section, dynamic multipliers are produced in order to illustrate responses to specific shocks to the dynamic multiple equation model. For the purpose of dynamic simulation, an equation that explicitly give the housing stock as a function of housing starts is added to the system.<sup>25</sup> This makes it possible to separate the responses in real household debt and the housing stock from the relationship  $(d - h)$  and observe more clearly the supply side responses implied by the model, as housing starts are impacted by shocks and lead to changes in the housing stock over time. Indeed, introducing the equation for the housing stock does not involve any notable consequences for the estimated coefficient values in the model as the housing stock has been treated as an endogenous variable throughout the econometric analysis in the relationship  $(d - h)$ .<sup>26</sup>

In the following, the figures illustrate the dynamic responses in growth rates and in levels for the endogenous variables when considering exogenous shocks to real house prices, real disposable income and the real after-tax interest rate. The horizontal axis of the respective graphs measures the number of quarters following a given shock. Finally, the results are compared to the simulation results reported by A&J (2013) of their extended model (see section 7.2 in their paper).

Figure 8.3 illustrates that an increase in the growth of real house prices of 1 percentage point leads to growth in real house prices, real household debt, housing starts and the housing stock. The initial impact of the shock is amplified by the simultaneous two-way interaction between house prices and credit, as the debt ratio increases by 0.96 percent and real house prices by 1.9 percent at the time of the shock. This gives rise to an upwards price-credit spiral. Higher house prices increase the collateral value of dwellings, which leads to further credit growth and upward pressure on house prices. The lagged impact of house prices on the debt ratio was estimated to be negative, which dampens these self-reinforcing effects.<sup>27</sup> Housing starts react positively to higher house prices as the profitability of supplying new housing increases. In the short-run, the model results imply that housing starts amplify the price-credit spiral.<sup>28</sup> Over time, increasing supply put downward pressure on house prices and the price-credit spiral seems to be reversed in the long-run. Also, the equilibrium correction terms dominate over time as the effects of the shock die out. House prices reach a top of 2.8 percent after about one year before turning downwards, adjusting towards a new long-run equilibrium level just above the initial level. Housing starts follow a similar path reaching a top of about 3 percent after two years.

<sup>25</sup>The housing stock is found to depend on its lagged value and the level of housing starts over the previous five quarters. The equation is:  $h_t = \underset{(0.000)}{0.996}h_{t-1} + \underset{(0.010)}{0.044}s_t - \underset{(0.013)}{0.045}s_{t-1} + \underset{(0.008)}{0.016}s_{t-2} - \underset{(0.005)}{0.004}s_{t-3} - \underset{(0.005)}{0.010}s_{t-4} + \underset{(0.004)}{0.009}s_{t-5} + \text{seasonals}$ , with standard errors in brackets.

<sup>26</sup>It may involve other consequences, for example for the estimated standard errors of the model, but only the respective coefficient values are of interest in this part.

<sup>27</sup>This negative lagged impact is also the reason behind the negative dip in both house prices and the debt ratio after about 1 year

<sup>28</sup>As table 8.3 show, the contemporaneous change in housing starts was estimated to have a positive impact on the debt ratio. Also, the lagged change in housing starts enters with a positive coefficient in the house price equation.

The debt ratio adjusts more slowly, reaching a top after about six years, while it is not clear at what level it stabilizes within the horizon of the simulation period. Split into its respective components, household debt follows a similar pattern as the ratio, while the housing stock gradually adjusts towards a higher level as new construction takes place. It is evident that the adjustment to the new steady state is relatively slow. This is not surprising as the estimated adjustment parameters were rather small in magnitude. As mentioned in the literature review of chapter 5, studies such as Borio (2014), Drehmann et al. (2012) and Claessens et al. (2011) argue that house price and credit cycles tend to be particularly long lasting, with Drehmann et al. (2012) estimating the length of such cycles to average 16 years based on a sample of industrialized countries.

Figure 8.3: Dynamic multipliers of an increase in real house price growth of 1 percentage point

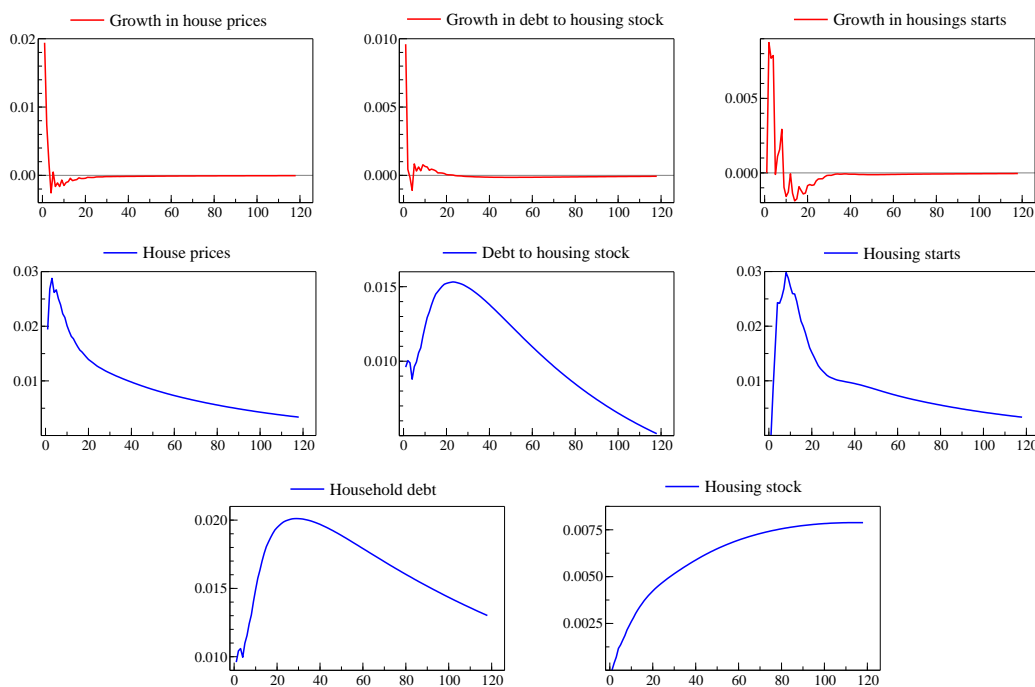
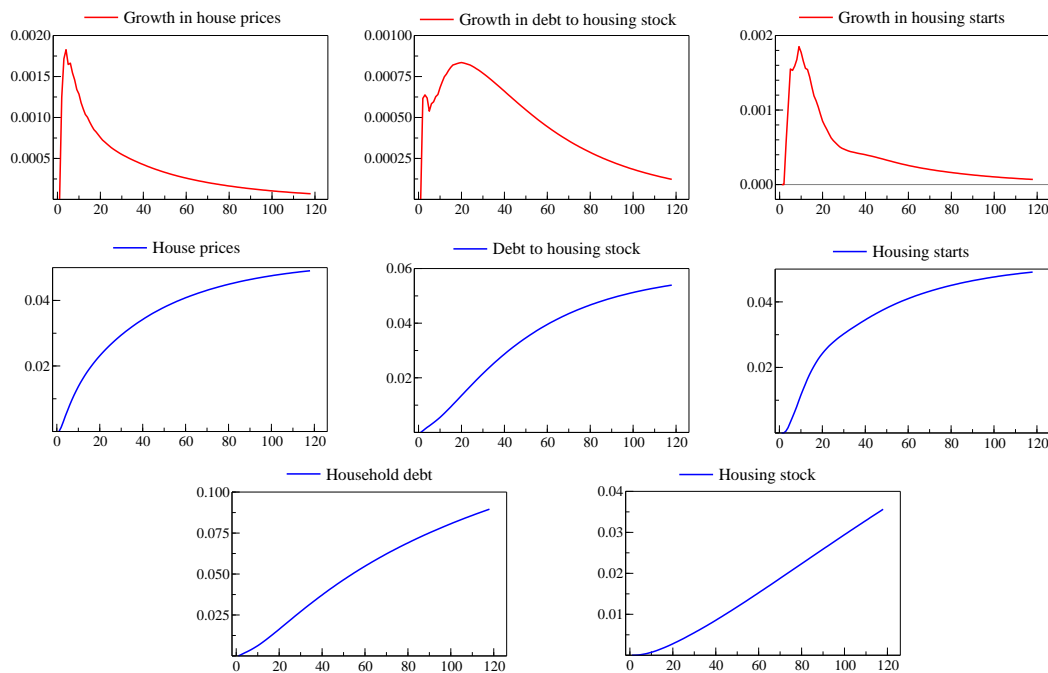


Figure 8.4 shows the responses of an increase in the level of real disposable income of 1 percent. In practice, the shock is implemented by adding an equation for real disposable income. Real disposable income enters only through the long-run equation for real house prices and the responses are much more persistent in this case. The growth in both house prices and housing starts reach a top of about 0.18 percent after about one year, while the change in the debt-ratio adjusts more slowly. Clearly, the response dies off very slowly as a new steady state is not reached within the simulation period, which amounts to 30 years following the shock. The plots indicate that the system is gradually moving towards a steady state with higher equilibrium levels for house prices, household debt and housing supply. Since the growth rates stay positive for such a long time, the cumulative responses are predicted to be rather big in the long-run.

