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Is the Oslo housing market *overpriced*?

An empirical study assessing Oslo housing market prices based on its fundamental determinants

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Abstract

Fluctuations in housing prices have large repercussions on the economy. A housing bubble burst could have adverse consequences for households and investors. In this paper, we discover fundamental determinants in the pricing of the Oslo housing market. We examine the dynamics of their relationship in both the long- and short-run with a vector error correction model. The predominant factors found to explain house prices are average income and lending rate. Shocks to both variables exhibit permanent effects on house prices. If prices deviate from their long-run equilibrium in the short-run, prices are adjusted by 12.5% per quarter. Based on fundamental determinants, the long-run results indicate no signs of overvaluation of house prices in Oslo.

Acknowledgment

We want to take the opportunity to express our gratitude to our thesis supervisor Alessandro Graniero, for valuable help, guidance, and support throughout the master thesis. We would also like to thank the Department of Finance at BI for providing us with the necessary knowledge to accomplish this master thesis.

Table of Contents

1. Introduction

1.1 Background and Context

The Oslo housing market has experienced a long period of steady price growth, clearly outpacing every other city in the country. High demand and low cost of credit have substantiated the price increase and enhanced the expectations of a continuously strengthened market[1]. Nobel prize-winning economist Paul Krugman alarmed signs of a Norwegian house price bubble already back in 2014. The price level in the Oslo area has shown no signs of slowing down as real house prices have appreciated on average almost 8% yearly since the statement.

The Oslo housing market has experienced a 165% increase in prices from 2003 to 2020. The rapid growth has attracted investors seeking profit. Interestingly, a household's real income increased 25% during the same period. Stiglitz (1990) characterizes the state of fundamental factors not being able to justify a price as a bubble. There is disagreement in the industry about whether this trend is sustainable due to development in underlying fundamental factors or indications of a housing bubble.

1.2 Why Assess the House Price Level?

There are primarily two reasons why we choose the Oslo housing market as the research area for this dissertation:

First, the development of the housing market is an integral part of the financial stability, household economy, and the Norwegian economy as a whole. Understanding whether fundamental factors can explain the price level is essential in order to evaluate the prospect of a financial crisis (Kivedal, 2013). The financial crisis in 2008 displayed possible adverse wealth effects on households owning a dwelling and the real economy when a housing bubble burst. As of 2018, Norwegians have 70% of their gross wealth in housing (Norman & Lindvik, 2021).

[1] See https://www.nbbl.no/media/rb3irbed/boligmarkedsbarometeret-mars-2022-nbbl.pdf

Secondly, profit from the transaction of any asset, including housing, is obtained by selling at a higher price than the acquired price. The low Sharp ratios on individual house prices due to high volatility, idiosyncratic risk[2], and high transaction costs suggest housing as a less attractive investment (Piazzesi et al., 2007). However, investments in secondary residences have boomed in the past couple of years, and investors can point to significant profits. Understanding whether the current price level seems fundamentally reasonable is essential for the outlook of possible future excess returns as relatively high prices signal low subsequent returns and vice versa due to the nature of mean reversion (Gao et al., 2009).

1.3 Contribution, Research Question, and Organization

Several top economists and practitioners have failed to predict the market to crash following a housing bubble. Therefore, our aim is not to disclose such an upcoming event but rather to indicate whether the current price level seems sustainable based on fundamental factors proven to explain house price variation in Oslo. By analyzing several factors, we aim to determine what fundamentals are the most important in explaining the house price variation in Oslo and whether the current price level seems sustainable based on these factors. Thus, this dissertation aims to investigate the following research question:

RQ: *"Are prices in the Oslo housing market indicating signs of a bubble?"*

To address the research question, we build on the framework introduced by Case & Shiller (2003) to uncover fundamental factors explaining house price variation in Oslo. Further, we apply a Vector Error Correction Model to determine the long- and short-run effects and speed of convergence back to equilibrium of the factors.

This paper is organized into five parts. Chapter 2 reviews essential articles related to fundamentals in the housing market and bubble theory. Chapter 3 presents testable hypotheses to answer the research question and competing theories related to it. Chapter 4 introduces data and variables, sources they are collected from, and motivation for including these specific variables. Chapter 5 elaborates on the methodology and tools used to examine

[2] Houses are indivisible. Meaning they are sold as a unit, not in small pieces as, e.g., stocks. Consequently, it is difficult to diversify.

the questions presented. In Chapter 6, we present the empirical results and discuss the findings in relation to the hypotheses we have tested.

2.0 Literature review

2.1 Fundamental variables

The relationship between income and house prices is widely documented in the literature. Already in 1972, a long-term equilibrium between house prices and income was depicted by Fair (1972). Later studies have found income and house prices to be linked with a stable long-run relationship (Hort, 1998; Meen, 2002). Case & Shiller (2003) examine the relationship between income per capita and house prices with quarterly data from 1985 to 2002 on each of the fifty states in America. They performed linear and log-linear reduced form regressions with the level of the home price, quarter-to-quarter change in home prices, and price-to-income as dependent variables. They found that income growth alone could explain patterns of home price increases in all but eight states. The analysis was extended by including more fundamentals, which did not contribute much explanatory power to the states well explained by income. However, for the rest of the states, it did. Himmelberg et al. (2005) argue that important economic differences are present among cities, and psychological factors may drive some of the price increases.

Algieri (2013) applies an Error Correction Model (ECM) to fundamental variables driving house prices in five European countries. The results show that house prices positively correlate with per capita income, population change, inflation, and stock prices. Conversely, interest rates and residential investment affect prices negatively. Similar results were found in Australia between 1970 and 2003 (Abelson et al., 2005). Their ECM estimates long-run elasticity of real house prices is 1.7 with respect to real disposable income and that a 1 percent rise in lending rate leads to a 5.4 percent fall in real house prices. Jacobsen & Naug (2005) contribute to the Norwegian literature in their ECM on fundamental drivers of quarterly data from 1990 to 2004. They find the interest rate, new construction, unemployment, and household income to be the most important factors. They obtain T-values and coefficients near zero for housing rents. This contradicts most literature on international markets, constituting rents as a pivotal factor in explaining house prices (Campbell et al., 2009; Wu et al., 2012).

Rent prices are widely considered fundamental in explaining house prices as the alternative to owning a home is to rent (Kivedal, 2013). The relationship between prices and rents is assessed by Himmelberg et al. (2005) to detect bubbles in American cities. Case and Shiller (1990) even find excess return on housing possible to predict based on the rent-to-price relationship. They get a positive coefficient on the rent-to-price ratio when running regressions of excess return on construction cost divided by price and rent-to-price ratio. Predicting high excess return the following year if the rent-to-price ratio is high. This is backed by Cochrane (2011), which finds that high prices compared to rents signal low subsequent returns. He compares predictability regressions for houses and stocks and reveals similar patterns for the two assets. Rent-to-price and dividend-to-price are persistent but stationary.

2.2 Bubble theory

There is consensus that changes in housing prices are either due to changes in fundamental factors and/or speculation among investors. Stiglitz (1990) characterizes the state of fundamental factors not being able to justify a price as a bubble. Irrational optimistic expectations may result in irrational bubbles (Shiller, 2000). Rational bubbles occur when prices rise because investors believe the asset can be sold at a higher price in the future (Flood & Hodrick, 1990). Both instances are examined in the questionnaire conducted by Case & Shiller (2003).

2.3 Vector Error Correction Model

The possibility of examining long-term relationships has made the error-correction framework a leading modeling technique in recent times. Malpezzi (1999) tests whether prices tend to revert to an equilibrium ratio of price to income in the long run. Gallin (2008) assesses the long-run relationship between house prices and rents. Both studies find evidence that prices and the fundamental variable examined are cointegrated and correct toward each other. The price-to-rent ratio is investigated by evaluating explosive behavior in 18 OECD countries by Engsted et al. (2015). They find significant differences between the different markets but that most relationships are indistinguishable from the ordinary I(1) trend without explosiveness. Krakstad & Oust (2015) estimate equilibrium values of prices, wages, construction costs, and wages in the Oslo housing market. Their research relates most to ours as both specify the VECM with multiple endogenous variables. Contrary to our research, they restrict the long-term cointegration matrix by imposing factors as ratios (to price). They expect prices to fall compared to the fundamentals investigated and conclude that the Oslo market was overpriced by 35% in 2012.

3.0 Testable hypotheses

This dissertation aims to form an opinion on the price level of the Oslo housing market. We build on the framework presented in Case & Shiller (2003), which analyzed fundamental factors explaining the pricing in each American state in 1985-2002.

H1: "*What are the most important factors explaining the prices of the Oslo housing market?"*

Understanding which are the predominant factors explaining house price variation is crucial before proceeding with further analysis. An important remark is that the standard Ordinary Least Square (OLS) procedure of Case & Shiller (2003) is not appropriate for further inference other than as a reference point to which factors explain house prices and in what direction.

Based on the results in the first part of the analysis, we will investigate some of the factors' relationship with house prices more thoroughly in a VECM framework. This will provide a more holistic picture of how the fundamental variables relate to the pricing. Granziera & Kozicki (2012) depict extrapolative expectations' importance in explaining house prices. Stigliz (1990) categorizes pricing based on such inflated expectations rather than fundamentals as a housing bubble. Thus, in the second part of the analysis, we seek to answer how well fundamentals can explain the price level.

H2: "Is the pricing of the Oslo housing market explained by fundamental factors?"

Answering the two hypotheses facilitates drawing well-founded conclusions regarding the research question of whether the Oslo housing market indicates signs of a bubble.

4.0 Data

4.1 Data Description

The data used in this dissertation is secondary data and collected from:
Eiendom Norge AS (EN), Boligbygg Oslo kommune (BOK), Norwegian Statistical Bureau (SSB), Norwegian Labor and Welfare administration (NAV) and Bloomberg. We use the natural logarithm of all variables when conducting the analysis to get a more normalized dataset.

All variables are quarterly and span the period 2003-2020. Because of insufficient data on key variables prior to 2003, we have chosen to restrict our sample to this period. This gives a sample of 72 observations for each variable. Despite the fact that longer samples should yield more consistent estimators results (Brooks 2014), we argue that the number of observations is sufficient for our purpose as several highly regarded papers within the literature have operated around the same amount[3]. A descriptive statistic of the data is presented at the end of the chapter in Table 1.

We obtained *house prices (HP)* specific for Oslo by request from EN. The *rent price (RP)* data were also provided to us by request from BOK. One could retrieve this data dating back to 1992 from other available sources. A drawback of this publicly available data is that they include Akershus county. Also, the rent index is based on a yearly collection of self-completion forms on rent levels called "Leiemarkedsundersøkelsen," which we consider less exact and reliable[4]. To avoid biased results, we use the nominal values of price per square meter provided by EN and BOK and adjust both variables for inflation to obtain the real values.

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[3] Jacobsen & Naug (2005) and Case & Shiller (2003) include 56 and 71 quarters, respectively.
[4] The self-completion forms empirically gives less exact results due to sources of error from the data collection, and the processing of the data. See: https://www.ssb.no/priser-og-prisindekser/boligpriser-og-boligprisindekser/statistikk/leiemarkedsundersokelsen.

The variables *average income* (AI) and *average debt* (AD) were collected as nominal quarterly data from SSB and further adjusted for inflation.

The *debt-to-income ratio* (DR) is a representation of real average debt divided by real average income per capita. The nominal *lending rate* (LR), as percentage points, is retrieved from SSB. We computed the real lending rate by adjusting for inflation; this is similar to several other studies like Jacobsen and Naug (2005).