Next, two different shocks to the real after-tax interest rate are considered: (1) an impulse to the change in the real after-tax interest rate of 1 percentage point and (2) a permanent

Figure 8.4: Dynamic multipliers of a permanent increase in real disposable income of 1 percent



increase in the level of the real after-tax interest rate of 1 percentage point. The distinction is that in the first case, the first order impacts of the shock are just inserted for the endogenous variables and there is no relation in the model specifying that the change in the real after-tax interest rate actually shifts the interest rate level as well. In the second case, an equation for the real after-tax interest rate is added to the model, which implies that the level of the interest rate shifts permanently.<sup>29</sup>

Figure 8.5 shows the dynamic multipliers for the first shock, which leads to negative responses in house prices and housing supply. However, the impact on household debt is somewhat unclear as it is predicted to first increase before decreasing for several periods. This is a result of the unexpected positive coefficient of the interest rate that was estimated in the dynamic debt to housing stock equation. As an alternative, figure 8.6 graphs the same shock with that particular coefficient restricted to zero.<sup>30</sup> In that case, the impulse to borrowing costs leads to negative responses in all the endogenous variables. Again, real house prices are found to turn after about a year before the response dies off gradually. The response in housing starts follows a similar pattern. Household debt adjusts more slowly, reaching a low point after about five years.

Figure 8.7 shows the responses of a permanent increase in the real after-tax interest rate of 1 percentage point, not imposing the extra restriction considered in the previous case. The shock leads to similar dynamics as for the permanent shock to the income level, but with

<sup>29</sup>Indeed, one may argue that it only makes sense to look at the second case. However, the first shock is still included in order to demonstrate some properties of the model.

<sup>30</sup>Imposing the restriction did not impact the rest of the coefficients considerably.

Figure 8.5: Dynamic multipliers of an impulse to the real after-tax interest rate of 1 percentage point

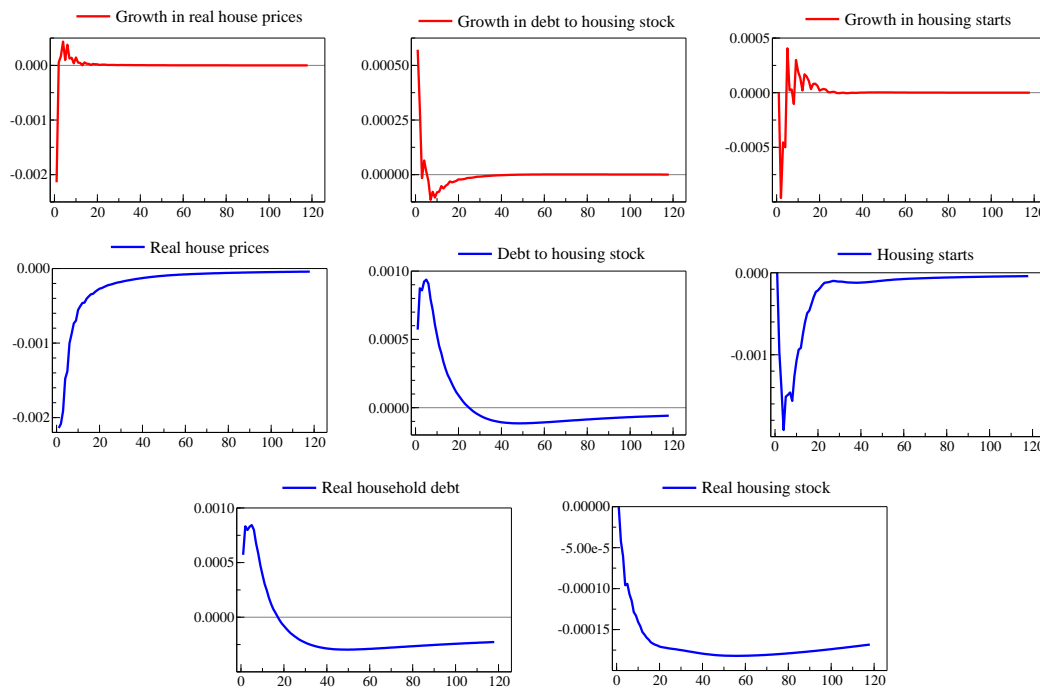
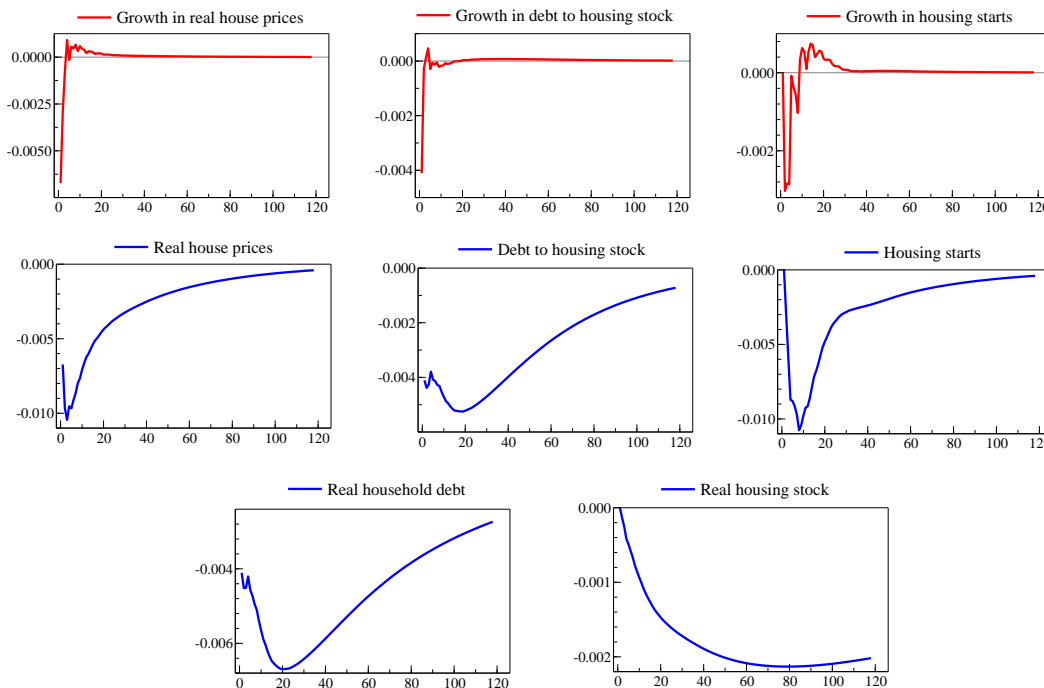
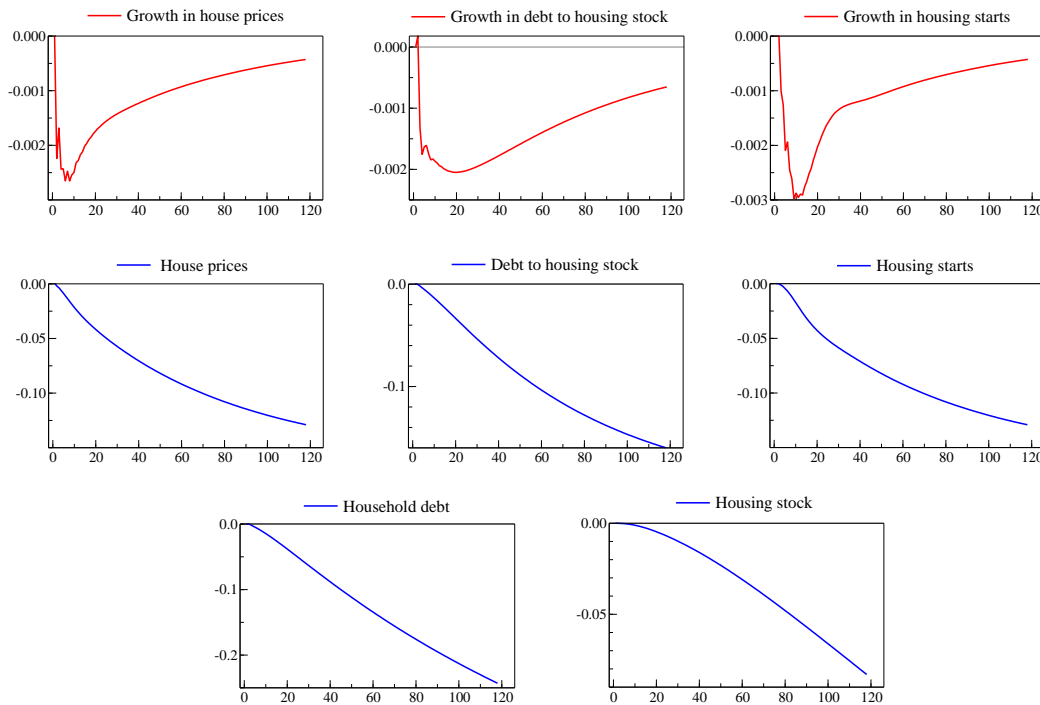


Figure 8.6: Extra restriction imposed: dynamic multipliers of an impulse to the real after-tax interest rate of 1 percentage point



opposite signs. The negative impact of higher borrowing costs is amplified by the two-way interaction of house prices and borrowing, leading to a negative response in the housing supply. Again, the equilibrium correction appears to be rather weak and a new steady state is not

Figure 8.7: Dynamic multipliers of a permanent increase in the real after-tax interest rate of 1 percentage point



reached within the simulation period. The responses in the growth rates are moderate, but the responses in levels become large over time since the impact of the shock dies off slowly.

### Comparing to A&J (2013) and Discussion of Results

Compared to the dynamic simulation results reported in A&J (2013), there are interesting similarities and differences. As in A&J (2013), the mutual relationship between house prices and credit amplify the responses to exogenous shocks. Over time, supply side dynamics dampen these fluctuations. Regarding the shock to house prices, in A&J's case, house prices are predicted to increase by about 12 percent over the first four years before gradually decreasing. In contrast, my model predicts a much lower price increase of about 2.8 percent, which dies off earlier (approximately after a year). Correspondingly, the responses in household debt and housing are also more moderate.

Regarding the shocks to real disposable income and the real after-tax interest rate, the permanent responses shown in figure 8.4 and 8.7 can be compared to the shocks to income and the interest rate reported in A&J (2013). In both cases, my model implies much more moderate responses in the growth rates of the endogenous variables, but the shocks die off more slowly than in A&J (2013) leading to larger cumulative responses. There may be two reasons for this. First, the equilibrium correcting forces in A&J's model are stronger. Second, there are differences in how housing supply impacts the rest of the model. In A&J's case, the supply side is restricted to only impact house prices and household debt *through* the housing stock. In my case, housing starts impact both house prices and household borrowing directly,



amplifying fluctuations in these variables. Thus, my model results imply that the supply of housing impact house prices and household borrowing not only through changes in the *existing* stock of housing, but also through changes in the *flow* of new dwellings. Overall, this makes the impact of supply side responses less pronounced in my model.

According to the theoretical framework outlined in chapter 3, the supply of housing is expected to only impact the rest of the model through the housing stock. A direct impact of changes in the flow of new dwellings is not to be expected. Hence, a strict interpretation of that theory would lead to the conclusion that the significant impacts of housing starts on house prices and household debt (reported in table 8.3) only represent irrelevant correlations. This could have motivated more restrictions on how housing starts enters in the final model. On the other hand, it may be argued that changes in the flow of new dwellings can involve direct causal effects that are relevant, at least on house prices. As mentioned in chapter 3, new dwellings tend to be listed in the market even before construction has begun. Thus, there is uncertainty related to exactly when supply side responses impact the housing market. Correspondingly, it is uncertain to what extent market participants pay attention to housing starts. What may be more certain is that if the way the supply of housing enter the extended model of A&J (2013) is a *good* representation of the data, then my econometric procedure should have lead to a model specification that is more similar to A&J's extended model.

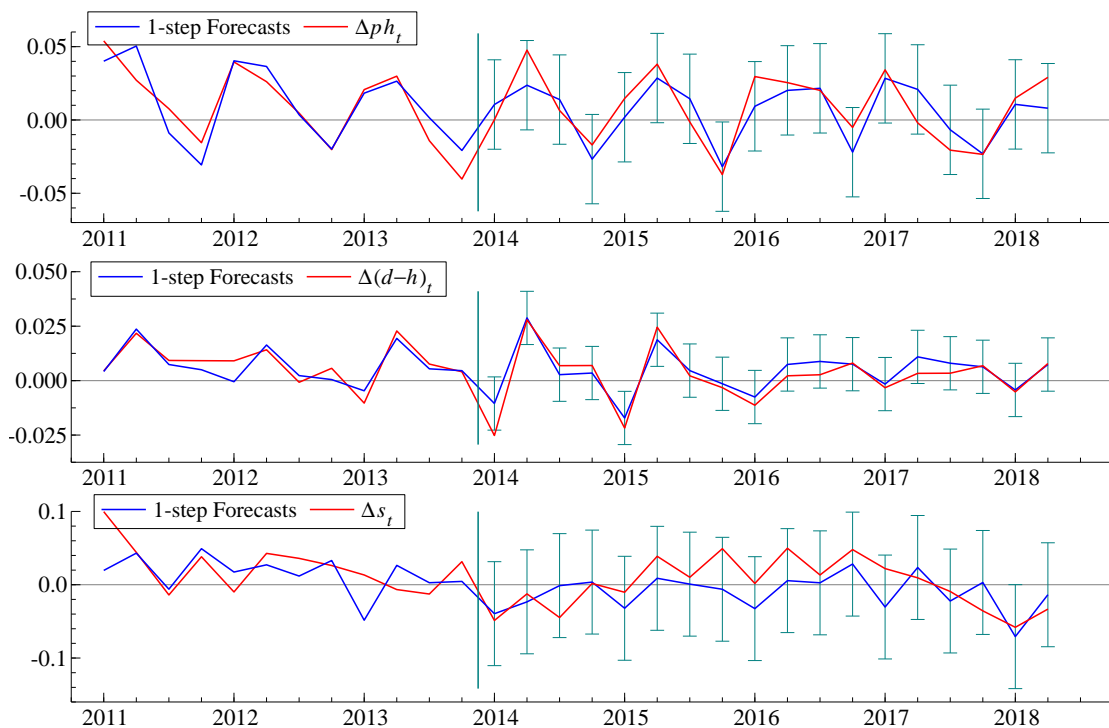
In addition, combining household debt and the housing stock into the relationship  $(d - h)$  also plays a role here, as  $h$  is restricted to the same coefficients as  $d$ . The estimated impact of  $h$  on house prices is stronger in A&J (2013) than in my case.

To summarize, the dampening effect of the supply side on fluctuations in house prices seems to be stronger in A&J's model and there are some uncertainties related to how the housing supply enter in my final model specification. This is interesting, as I would argue that my econometric analysis involves a more careful treatment of supply side effects.

## 8.4 A Short Note on Changes in Macroprudential Policy

The econometric analysis has not accounted for the changes in macroprudential policy in recent years that was discussed in chapter 2. To briefly address possible implications for the model, figure 8.8 shows one-step forecasts for the changes in the endogenous variables for the period 2014Q1-2018Q4. New mortgage regulations was introduced in 2015Q3 and extended with additional requirements in 2017Q1 (Lindquist and Riiser, 2018). Overall, the model does a fairly good job of predicting the variation in house prices and household debt (relative to the housing stock). The model predicts the decline in house price growth in 2015, but underpredicts the recovery in 2016. Further, house prices decreased in 2017, which the model also underpredicts. The model can predict the variation in the debt ratio in 2015, but overpredicts the change in 2016 and 2017. For housing starts, the picture is different as the model underpredicts it from 2015 to 2017. There is uncertainty related to exactly when banks and households began adapting to the regulations, but overall there is some indication that the policies introduced in 2017Q1 should be controlled for. However, based on this brief discussion, it is uncertain whether the policy changes imply any structural breaks for the model parameters.