The expectation variable (EXP) is based on a survey conducted by Kantar on behalf of Finans Norge. The survey asks thousand Norwegian households five questions about their beliefs concerning their own and the Norwegian financial situation in one year. One of the questions is: "Would you consider the economic situation of your household to be better than one year ago, or is there no difference?". The indicator is calculated by taking the difference in optimistic and pessimistic responses and dividing by the number of questions to get an average. The variable serves as an indication of the level of optimism regarding the outlook of the economy.

The *unemployment rate* (UE) was received as the percentage point of unemployment for the Oslo area by NAV. From SSB, we collected data on net migration for Oslo, representing *population increase* (PI) and the number of started dwellings under construction in the Oslo area as our variable housing starts (HS). The *OSEBX*[5] (OX) variable is the quarterly closing price, collected through the Bloomberg terminal at BI, campus Oslo. OX is adjusted for inflation.

Table 1

Descriptive Statistics

Variable	Mean	St. dev.	Max	Min	Kurtosis	Skewness
HP	42 286.08	12 431.51	69 113.26	25 638.79	-1.16	0.25
RP	2 437.78	299.09	2 763.70	1 891.70	-1.04	1.87
UE	3.59	1.15	9.13	1.97	6.23	1.87
AI	115 475.04	7 342.05	127 727.00	100 029.41	-0.71	-0.36
DR	1.74	0.23	2.03	1.25	-0.19	-0.87
LR	4.08	1.20	7.42	1.30	0.53	0.55
PI	0.42	0.21	0.96	-0.08	-0.10	0.31
HS	276.32	153.45	812.00	32.00	1.23	0.97
OX	502.61	220.21	940.97	104.30	-0.69	0.35
EXP	14.87	12.93	31.17	-16.09	-0.34	-0.80

Note, The variables: HP, RP, AI, and OX are presented in NOK. UE, LR, EX, and PI are stated in percentage points. DR is a ratio of debt to income. HS is presented in units.

[5] Oslo Børs Benchmark Index

4.2 Variable description

In this section, we will present factors we believe to have an impact in explaining the house price variation. An important aspect to be aware of is that two variables do not necessarily have a causal relationship despite being correlated. Including variables without a causal relationship with housing prices provide spurious results and an erratic model. Included variables must be based on defensible intuition and economic theory (Brooks, 2014).

Table 2

Correlation Matrix

	HP	RP	UE	AI	DR	LR	PI	HS	OX	EXP
HP	1									
RP	0.87	1								
UE	-0.15	-0.31	1							
AI	0.81	0.77	-0.01	1						
DR	0.91	0.92	-032	0.69	1					
LR	-0.62	-0.38	-0.25	-0.56	-0.49	1				
PI	-0.21	-0.02	-0.34	-0.18	-0.03	0.19	1			
HS	0.07	-0.07	-0.06	-0.03	-0.04	-0.14	-0.09	1		
OX	0.94	0.78	-0.20	0.77	0.86	-0.59	-0.14	0.02	1	
EXP	-0.43	-0.47	-0.10	-0.38	-0.41	0.22	0.11	0.22	-0.29	1

Many economic factors can be argued to affect the house price. A challenge we face when building the model is which to include. To avoid perfect collinearity[6], we utilize the correlation matrix to motivate our exclusions. Table 2 shows that the debt-to-income ratio has a strong positive correlation with the rent price and the OSEBX. There also exists a high correlation between the rent price, OSEBX, and average income as well. This could prove crucial as these variables might introduce multicollinearity to our model, which we must keep in mind when performing our estimations.

4.2.1 Dependent variable

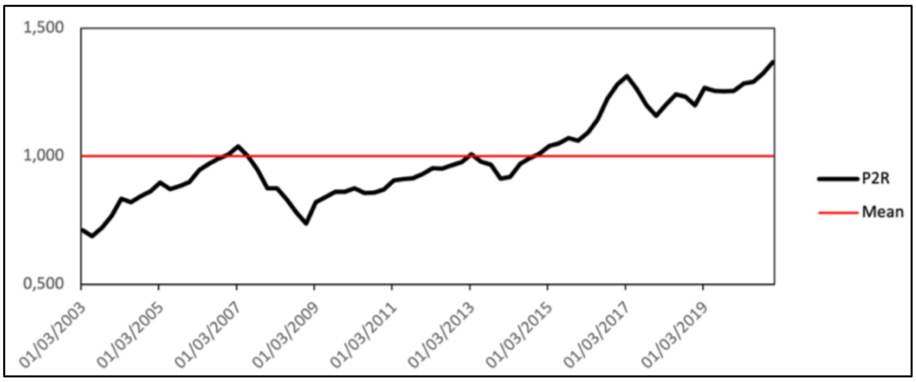
The house price per square meter will act as the dependent variable when addressing the hypotheses. The nominal values are adjusted for inflation to obtain the real house price per square meter.

[6] The marginal effect of one explanatory variable ($x_{1,t}$) on the dependent variable (Y_t) being impossible to estimate when holding another explanatory variable ($x_{2,t}$) constant due to the two explanatory variables moving simultaneously.

4.2.2 Explanatory variables

The alternative to owning a house is to rent it. Consequently, the **price-to-rent ratio** is widely considered an essential factor explaining the variation in housing prices. Past research disagrees on whether divergence of its mean ratio indicates a bubble or is due to development in the fundamental factors. Nevertheless, long-term signs of divergence from its mean ratio should raise questions of concern as this is often an indication of a bubble (Grytten, 2009). From Figure 1, we can observe that the price-to-rent ratio has increasingly diverged from its mean over the last five years. If this trend continues, it might decrease the pressure on becoming a homeowner, as the alternative of renting could be considered a cheaper alternative. The increasing price-to-rent ratio could also reduce the incentives for investors who purchase secondary dwellings for the sole purpose of renting them out. Moreover, Cochrane (2011) argues price-to-rent ratio is like price-to-dividend when predicting stock returns. Thus, we consider the rent price to be an exciting factor when attempting to explain the pricing of the Oslo housing market.