Figure 8.8: One-step ahead forecasts, 2014Q1 - 2018Q2



# Chapter 9

## Conclusion

This thesis has aimed at understanding what are the driving forces behind the development in house prices and household debt in Norway since the 1980s. In doing so, emphasis was put on previous empirical work. The model of house prices and household debt developed in Anundsen and Jansen (2013) was studied in detail and re-estimated over an extended sample. To better match the extended data sample, a re-specification of the long-run relationships of their original model was introduced.

Further, by building on Anundsen and Jansen (2013), a new model of the housing market and household debt was developed. In this part, two assumptions made by Anundsen and Jansen were challenged: (1) that the supply of housing can be treated as an exogenous variable when modelling house prices and household debt and (2) that none of the variables in the information set are integrated of an order higher than one. The first assumption was addressed by allowing for an endogenous supply side throughout the econometric analysis. The results suggested that it is valid to condition on housing starts when estimating long-run relationships for real house prices and real household debt. Regarding the second assumption, it was found that two variables of interest in the analysis, real household debt and the housing stock, showed clear indications of being  $I(2)$  variables. To make sure that all unit roots were accounted for in the econometric analysis, it was found that the relative relationship between the two  $I(2)$  variables could be taken as a cointegrated relationship that is  $I(1)$ .

Using cointegration analysis, a system of long-run relationships explaining the levels of real house prices, real household debt measured relative to the housing stock and housing starts was identified and estimated. Like Anundsen and Jansen (2013), a two-way relationship between the levels of house prices and household debt was established. Housing starts were found to depend on a proxy for the profitability of supplying new dwellings.

Based on the cointegration analysis, a structural vector error correction model (SVECM) was developed to study short-run dynamics. The estimation results suggested that mutual dependence between house prices and household credit is of importance in the short-run as well. Overall, the model does a fairly good job of explaining changes in house prices and household borrowing, while the same is not the case regarding housing starts.

The analysis of dynamic multipliers showed that shocks to the model are amplified by self-

reinforcing effects between house prices and credit. Over time, the supply of housing responds to changes in house prices and dampen the fluctuations. Finally, how the supply of housing enter the model was discussed leaving some unsolved questions for future research. An interesting modification that could possibly lead to a simpler model would be to disregard housing starts and only model the housing stock, assuming that it depends on the same variables as housing starts. Regarding future research, closer inspection of possible structural breaks arising from the changes in regulatory policy in recent years would also be interesting.

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# Appendix A

## Appendix

### A.1 Appendix A: Supplement to Chp. 4, Concepts from Time Series Econometrics

The following is based on Nymoen (2019) and references therein.

#### Stationarity

A time series variable,  $X_t$ , is said to be stationary if:

1.  $E(X_t) = \mu, \quad \forall t$
2.  $COV(X_t, X_t - j) = E(X_t - \mu)(X_{t-j} - \mu) = \gamma_j, \quad \forall t, j$

Meaning that a variable is stationary if its expected value and variance are constant over time, and the covariance only depends on the distance in time between two observations. A stationary time series is often characterized as fluctuating around its mean. Most time series analyzed in this thesis are not stationary. For example, the aggregate household debt is likely to be trending and fluctuations may be permanent and not only temporary, as they would be for a stationary process. Further, if a series is neither stationary nor trend stationary, it contains a stochastic trend and is characterized as non-stationary. Non-stationary variables can be difference stationary. Generally, a variable that become stationary after being differenced  $d$  times is characterized as a I(d) variable, or a variable containing  $d$  unit roots (where  $d \geq 0$ ). A stationary variable is said to be a I(0) variable.

Further, consider the linear model specification:

$$Y_t = \beta X_t + \epsilon_t \tag{A.1}$$

The model specification is only valid if  $Y_t$  and  $X_t$  are integrated of the same order (ie. the variables contain the same number of unit roots). If  $Y_t$  is an I(0) variable and  $X_t$  and I(1) variable, the model equation will be *unbalanced*, since a I(1) variable cannot explain an I(0) variable. In this case, estimation by ordinary least squares (OLS) and normal inference theory

is not valid and can lead to misguided interpretations about significant relationships. The model equation is balanced if both variables are  $I(0)$ . A model with  $I(1)$  variables on both sides is also balanced, but it only represents a genuine relationship if the variables are cointegrated, meaning that there exists a linear combination of  $Y_t$  and  $X_t$  that is stationary.

### Cointegration

If two  $I(1)$  variables contain a common stochastic trend, then the variables will follow a similar pattern since the trend component lead the series to not fluctuate *far away* from one another. In that case, the variables are said to be cointegrated and normal regression methods and inference theory can be employed. Generally we have that  $s$  different  $I(1)$  time series variables are cointegrated if there exists a  $s$  vector  $\beta$ , such that  $\beta' x_t \sim I(0)$ , where  $x_t$  is a vector containing the  $s$  variables.  $\beta$  is then characterized as the cointegrating vector. There may be more than one  $\beta$  vectors satisfying the condition. If there is  $i$  such  $\beta$  vectors, then the cointegration rank is said to be  $i$  as there exists  $i$  different linear combinations of the variables in  $x_t$  that are stationary.

Variables containing more than one unit root can also be cointegrated, for example, two  $I(2)$  variables. Variables that are not integrated of the same order cannot be cointegrated.

### Unit Root Testing

To help determine the order of integration of the variables analyzed in this thesis, the Augmented Dickey-Fuller (ADF) test is applied. Consider a time-series following an auto-regressive process of order  $p$ :

$$Y_t = \mu + \beta t + \sum_{i=1}^p \phi Y_{t-i} + \epsilon_t, \quad (\text{A.2})$$

where  $\mu$  is a drift and  $\beta t$  a linear trend. Equation A.2 can be reparameterized into:

$$\Delta Y_t = \mu + \beta t + \pi Y_{t-1} + \sum_{j=1}^{p-1} \alpha_j \Delta Y_{t-j} + \epsilon_t, \quad (\text{A.3})$$

where  $\pi = \sum_{i=1}^p \phi Y_{t-i} - 1$  and  $\alpha_j = -\sum_{k=j+1}^p \phi_k$ .

A regression of equation A.3 is often referred to as the Dickey-Fuller (DF) regression. The deterministic terms are included to account for the trend behaviour of the series both under the null of a unit root, and under the alternative hypothesis of stationarity. The lag specification generally depends on the number of lags needed to account for autocorrelation such that the residuals can be considered white noise.<sup>1</sup> The order of integration is tested by the following:

$$H_0 : \pi = 0, \quad H_A : \pi < 0$$

---

<sup>1</sup>On the other hand, the power of the test may decrease with the size of the model. The lag specification can be decided with the help of information criteria or inspection of the significance level of lags.

Under the null hypothesis, the coefficient follows a non-standard distribution. Thereby, critical values must be taken from the Dickey-Fuller distribution.<sup>2</sup> The null hypothesis refers to the non-stationary case. Rejection of the null hypothesis leads to the conclusion that the variable does not contain any unit roots and is thereby stationary. Accepting the null hypothesis means that  $Y_t$  contains at least one unit root. , the variable can be differenced once more and the test can be repeated. If the null hypothesis is then rejected it leads to the conclusion that  $\Delta Y_t$  is stationary, which implies that  $Y_t$  is integrated of order one (I(1)).

### VAR Model and Conditional VECM Formulation

The general form of a VAR model is:

$$Y_t = \Pi_1 Y_{t-1} + \Pi_2 Y_{t-2} + \dots + \Pi_p Y_{t-p} + \Phi D_t + \varepsilon_t, \quad t = 1, 2, \dots, T \quad (\text{A.4})$$

Where  $Y_t$  is a  $nx1$  matrix representing the variables in the model,  $p$  is the number of lags included and  $D_t$  represent deterministic terms such as a constant, linear trends and dummy variables. The residuals, represented by the  $nx1$  matrix  $\varepsilon_t$ , are assumed to be independently Gaussian distributed,  $N(0, \Sigma)$ , where  $\Sigma$  is the variance-covariance matrix .

A conditional VECM will be formulated in chapter 8 taking the following general form:

$$\Delta X_t = \tilde{\Pi} \tilde{Y}_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta X_{t-i} + \sum_{i=0}^{q-1} \Psi_i \Delta Z_{t-i} + \tilde{\Phi} \tilde{D}_t + \varepsilon_t \quad (\text{A.5})$$

where  $X_t$  is a  $nx1$  matrix of  $n$  endogenous variables,  $Y_t = (X_t', Z_t')'$  is a  $(n+k) \times 1$  matrix where  $Z_t$  is a  $kx1$  matrix consisting of the  $k$  weakly exogenous variables and  $\tilde{Y}_t = (Y_t', t)'$  where  $t$  denotes a deterministic trend and  $\tilde{D}_t$  include a constant and seasonal dummies.

---

<sup>2</sup>The exact correct critical values depends on the deterministic terms and the number of exogenous variables included in the specification.

## A.2 Appendix B. Data Definitions and Additional Information

The data set consists of the same series as that of Anundsen and Jansen (2013). All data series are taken from the National Accounts published by Statistics Norway.<sup>3</sup> Due to revisions of data by Statistics Norway, there are some differences between my dataset and the dataset of Anundsen and Jansen (2013). The respective series measuring the real after-tax interest rate (R) and real household debt (d) differ to some extent compared to the dataset of Anundsen and Jansen (see below).

### Consumption deflator(pc)

The consumption deflator in the National Accounts. Source: Statistics Norway.

### Real house prices (ph)

Real house prices are proxied by the house price index for existing dwelling published by Statistics Norway, and deflated by the consumption deflator. The index measures average house prices in secondary markets across Norway and are adjusted for quality improvements. Source: Statistics Norway.

### Real household debt (d)

The total amount of gross outstanding household debt to Norwegian private financial institutions. In 2014 the calculation of this series was changed, impacting the level of the series from 1995Q4.<sup>4</sup> Source: Statistics Norway.

### Real housing stock (h)

The stock of existing dwellings enters as the real housing stock measured in fixed prices. Source: Statistics Norway.

### Real after-tax interest rate (R)

Up to 2013, the real after-tax interest rate is calculated based on nominal interest rates paid by households for outstanding loans to Norwegian private financial institutions. After 2013, the nominal interest rate is based on interest paid by households for outstanding mortgage loans, as the former interest rate measure is a discontinued series.<sup>5</sup> This nominal interest rate is deflated by the inflation rate and adjusted by the capital tax rate. Source: Statistics Norway

### Real disposable income (yh)

This variable is calculated as households disposable income excluding equity income and deflated by the consumption deflator. Source: Statistics Norway

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<sup>3</sup>See <https://www.ssb.no/en/knr>

<sup>4</sup>See the following link for more information about this revision [https://www.ssb.no/nasjonalregnskap-og-konjunkturer/artikler-og-publikasjoner/\\_attachment/209561?\\_ts=14a0ffeea20](https://www.ssb.no/nasjonalregnskap-og-konjunkturer/artikler-og-publikasjoner/_attachment/209561?_ts=14a0ffeea20)

<sup>5</sup>See <https://www.ssb.no/renter>.

**Real construction costs (pj)**

This variable is proxied by a price index for construction of dwellings published by Statistics Norway and it is deflated by the consumption deflator. The index measures what real estate developers pay for inputs such as labor, materials and machines. It does not include land prices.

Source: Statistics Norway

**Housing starts (s)**

This variable measures the number of new housing units which have been granted permission to build by a given municipality. Source: Statistics Norway

**Housing turnover (th)**

This variable measures the number of housing transactions. Source: Statistics Norway.

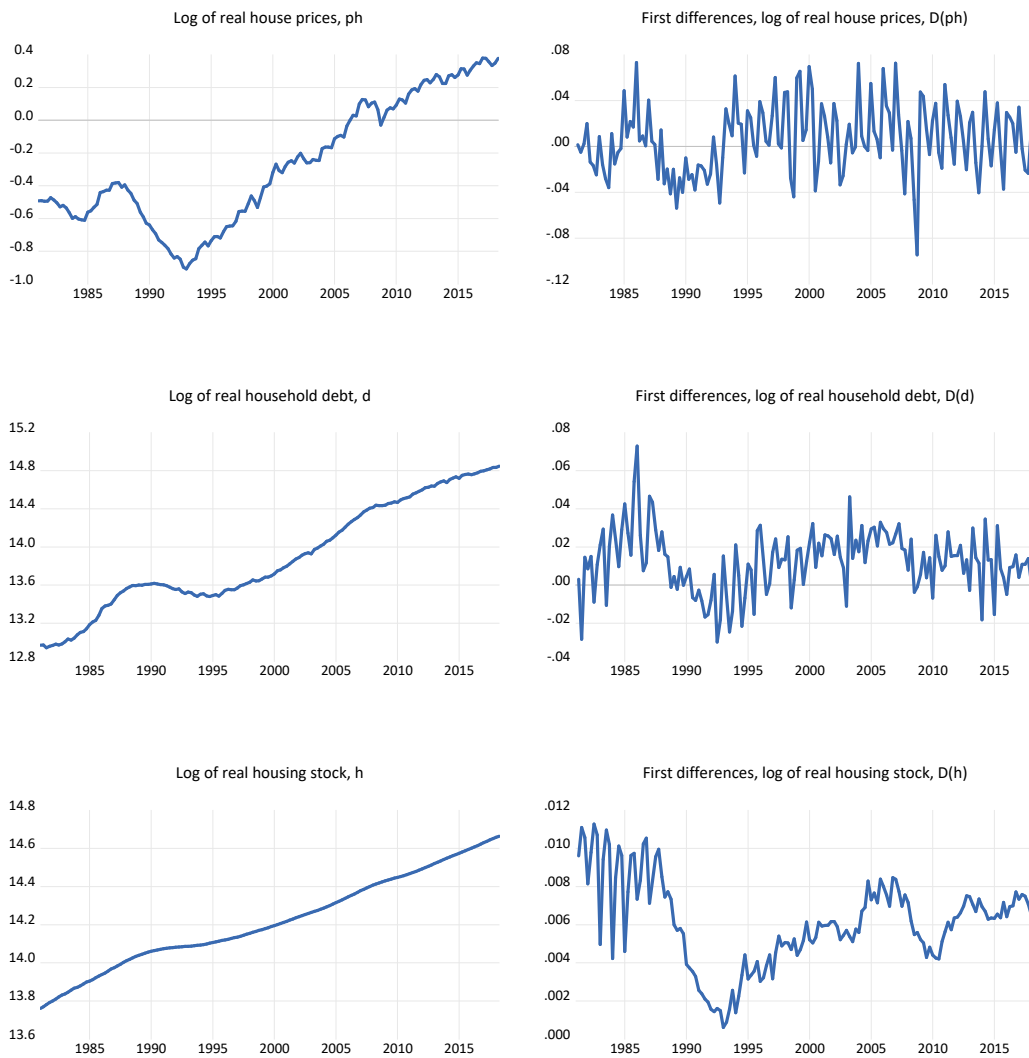
**Expectations (E)**

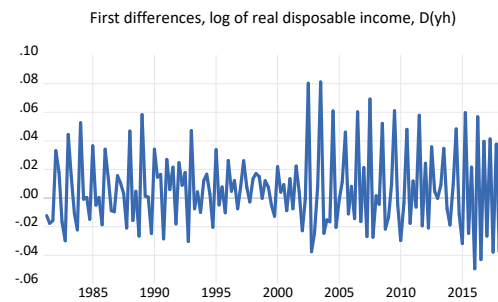
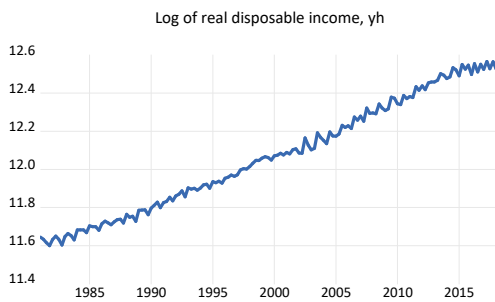
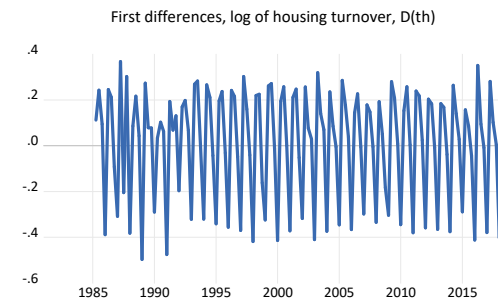
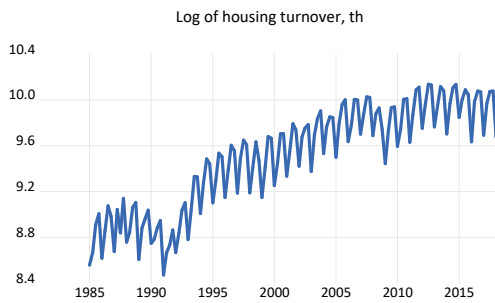
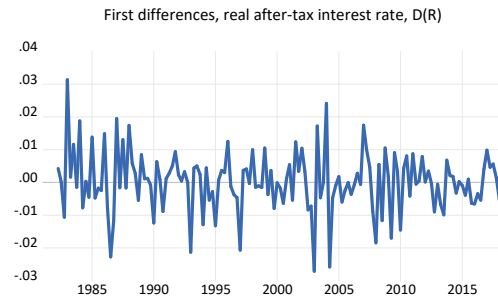
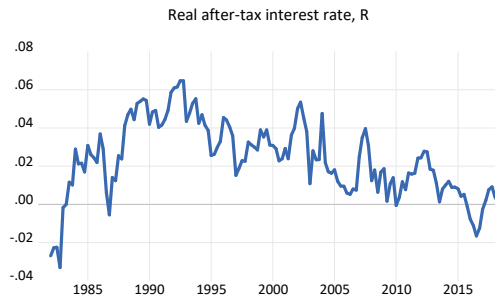
The expectations variable can be seen as a consumer confidence indicator and is taken from TNS Gallup. It is based on a survey measuring households expectations concerning the state of the economy and the development in their personal economy. The average score can range between -100 to 100, but I have normalized it to lie between -1 and 1. Source: TNS Gallup.