Figure 1: *Actual Price-to-Rent vs. Mean Value (set to 1)*



Note, The «mean» is represented as the average Price-to-Rent value for the period 2002-2020. The P2R represents the percentage deviation from the mean.

High levels of both **household debt** and real estate prices are currently the most critical vulnerability in the Norwegian financial system (Finanstilsynet, 2021). To keep our analysis aligned with previous research and the result more comparable, we will analyze how household debt affects house prices by using the variable *debt-to-income ratio* as the measure of debt. On average, the purchase of a house is the most significant investment of a household. It is often highly debt-financed and collateralized by the property itself. The credit market and housing market are therefore highly correlated. In 2015, the Ministry of Finance in Norway tightened the lending regulations to prevent further sharp increases in household debt and housing prices (Regjeringen, 2021)

Considering the current level of household debt, the **lending rate** becomes an exciting factor. Himmelberg et al. (2005) ascribe a significant amount of the house price boom in the early 2000s to a decline in interest rates, implying an inverse relationship between interest rates and house prices. A critical remark is that the Norwegian credit market has experienced a period of the lowest lending rate since the record began in 1954, which may lower its relevance in our model. Considering its importance in previous research, the variable will be included but carefully considered in the analysis. Interestingly, the latest monetary policy report depicts a steep increase in the interest rates for the years to come (Norges bank, 2021), which might show up in the expectations variable. Highly levered Norwegian households should expect increased costs of borrowing.

Essential factors for understanding whether households can handle higher financing costs at all-time high leverage are their **income** and the **unemployment level**. Jacobsen & Naug (2005) argue that increased unemployment results in uncertainty in households' ability to repay debt due to expectations of lower wage growth. In consequence, the inclination to pay for owner-occupied dwellings is reduced. As a result, we believe that both average income and the unemployment rate could be possible fundamental factors for house prices in Oslo. An increase in house prices and average income, as well as a decrease in the unemployment rate, are typical indications of a booming economy.

Like all markets, supply and demand will affect the housing market. An increasing population would most likely result in increased housing demand. Oslo has experienced a growing population over the last decade, which could be one explanation for the rising Oslo house prices. The change in **population** could therefore be a possible fundamental variable for the pricing of the housing market. Another variable found in the research by Case and Shiller (2003) is the **housing starts**. The housing starts variable is considered a measure of the housing supply, and we believe that increased housing starts could lead to a descending house price.

The use of a stock market variable to examine the housing market is rare in previous research within this field. However, we argue that the **OSEBX** can be considered an alternative investment for investors who view the purchase of houses as a pure investment, either to resell the house with a profit or to earn revenue from rent (Cocco et al., 2005). The Norwegian stock market index could also be viewed as a measure of the financial situation locally and globally.

The **expectation** variable is the last factor included in our analysis**.** This is an essential measure as several studies state that if house prices are determined mainly as a result of people's expectations rather than actual economic events, it indicates a bubble in the housing market (Stigliz,1990; Case & Shiller, 2003). The expectation variable has some limitations in representing the true expectations of the population. Retrieving reliable information and data regarding the population's financial expectations requires much research and data generated only within this subject. Therefore, the variable will be included in the analysis as a possible measure of bubble indication but with some caution.

5.0 Methodology

The structure of the methodology is divided into two parts. In the first part, we apply the OLS framework of Case & Shiller (2003) with some adjustments for the Oslo market to get an insight into factors explaining the Oslo housing market. The second part discusses requirements that must be met preparatory to model estimation before the VECM and its extensions are considered.

5.1 The Case and Schiller model

Following the framework of Case & Shiller (2003), we assess the stability of the relationship between income and other fundamentals on house prices to judge the plausibility of an existing bubble. We aim to compare our results to those obtained in Case and Shiller.

First, we investigate the relationship between house prices and annual income per capita throughout the sample. We estimate the simple regression of house price on income per capita by OLS.

$$House\ Price_t = \hat{\alpha} + \hat{\beta}\ Income_t + u_t \ (1)$$

The purpose of the regression is to capture the explanatory factor of income on the house prices, as Case and Shiller (2003) concluded that income alone explains most of the changes in house prices. To better understand the dynamics of the prices, the model is extended to capture relationships between housing prices and other fundamental variables. We will estimate three different models with three dependent variables: The level of housing prices, the quarter-to-quarter change in housing prices, and the price-to-income ratio. The analysis is conducted using OLS, and the explanatory variables are stated in the equations below.

$$Y_t = \hat{\beta}_0 + \hat{\beta}_1 \, Income_t + \hat{\beta}_2 \, Population_t + \hat{\beta}_3 \, Unemployment_t + \hat{\beta}_4 \, \Delta Unemployment_t + \hat{\beta}_5 \, Housing\ Starts_t + \hat{\beta}_6 \, Lending\ Rate_t + u_t \quad (2)$$

In the paper by Case and Shiller, this extension improved the model's explanatory power. However, the improvement compared to model (1) is small. And as elaborated in section 2.1, there exists theoretical justification that other factors than those tested per Case & Shiller (2003) affect housing prices. Thus, we exclude the insignificant variables based on prior estimations and extend the model based on similar research within house pricing. Based on this, we derive what becomes the foundation for our main model, which is subject to further analysis.

$$HP_t = \hat{\beta}_1 AI_t + \hat{\beta}_2 RP_t + \hat{\beta}_3 LR_t + \hat{\beta}_4 UE_t + \hat{\beta}_5 OX_t + \hat{\beta}_6 \, EXP_t + u_t \qquad (3)$$

A positive(negative) coefficient suggests a positive(negative) relation between the explanatory variable and the house prices. This model will to some extent, show if changes in house prices can be explained by changes in fundamentals. From these estimations, we establish an idea of what factors contribute to the pricing of homes and to what extent they do to answer the first hypothesis.

H1: "What are the most important fundamental factors explaining the pricing of the Oslo housing market?"

5.2 Stationarity

Brooks (2014) defines a stationary process as a process with a constant mean, constant variance, and constant autocovariance for each given lag. A stationary time series tend to be mean-reverting because the mean and variance of the stationary variable revert to its long-run equilibrium (Hobdari, 2014). Testing whether a variable is stationary or not is essential when dealing with time series, as estimating with non-stationary series could lead to spurious regressions. If one were to estimate a model of two non-stationary variables that experience a similar time-trend, this could lead to falsely significant coefficients and artificially high R^2, despite the variables having no actual relationship. This is because the t-ratios will not follow a standard t-distribution as the assumption of asymptotical analysis is unsatisfied (Brooks, 2014).

Most financial and economic time series are non-stationary, usually containing one unit root. Our data consists of several macroeconomic factors, mainly with an upward sloping trend and possible connection to changes in other macro variables. For instance, the Oslo house prices and the OSEBX show a similar upward sloping trend at first glance. The fact that these two variables may contain a unit root could result in an increased probability of type I error when estimating how one variable affects the other through regression analysis.

The unit root term is presented in equation (4), a random walk with drift.

$$y_t = \mu + \phi y_{t-1} + u_t, \;\; if \;\begin{cases} \phi = 1 : The\ procces\ contains\ an\ unit\ root \\ \phi < 1 \;: The\ procces\ contains\ no\ unit\ root \end{cases} \qquad (4)$$

$$\Delta y_t = \mu + u_t \qquad (5)$$

Equation (5), however, shows a time series integrated of order one, which could be enforced to stationarity by taking first differences. However, differencing the variables introduces a new issue, as the long-run dynamics between the variables no longer exist. A comparison of regression models with first differences and levels showed that first differenced models proved relatively inefficient on trending data (Harvey, 1980). To investigate the short-term and long-term relationships of the variables, we will introduce a VECM.

5.2.1 Testing for Stationarity and lag selection

The most common approach to detect unit roots in time series is the Augmented Dickey-Fuller (ADF) test. The ADF model is expressed as follows by Brooks (2014):

$$\Delta y_t = \psi\, y_{t-1} + \sum_{i=1}^{p} \alpha_i\, \Delta y_{t-1} + u_t \qquad (6)$$

$Hypothesis$: $\quad H_0: \psi = 0 \quad H_a: \psi < 0$

The null hypothesis is that the series contains a unit root against the one-sided alternative hypothesis that the series is stationary. An important aspect when conducting the test is to use the optimal number of lags of the series. Introducing too few or many lags could result in biased results. Hence we apply the ADF test with automatic lag selection based on Schwarz Bayesian information criterion. Maximum lag is set to 4 periods, as we use quarterly data. This is supplemented with the KPPS[7] test. In contrast to the ADF, the null hypothesis is that the time series is stationary.

Brooks (2014) argues that confirmatory data analysis is inadequate when one or more structural breaks are present in the time series. Leybourne et al. (1989) emphasize that structural breaks in time series increase the probability of type I error. Thus, Chow tests for structural breaks and estimated break dates are conducted.

In the event of structural breaks, the Phillips-Perron test (1997) is more appropriate as it allows for structural breaks at any point of time in the time series. Thus, emphasis is put on this test, as non-stationarity in levels of variables is a requirement for the VECM. The null hypothesis is that the time series contains a unit root compared to the alternative hypothesis that the variables are generated by a stationary process. The PP model is presented in Equation 7.

$$y_t = c + \delta_t + \alpha\, y_{t-1} + \varepsilon_t \qquad (7)$$

[7] Kwiatkowski-Phillips-Schmid-Shin Test.

5.3 Cointegration

If two or more variables are integrated at order one, their linear combination could become non-stationary (Brooks, 2014). If multiple variables share the same stochastic trend, the factors could be defined as cointegrating, and a long-run relationship will exist between the variables (Johansen, 1988). If the residuals of a multiple regression containing three non-stationary variables are stationary, the variables are cointegrated as the residuals can be considered a linear combination of y_t, x_{1t}, and x_{2t}, as expressed in equation (8).

$$\hat{u}_t = y_t + \hat{\beta}_1 + \hat{\beta}_2 x_{1t} + \hat{\beta}_3 x_{2t} \qquad (8)$$

The Johansen method uses a systems approach to cointegration. This allows the determination of all cointegrated relationships in the system (Brooks, 2014). The test is based on the vector autoregression of *k* variables (VAR(p)), with the number of lags equal to p-1. The matrix Π consists of a vector of adjustment parameters and cointegration vectors (Dwyer 2015). The model is presented in Equation 9.

$$\Delta x_t = \Pi x_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta x_{t-i} + u_t \qquad (9)$$

The Π matrix is examined to find the number of cointegrating vectors in the multivariate setting. Johansen (1995) suggests performing two likelihood ratio tests to obtain the number of cointegrating equations: the trace test and the maximum eigenvalue test. The tests are performed by computing the rank of the Π matrix by inspecting the number of eigenvalues (Brooks 2014). With r^* representing the number of cointegrating equations, we test for *k*-1 number of cointegrating equations. Both methods share the similar null hypothesis that there is r^* or fewer cointegrating vectors. The trace test is a joint hypothesis test with the alternative hypothesis that there are more than r^* cointegrated vectors. While the eigenvalue approach performs a separate test with the alternative hypothesis for the test stating that there are r^*+1 cointegrating vectors. Both methods should yield the same results.