### A.3 Appendix C: Data Plots

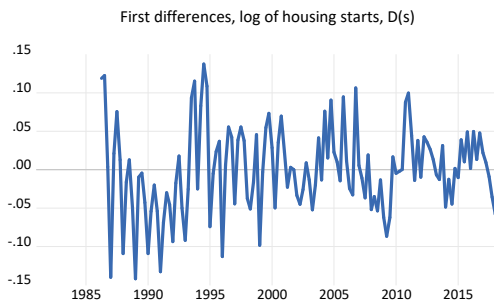
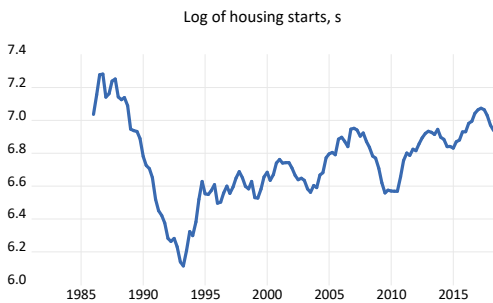
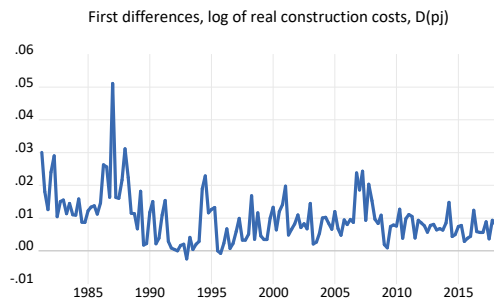
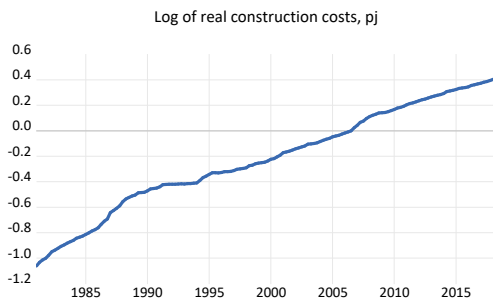
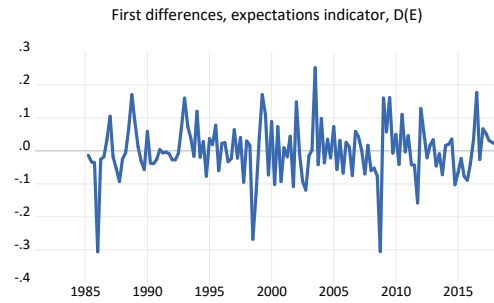
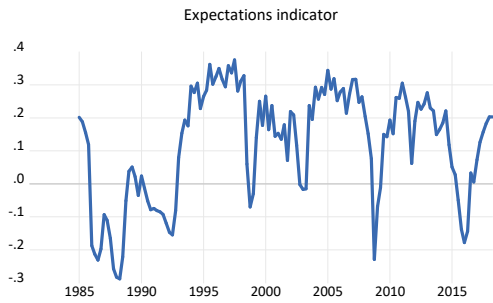
See figure A.1 below.

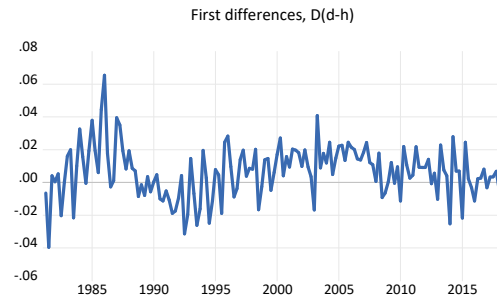
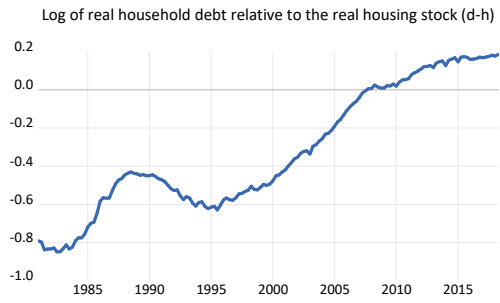
Figure A.1: Data plots











## A.4 Appendix D: ADF-Tests

Table A.1: Augmented Dickey-Fuller tests <sup>a</sup>

Variable	t-ADF	5% critical value	Deterministic terms
In levels:			
<i>ph</i>	-2.49	-3.44	Constant and trend
<i>d</i>	-3.13	-3.44	Constant and trend
<i>h</i>	-2.15	-3.44	Constant and trend
<i>ydp</i>	-2.01	-3.44	Constant and trend
<i>r</i>	-4.20	-3.44	Constant and trend
<i>t</i> <sup>b</sup>	-2.30	-3.44	Constant and trend
<i>pj</i>	-2.16	-3.44	Constant and trend
<i>s</i> <sup>c</sup>	-3.73	-3.44	Constant and trend
<i>E</i> <sup>b</sup>	-4.05	-2.88	Constant
<i>d-h</i> <sup>b</sup>	-2.87	-3.44	Constant
First differences:			
$\Delta ph$	-2.97	-2.88	Constant
$\Delta d$	-2.45	-2.88	Constant
$\Delta h$	-2.72	-2.88	Constant
$\Delta ydp$	-8.10	-2.88	Constant
$\Delta r$	-7.20	-2.88	Constant
$\Delta th$	-3.77	-2.88	Constant
$\Delta pj$	-4.60	-2.88	Constant
$\Delta s$	-3.43	-2.88	Constant
$\Delta(d - h)$	-2.65	-2.88	Constant
Second differences:			
$\Delta^2 d$	-20.80	-1.94	None
$\Delta^2 h$	-4.34	-1.94	None
$\Delta^2(d - h)$	-16.89	-1.94	None

<sup>a</sup> The null hypothesis of the ADF-test is the existence of a unit root. A maximum of eight lags is included in the DF-regressions. The sample is 1986Q1 - 2018Q2.

<sup>b</sup> Only have data on housing turnover (*th*) and expectations (*E*) from 1985Q2, which means that with 8 lags in the ADF-regression, the sample starts in 1987Q1.

<sup>c</sup> Only have data on housing starts (*s*) from 1986Q1, which means that with 8 lags in the ADF-regression, the sample starts in 1988Q2.

### A Note on Housings Starts (*s*)

It is challenging to determine the order of integration of this series. Indeed, the ADF-test indicate that the series is trend stationary, but I will make the same assumption as in Boug and Dyvi (2008), and assume it to be  $I(1)$ . Looking at the plot in appendix B, housing starts were at its highest before the banking crisis. During the crisis period, it decreased rapidly, which is likely to represent a structural break that the ADF-test does not take into account. Inspecting the lag length of the Dickey-Fuller regression, it is found that including nine lags is appropriate (by t-values of lagged changes and AIC). However, the power of the test decrease by the number of lags included. Following 1993 the series is slightly trending upwards with

indications of being trend stationary. However, according to the data plot, the variance does not look to be constant with indications of higher volatility in more recent years.