5.4 Vector Error Correction Model

The Vector Error Correction Model (VECM) is frequently utilized in housing literature as it contains some desirable features in investigating long-term relationships (Gallin, 2008;

Malpezzi, 1999). The model is an extension of VAR and avoids some of its core weaknesses. Brooks (2014) highlights the possibility of combining levels and differenced terms without discarding information of any long-run relationships between the series. The error-correction term, $Y_t - \alpha X_t$, eliminates the stochastic trend, meaning the difference between the series is stationary, and Y_t and X_t are cointegrated. Moreover, it captures each period's adjustment in Y_t when its value deviates from the long-run equilibrium. Johansen (1995) specifies the model without extended lags with *m* variables:

$$\Delta Y_t = \alpha\beta' Y_{t-1} + \Gamma \Delta Y_{t-1} + \mu + \varepsilon_t \quad (10)$$

Allowing for lags in the matrix containing cointegrated coefficients, we extend the equation as follows:

$$\Delta Y_t = \alpha\beta' Y_{t-1} + \Sigma_{i=1}^{l-1} \Gamma_i \Delta Y_{t-i} + \mu + \varepsilon_t \quad (11)$$

- Y_t is an *m*-by-1 vector of all the variables with a unit root.
- α is an *m*-by-*r* matrix of the adjustment coefficients, with *r* being the cointegrated rank found in the cointegration tests.
- β is an *m*-by-*r* matrix of the cointegrating coefficients containing information about the long-run relationship between the variables.
- Γ is an *m*-by-*m* matrix containing short-run coefficients. Lag length specified by *l*.
- μ is the overall constant.
- ε is an *m*-by-1 vector of random Gaussian errors, with a zero mean and a combined *m*-by-*m* covariance matrix Σ.

5.4.1 Extensions of the VECM

The possibility to examine both short-run dynamics and long-run equilibrium prices lays the foundation for further examination of housing prices. Impulse Response Functions provide information on how the House Prices react to a one standard deviation shock into one of the fundamental variables, with all other factors held constant. Variance Decomposition helps determine the variation each fundamental factor contributes to the House Price in the autoregression (Brooks, 2014). Forecasts on future house prices based on simulation of fundamental factors affecting the variation throughout the sample period provide information on the current price level according to its fundamentals.

6.0 Results and analysis

6.1 Case and Schiller

Following the procedure of Case & Shiller (2003), we run two separate models with three different dependent variables. The results of the regressions are presented in Model 1 and Model 2. In Model 3, we include factors assumed to impact the pricing in Oslo. All three models are run with each of the dependent variables: House prices, House price to Income, and ΔHouse prices. The models ran with ΔHouse prices performed weakly, and results can be found in Table A1 in the Appendix. On the other hand, the two models with House Price and Income to House Price as the dependent variable provided indistinguishable results. Consistent with further analysis, we choose to discard the regressions dependent on House Price to Income. The sign of the coefficients and significance level of the explanatory variables in the regressions with House Price as dependent variables are reported in Table 3.

Table 3

OLS Regression Results

Independent Variable(s)	Model 1	Model 2	Model 3
Average Income	$+^{***}$	$+^{***}$	$+^{***}$
Housing Starts			
Lending Rate		$-^{***}$	$-^{**}$
Δ Unemployment		$+^{*}$	
Unemployment Rate		$-^{***}$	
Δ Population			
Rent Price			$+^{*}$
OSEBX			$+^{***}$
Expectations			
Debt-to-Income ratio			$+^{**}$
R^2	.664	.799	.958

Note. *, **, *** Indicates the rejection of the null hypothesis at a 1,5 and 10% significance level. Model 1 represents a simple regression of house prices on average income. Model 2 a multiple regression with the inclusion of *HS, LR, ΔUnemployment rate, Unemployment rate,* and *population increase.* Model 3 is a multiple regression with the inclusion of all significant variables from Model 2 with the addition of *Rent price, OSEBX, Expectations,* and *Debt-to-Income ratio.*

Case & Shiller (2003) concluded that, to some extent, house prices could be explained by fundamentals in their econometric analysis. They found income alone to explain most of the house price patterns in 42 out of 50 states in the US. A simple regression of income on house prices generated an R^2 of 99% in the state with the least volatile house prices. The inclusion of more fundamentals provided little additional explanatory variable to the least volatile states. However, the extended model performed remarkably better in more volatile states.

Interestingly, Hawaii is the most volatile state in Case & Shiller studies, with a standard deviation of 17.1 % of its mean, which means that the Oslo housing market, with a standard deviation of 26.8% of its mean, is far more volatile than any US state at the time of their study. As expected, if markets are comparable, we find additional fundamentals to provide substantial explanatory power. Model 1 provides an explanatory power of 66%, whereas Model 2 increases the explanatory power to 80%.

Model 1 finds Average Income to be positive and significant at the 1% level, explaining much of the house prices. In Model 2, three of the four explanatory variables are significant at the 1% level, while Unemployment is significant with a positive sign at a 10% level. In the following, we will discuss the results found in relation to expectations and previous literature.

A*verage Income* is positive and significant at the 1% level in all of the models. The result is consistent with previous literature finding that increased average income positively correlates with house prices (Piazzi & Schneider 2016). As expected, the *Lending Rate* has negative and significant coefficients, which is in line with previous literature (Jacobsen and Naug 2005; McCarthy et al. 2012). The findings make sense as home purchases are often financed with a large amount of debt. Increased lending rates enlarge the debt repayments of households and investors, which consequently reduces their purchasing power. Model 2 yields significant coefficients for *Unemployment Rate and ΔUnemployment Rate.* The first is negative and significant at the 1% level, and the latter is positive and significant at the 10% level. Jacobsen and Naug (2005) state that growth in unemployment would increase the consumer's uncertainty regarding future income and consequently risk the ability to service the debt, leading to a reduced willingness for housing investments. As such, we would expect an increase in *ΔUnemployment* from one quarter to the next to be associated with a negative effect on house prices.

Contrary to our expectations, the results from Model 2 indicate a positive correlation at the 10% significance level. Nevertheless, the *Unemployment Rate* is negative and significant at the 1% level. Excluding the *Unemployment Rate* from the regression proved to alter the sign of the *ΔUnemployment Rate* to be negative and highly significant. Thus, we argue that both *Unemployment Rate and ΔUnemployment Rate* have a negative correlation with house prices in Oslo, but multicollinearity causes statistical limitations in the simple regression model.