## A.5 Appendix E: Reduced Form Loading Parameters Corresponding to Table 6.1

Table A.2: Long-run relations: loading parameters

(1) Anundsen og Jansen			
$\alpha_{1,ph} =$	-0.24	$\alpha_{1,d} =$	-0.10
	(0.05)		(0.03)
$\alpha_{2,ph} =$	0	$\alpha_{2,d} =$	-0.04
			(0.01)
(2) Re-estimation			
$\alpha_{1,ph} =$	-0.23	$\alpha_{1,d} =$	-0.09
	(0.04)		(0.02)
$\alpha_{2,ph} =$	0	$\alpha_{2,d} =$	0.03
			(0.01)
(3) Extended sample			
$\alpha_{1,ph} =$	-0.16	$\alpha_{1,d} =$	-0.10
	(0.03)		(0.02)
$\alpha_{2,ph} =$	0	$\alpha_{2,d} =$	-0.05
			(0.01)

## A.6 Appendix F: Johansen Test Corresponding to Section 6.3

Table A.3: Trace test for cointegration<sup>a</sup>

<i>Eigenvalue: <math>\lambda_i</math></i>	$H_o$	$H_A$	$\lambda_{trace}$	p-value
0.29	$r = 0$	$r \geq 1$	73.54	[0.000]***
0.20	$r \leq 1$	$r \geq 2$	29.40	[0.000]***
Diagnostics	Test Statistic	Value [p-value]		
Vector AR 1-5 test:	F(20, 188)	1.86[0.02]*		
Vector Normality test:	$\chi^2(6)$	7.48 [0.11]		
Vector Hetero test:	F(312,402)	1.27[0.06]		
Estimation period:	1986Q2 - 2018Q2			

<sup>a</sup> Endogenous variables: Real house prices ( $ph$ ), real household debt ( $d$ ). Restricted variables: Real after-tax interest rate ( $R$ ), housing turnover ( $th$ ), real disposable income ( $yh$ ), the housing stock ( $h$ ) and a trend ( $t$ ). Unrestricted variables: Constant, centered seasonal dummies for the first three quarters and one impulse dummy for 2008Q3-Q4.

## A.7 Appendix G: Johansen Test for $(d - h)$

This section explains how the Johansen test is used to address possible cointegration between real household debt and the housing stock. The test is based on a fifth order VAR model in real house prices, real household debt, housing starts and the housing stock, conditioning on real disposable income, real after-tax interest rate, housing turnover and real construction costs and two dummies. The first dummy is equal to one in the third and fourth quarter of 2008 to control for the external shock of the financial crisis. The second dummy is equal to one in the last quarter of 1995 to control for the change in how the series for aggregate household debt is calculated (see Appendix C). By applying AIC and F-tests to lag reduction, it is found appropriate to include five lags of the endogenous variables and only one lag for the exogenous variables.<sup>6</sup>

The Johansen test yields evidence of full rank, i.e that there exists four cointegrated relationships between the variables. To test whether  $(d - h)$  can represent a cointegrated relationship, a likelihood ratio test is applied to the following restrictions: in the first vector, all variables are excluded except for real household debt ( $d$ ) and the housing stock ( $h$ ). In addition,  $(d - h)$  is restricted to hold in all four vectors. Tested jointly, the restrictions are not rejected, are the likelihood ratio test has a p-value of 13%. The system of cointegrating vectors can thereby be written as:

$$\beta' y = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ \beta_{2,ph} & \beta_{2,(d-h)} & \beta_{2,s} & \beta_{2,yh} & \beta_{2,R} & \beta_{2,th} & \beta_{2,pj} \\ \beta_{3,ph} & \beta_{3,(d-h)} & \beta_{3,s} & \beta_{3,yh} & \beta_{3,R} & \beta_{3,th} & \beta_{3,pj} \\ \beta_{4,ph} & \beta_{4,(d-h)} & \beta_{4,s} & \beta_{4,yh} & \beta_{4,R} & \beta_{4,th} & \beta_{4,pj} \end{pmatrix} \begin{pmatrix} ph \\ d - h \\ s \\ yh \\ R \\ th \\ pj \end{pmatrix}$$

Where the first vector represents the cointegrated relationship between  $d$  and  $h$ , implying that the corresponding cointegrating parameter is set to -1, and where  $(d - h)$  is imposed in the other three vectors. This procedure is taken as an indication that the relative relationship between real household debt and the housing stock,<sup>7</sup>  $(d - h)$ , reduces the degree of non-stationarity from I(2) to I(1), and that it is assumed to further cointegrate with the other I(1)-variables to arrive at stationary relationships. Note that the vectors are not identified when testing the restrictions. The procedure is only focused on testing the validity of the restrictions by testing how the restrictions impact the log-likelihood.

<sup>6</sup>Diagnostic tests indicate that the residuals are well-behaved: Vector AR 1-5 test:  $F(80,266) = 1.10[0.29]$ , Vector Normality test:  $\chi^2(8) = 6.52 [0.59]$ , Vector Hetero test:  $F(240,238) = 1.16 [0.13]$

<sup>7</sup>Since both variables are in logs,  $(d - h)$  represent the log of the relative relationship between  $d$  and  $h$ .

## A.8 Appendix H: Lag Reduction of the Exogenous Variables in the VAR Model of Chp. 8.2.1

Following is the information reported by PcGive when reducing the number of lags of the exogenous variables in the VAR(5) model. This includes information criterion's (Schwarz Criterion (SC), Hannan-Quinn information criterion (HQ), Akaike information criterion (AIC)) and F-tests of the restrictions. The null hypotheses of the F-tests are that the respective coefficients of the lags are equal to zero.

Table A.4: Lag length reduction for the exogenous variable in the unrestricted VAR<sup>1</sup>

Lags	Log likelihood	SC	HQ	AIC
5	1159.4902	-13.221	-15.075	-16.344
4	1146.0708	-13.470	-15.163	-16.321
3	1129.1228	-13.663	-15.194	-16.242
2	1122.0888	-14.014	-15.384	-16.321
1	1112.8747	<b>-14.330</b>	<b>-15.539</b>	<b>-16.366</b>
0	1053.9734	-13.851	-14.899	-15.616
Tests of lag reduction				
5 to 4:	F(12,204) = 1.4372 [0.1512]			
5 to 3:	F(24,223) = 1.7016 [0.0253]*			
5 to 2:	F(36,228) = 1.4233 [0.0656]			
5 to 1:	F(48,229) = 1.3646 [0.0699]			
5 to 0:	F(60,230) = 2.9242 [0.0000]**			
4 to 3:	F(12,214) = 1.9301 [0.0323]*			
4 to 2:	F(24,235) = 1.3881 [0.1131]			
4 to 1:	F(36,240) = 1.3132 [0.1202]			
4 to 0:	F(48,241) = 3.2289 [0.0000]**			
3 to 2:	F(12,225) = 0.81544 [0.6344]			
3 to 1:	F(24,247) = 0.96560 [0.5126]			
3 to 0:	F(36,251) = 3.5138 [0.0000]**			
2 to 1:	F(12,235) = 1.1258 [0.3398]			
2 to 0:	F(24,258) = 4.9170 [0.0000]**			
1 to 0:	F(12,246) = 8.7842 [0.0000]**			
Estimation period:	1987Q2-2018Q2			

<sup>1</sup> Endogenous variables: real house prices (ph), real household debt relative to housing stock ( $d - h$ ) and housing starts (s). Exogenous variables: real after-tax interest rate (R), housingturnover (th), real disposable income (yh), real construction costs (pj) and a trend (t). Deterministic variables: constant term, centered seasonal dummies for the first three quarters and two impulse dummies, one for 1995Q4 and one for 2008Q3-Q4.