Opposite to what we expect from previous literature, Housing starts and ΔPopulation have no significant relationship with house prices in the model. A possible explanation is that the model is specified in reduced form, which may cause the coefficients to be affected by simultaneity bias (Case & Shiller, 2003). In the case of housing starts, the variable can proxy for supply restrictions, indicating low starts and consequently pushing up prices. However, higher prices incentivize increased building. Thus, causing somewhat unexpected results. Also, we argue that housing starts may have a lagged effect on house prices, as there is not yet a ready-to-move-in home at the time of the start to mitigate the demand. Moreover, population and other demographic factors change slowly over time, which may cause difficulty in identifying the effects over the short estimation period.

We bring on the three variables found significant in Model 2 when including additional explanatory variables in Model 3. We add four new variables not considered in Case & Shiller (2003). The Unemployment rate, which was highly significant in Model 2, turned insignificant when accounting for more variables, again enhancing the suspicion of multicollinearity among the independent variables. Average Income and Lending Rate remained significant at the 1% and 5% significance level, respectively. OSEBX and the Debt-to-Income ratio are significant at a 5% significance level. Rent prices are significant with a positive sign at a 10% level.

Little research on the relationship between house prices and the stock market is conducted. However, Cochrane (2011) highlights how house prices can be predicted similarly to stock, and Piazzi et al. (2012) state that the two markets show evidence of negative correlation. Piazzi et al. (2012) argue that the stock and housing markets can be viewed as alternative investments. Shapiro (2021) explains the evidence of a positive correlation in the American market and suggests they co-move due to both being dependent on economic expectations. On the other hand, Yao (2005) finds evidence of a low correlation between the markets. Discrepancies in the literature regarding the relationship between the stock market and housing prices are also the case for the Oslo housing market and the *OSEBX*. Hence, the positive and significant coefficient in Model 3 indicates a positive relationship that can arguably be defended by previous research.

Model 3 suggests that an increase in the consumer's debt-to-income ratio contributes to an appreciation of house prices. The findings are consistent with previous research. The debt-to-income ratio could be interpreted as a measure of credit availability. McCarthy et al. (2012) found that a higher average debt-to-income ratio is consistent with a more relaxed credit supply, which could result in an increase in demand in the housing market. However, the lending regulations in Oslo were sharply tightened in 2017 (Regjeringen, 2016), indicating other explanations exist. Possible causes could be that regulations prior to the tightening were way too loose or that investors are more inclined to take on excessive debt.

Rent Prices are found to be significant only at the 10% percent significance level. The positive sign of the coefficient is aligned with previous studies because increased rent prices increase the consumers' willingness to purchase a house as an alternative to paying rent and enhance the incentive for investment purposes to earn the rent. Consequently, pushing up house prices. Rent prices are arguably one of the most important variables in international research on housing bubbles (Himmelberg et al., 2005; Kivedal, 2013). Cochrane (2011) compares the relationship between rent prices and house prices as the equivalent to dividend for stock prices, which arguably is universal despite location. Hence, the variable will be subject to further investigation despite its weak significance in the estimated model.

A potential drawback is that the model suffers from autocorrelation, as presented in table A3 in the appendix. We, therefore, performed an additional estimation of Model 3 with Newey and West´s HAC standard error[8]. The inclusion makes no changes to the significance of the coefficients. Hence, we conclude that autocorrelation is not a relevant issue for the model. Results with HAC standard errors can be found in Table A4 in the appendix.

6.1.1 Stationarity

The results of the three different stationarity tests are presented in Table 5. When performing these tests, one must decide which model best suits the analysis. The different models include (1) Pure random walk, (2) Random walk with drift and (3) Random walk with a time trend.

[8] Heteroscedasticity and Autocorrelation Consistent

The graphical presentation of each time series decides which model is applied for the specific variable. Confirmatory data analysis suggests that all variables except the Unemployment Rate and Expectations are integrated of order one. Meaning they are non-stationary and thus contain one unit root at levels. However, the Phillips-Perron test suggests that all variables are integrated of order one. The Unemployment Rate suffers from a significant structural break because of the Covid Pandemic, as the unemployment rate in Oslo increased from 2.4 percent to above 9 percent during the first half of 2020. Hence, we argue that the most reliable test regarding this variable is the Phillips-Perron test. From which the time series is non-stationary. However, one limitation universal for all the stationarity tests is that they tend to reject the hypothesis of no unit root if the root is close to the non-stationary boundary (Brooks 2014). Meaning, that a coefficient below but close to one could be wrongfully interpreted as a unit root, especially in small samples.

Table 5

Stationarity Tests

Variables	**Philips-Perron**		**ADF**		**KPPS**	
	Stat	**Integration order**	**Stat**	**Integration order**	**Stat**	**Integration order**
House Price	3.7539	I(1)	-0.6429	I(1)	0.1645	I(1)
Average Income	0.8561	I(1)	-2.2867	I(1)	0.1508	I(1)
Housing Starts	-0.3901	I(1)	-5.4603	I(0)	0.1086	I(0)
Lending Rate	-1.6175	I(1)	-2.7465	I(1)	0.2243	I(1)
Unemployment Rate	-0.3947	I(1)	-2.6645	I(1)	0.1270	I(0)
Population increase	-0.2354	I(1)	-2.1368	I(1)	0.9660	I(1)
Rent Price	2.2038	I(1)	-1.4192	I(1)	1.3088	I(1)
OSEBX	2.0730	I(1)	-2.6864	I(1)	0.2990	I(1)
Expectations	-0.9622	I(1)	-3.7901	I(0)	0.0573	I(0)
Debt-to-Income	1.7650	I(1)	-2.4229	I(1)	0.8745	I(1)

Note. All test statistics reported in the table arise from tests performed on the variables at levels. Integration order for variables found to be non-stationary at levels is tested for stationary at first differences in an additional non-reported test. All variables were found to be stationary at first differences.