## A.9 Appendix I: Loading Parameters Corresponding to Table 8.2

The matrices below show the estimated loading parameters corresponding to each step in table 8.2. Standard errors in brackets.

$$\text{Panel 1:} \begin{pmatrix} \alpha_{1,ph} = 0.087 & \alpha_{2,ph} = 0.095 & \alpha_{3,ph} = -0.053 \\ (0.0256) & (0.017) & (0.011) \\ \alpha_{1,(d-h)} = 0.053 & \alpha_{2,(d-h)} = 0.016 & \alpha_{3,(d-h)} = -0.013 \\ (0.011) & (0.007) & (0.005) \\ \alpha_{1,s} = -0.098 & \alpha_{2,s} = -0.068 & \alpha_{3,s} = -0.099 \\ (0.054) & (0.037) & (0.025) \end{pmatrix}$$

$$\text{Panel 2:} \begin{pmatrix} \alpha_{1,ph} = 0.097 & \alpha_{2,ph} = 0.080 & \alpha_{3,ph} = -0.069 \\ (0.026) & (0.012) & (0.015) \\ \alpha_{1,(d-h)} = 0.063 & \alpha_{2,(d-h)} = 0.018 & \alpha_{3,(d-h)} = -0.019 \\ (0.011) & (0.005) & (0.006) \\ \alpha_{1,s} = -0.023 & \alpha_{2,s} = -0.007 & \alpha_{3,s} = -0.126 \\ (0.057) & (0.025) & (0.03) \end{pmatrix}$$

$$\text{Panel 3:} \begin{pmatrix} \alpha_{1,ph} = -0.088 & \alpha_{2,ph} = -0.092 & \alpha_{3,ph} = -0.064 \\ (0.026) & (0.015) & (0.03) \\ \alpha_{1,(d-h)} = -0.058 & \alpha_{2,(d-h)} = -0.019 & \alpha_{3,(d-h)} = -0.016 \\ (0.011) & (0.0063) & (0.006) \\ \alpha_{1,s} = 0.071 & \alpha_{2,s} = 0.038 & \alpha_{3,s} = -0.114 \\ (0.056) & (0.032) & (0.030) \end{pmatrix}$$

$$\text{Panel 4:} \begin{pmatrix} \alpha_{1,ph} = 0.090 & \alpha_{2,ph} = 0.093 & \alpha_{3,ph} = -0.064 \\ (0.026) & (0.015) & (0.014) \\ \alpha_{1,(d-h)} = 0.059 & \alpha_{2,(d-h)} = 0.020 & \alpha_{3,(d-h)} = -0.016 \\ (0.011) & (0.006) & (0.016) \\ \alpha_{1,s} = -0.072 & \alpha_{2,s} = -0.039 & \alpha_{3,s} = -0.114 \\ (0.016) & (0.032) & (0.024) \end{pmatrix}$$

$$\text{Panel 5:} \begin{pmatrix} \alpha_{1,ph} = -0.053 & \alpha_{2,ph} = -0.070 & \alpha_{3,ph} = -0.124 \\ (0.024) & (0.012) & (0.018) \\ \alpha_{1,(d-h)} = -0.051 & \alpha_{2,(d-h)} = -0.015 & \alpha_{3,(d-h)} = -0.030 \\ (0.010) & (0.005) & (0.007) \\ \alpha_{1,s} = 0.075 & \alpha_{2,s} = 0.034 & \alpha_{3,s} = -0.077 \\ (0.052) & (0.025) & (0.039) \end{pmatrix}$$

$$\text{Panel 6:} \begin{pmatrix} \alpha_{1,ph} = -0.574 & \alpha_{2,ph} = -0.375 & \alpha_{3,ph} = -0.132 \\ (0.096) & (0.070) & (0.0260) \\ \alpha_{1,(d-h)} = -0.181 & \alpha_{2,(d-h)} = -0.151 & \alpha_{3,(d-h)} = -0.029 \\ (0.040) & (0.029) & (0.011) \\ \alpha_{1,s} = 0.142 & \alpha_{2,s} = 0.082 & \alpha_{3,s} = -0.081 \\ (0.212) & (0.156) & (0.057) \end{pmatrix}$$

$$\text{Panel 7:} \begin{pmatrix} \alpha_{1,ph} = -0.306 & \alpha_{2,ph} = -0.193 & \alpha_{3,ph} = -0.185 \\ (0.048) & (0.035) & (0.033) \\ \alpha_{1,(d-h)} = -0.067 & \alpha_{2,(d-h)} = -0.073 & \alpha_{3,(d-h)} = -0.080 \\ (0.0201) & (0.015) & (0.014) \\ \alpha_{1,s} = 0.073 & \alpha_{2,s} = 0.036 & \alpha_{3,s} = -0.074 \\ (0.106) & (0.078) & (0.073) \end{pmatrix}$$

$$\text{Panel 8:} \begin{pmatrix} \alpha_{1,ph} = -0.358 & \alpha_{2,ph} = -0.249 & \alpha_{3,ph} = -0.190 \\ (0.054) & (0.042) & (0.032) \\ \alpha_{1,(d-h)} = -0.074 & \alpha_{2,(d-h)} = -0.086 & \alpha_{3,(d-h)} = -0.076 \\ (0.023) & (0.018) & (0.013) \\ \alpha_{1,s} = 0.00 & \alpha_{2,s} = 0.00 & \alpha_{3,s} = -0.097 \\ & & (0.029) \end{pmatrix}$$

## A.10 Appendix J: Alternative Model Specification Corresponding to Chp. 8.2.2

Table A.5 show the model results with fewer restrictions imposed than for the specification reported in table 8.3, section 8.2.2. The additional restrictions that were *not* imposed for the results given in table A.5 (see below) are as follows: the second and the third lag of the change in the debt-ratio are first excluded from the debt-ratio equation due to low significance levels. These two restrictions lead the coefficients of the same two variables in the housing starts equation to becoming highly insignificant and they were therefore excluded as well. However, the LR-test of the overidentifying restrictions responds to these restrictions, going from a p-value of 6% (see table below) to 2% for the model representation reported in chapter 8.2.2.

Table A.5: Final model: alternative specification

	$\Delta ph_t$	$\Delta(d-h)_t$	$\Delta s_t$
Constant	-0.742*** (0.134)	-0.361*** (0.041)	0.434*** (0.163)
$\Delta(d-h)_t$	0.901*** (0.156)		
$\Delta ph_t$		0.496*** (0.092)	
$\Delta s_t$		0.809** (0.319)	
$\Delta ph_{t-1}$	0.286*** (0.074)	-0.476** (0.202)	0.345** (0.160)
$\Delta ph_{t-2}$			
$\Delta ph_{t-3}$		-0.567** (0.281)	0.635*** (0.176)
$\Delta ph_{t-4}$	0.216*** (0.067)		-0.165** (0.075)
$\Delta(d-h)_{t-1}$	0.290*** (0.098)		()
$\Delta(d-h)_{t-2}$		-0.423 (0.264)	0.501** (0.268)
$\Delta(d-h)_{t-3}$		0.660* (0.366)	-0.829*** (0.271)
$\Delta(d-h)_{t-4}$		0.062* (0.034)	
$\Delta s_{t-1}$	0.171*** (0.036)	-0.404*** (0.144)	0.408*** (0.076)
$\Delta s_{t-2}$	-0.153*** (0.036)	0.286** (0.117)	-0.250*** (0.082)
$\Delta s_{t-3}$			
$\Delta s_{t-4}$		-0.216** (0.084)	0.270*** (0.081)
$\Delta R_{t-1}$	-0.280* (0.167)	0.250** (0.099)	
$\Delta E_t$	0.064*** (0.019)	-0.035*** (0.013)	
$\Delta E_{t-1}$		0.007 (0.004)	
$\Delta pj_t$			0.430** (0.167)
$\Delta pj_{t-1}$			-0.111* (0.063)
$\Delta ECM_{t-1}^{ph}$	-0.095*** (0.017)	-	
$\Delta ECM_{t-1}^{d-h}$		-0.053*** (0.006)	
$\Delta ECM_{t-1}^s$			-0.059*** (0.022)
IDUM, 1995Q4		0.018*** (0.004)	
IDUM, 2008Q3-Q4	-0.015*** (0.005)		
Dummy, Q1	0.033 (0.006)	-0.004 (0.013)	-0.025 (0.011)
Dummy, Q2	0.024 (0.006)	-0.018 (0.012)	0.017 (0.013)
Dummy, Q3	0.000 (0.005)	-0.009 (0.116)	0.005 (0.013)

Table A.6: Additional information

SE of regression	0.015 0.030 0.033
Sample	1987Q2 - 2018Q2
Estimation method	FIML
LR-test, overidentifying restrictions	$\chi^2(45) = 60.80[0.06]$
Log-likelihood	1093.04
Diagnostics:	
<i>Vector SEM AR 1-5 test</i>	$F(45,274) = 1.27 [0.13]$
<i>Vector normality test</i>	$\chi^2(6) = 6.22 [0.40]$
<i>Vector hetero test</i>	$F(324,397) = 1.16 [0.08]$