The results of the stationarity tests influence the research in two critical ways. First, the results from the OLS estimation in the Case and Shiller recreation suffer from the absence of stationarity in our variables. Suggesting the OLS estimates could be wrongfully interpreted, as they may suffer from spuriousness. As all variables proved stationary at first differences, we performed an additional analysis of only the first differenced variables. The results gave remarkably lower R^2 and only two significant variables, suggesting that the relationship between house prices and fundamental variables is primarily a long-run relationship. The results can be viewed in table A2 in the Appendix. Secondly, arguably the most important result from the stationarity tests is that for us to apply a VECM, the model requires that all variables must be non-stationary in levels and become stationary at the first difference (Brooks, 2014). This is the case for all the variables found to be significant from the first model we chose to include in the VECM estimations.

6.1.2 Conclusion of the Case and Shiller model

Following the procedure of Case and Shiller (2003), we observe apparent similarities between the US and Oslo markets. Income alone can arguably explain much of the housing prices in Oslo. However, the addition of other fundamentals provided additional explanatory power. Introducing additional variables suspected to explain house prices in Oslo further increased the explanatory power. Despite the statistical problems with the procedure, we are confident that fundamental factors are revealed with adequate certainty. Thus, the answer to H1 is that there is some evidence that average income, rent price, lending rate, OSEBX, and debt-to-income ratio could be important factors in explaining the pricing of the Oslo housing market, with income as the most important explanatory factor.

6.2 VECM

Due to the restricted number of observations at disposal, we needed to consider some trade-offs. Including all non-stationary fundamental variables resulted in an overfitted model. The number of estimated slope parameters exceeded the sample size and gave zero degrees of freedom. Overparameterization is a common issue in complex models such as the VECM, and it can cause the forecast ability to be weak because the model is not suitable (Haspari et. al., 2021). Thus, we considered the variables found to have a significant impact on the housing prices in Oslo. The variables included in the VECM are House Prices, Average Income, Lending Rate, and Rent Prices.

The VEC model suffers from autocorrelation in the residuals. By extending the number of lags to nine quarters, the null hypothesis of no autocorrelation could not be rejected at a 5% significance level. Again, this would lead to a model with the number of estimated slope parameters exceeding the number of observations. We argue the drastic increase in complexity is not defended by sufficient benefits and estimate the model with 4 four lags despite the possibility of inflated test statics. The Portmanteau test for serial correlation is reported in Table A5 in the Appendix.

Brooks (2014) argues there exists a trade-off between longer estimation windows to enhance the precision of parameter estimation and the occurrence of structural breaks. Our sample includes periods of the financial crisis and a pandemic, which may have contributed to structural changes in the variables included. The null hypothesis of no breakpoint is rejected for all variables in the Chow test. Moreover, some of the time series are estimated to have several and also different break dates between them. Low (2017) claims that structural economic models are incapable of capturing every aspect of reality and that pursuing so would make the model unwieldy for theoretical insight. Due to the restricted sample period at disposal and unsystematic estimated break dates, this point is imminent in our case. Discarding information or attempting to model for the breaks proved inefficient for our data. As the model provides a long-term solution without adjustments, we argue this is the best fit for our purpose[9]. Chow tests for breakpoints can be found in table A6 in the Appendix.

6.2.1 Johansen Cointegration Test

The Johansen test is applied to examine the number of cointegrating equations in our model. We choose the appropriate lag length through a lag order selection criterion on the VAR process. There are tested four different information criteria, namely Akaike´s (AIC), Schwarz´s Bayesian (SBIC), Hannan-Quinn's (HQIC), and Final Predicting Error (FPE). All tests suggest an optimal lag length of the VAR process equal to 5, except for SBIC, which

[9] Negative and significant Error Correction Term provides a long-term solution. Structural breaks, errors in data, or model specifications often alter the sign to be positive.

suggest 4. As there is no universal agreement on which information criterion is superior, we decide to rely on the consensus of the test and conclude that the VAR process has an optimal lag length of 5. This means that the Johansen test is specified with 4 lags, as mentioned in the methodology chapter. The Johansen trace test and maximum eigenvalue test for cointegration are presented in Table 6.

Table 6

Cointegration Tests

Trace Test				
		Critical value at significance level = α		
Null hypothesis	Test stat	α = 10%	α = 5%	α = 1%
$r^* <= 3$	4.96	7.52	9.24	12.97
$r^* <= 2$	11.29	17.85	19.96	25.60
$r^* <= 1$	32.03*	32.00	34.91	41.07
$r^* <= 0$	65.16***	49.65	53.12	60.06

Max eigenvalue Test				
		Critical value at significance level = α		
Null hypothesis	Test stat	α = 10%	α = 5%	α = 1%
$r^* <= 3$	4.96	7.52	9.24	12.97
$r^* <= 2$	6.33	13.75	15.16	20.20
$r^* <= 1$	20.74*	19.77	22.00	26.18
$r^* <= 0$	33.13**	25.56	28.14	33.24

Note. *, **,*** Indicates the rejection of the null hypothesis at a 1,5 and 10% significance level. The test is performed with p = 4 on the variables HP, RP, AI, and LR.

Both tests reject the null hypothesis that no cointegrating relationships exist at a 5% significance level but cannot reject that only one exists. However, the tests suggest two cointegrated vectors exist at the 10% level. As there is presence of autocorrelation in our model, the test statistic could possibly be inflated. Though other research chooses to proceed with the cointegrated vectors found at the 10% significance level, we argue this is inappropriate due to the possibly inflated test statistics. Therefore, we conclude that one cointegrated equation exists in our model, $r^*=1$.

6.3 Results from VECM estimations

6.3.1 Cointegrating relationship – long-run dynamics

The requirement of non-stationarity in levels and stationarity in first differences is fulfilled, from which one cointegrated equation is found. The equation exhibit existence of a long-term equilibrium relationship between the variables House Price, Average Income, Rent Price, and Lending Rate. From the beta-vector of cointegrating coefficients, we can specify the long-run equation as follows:

$$lnHP = 3.25 + 2.94lnAI - 0.38lnLR + 0.36lnRP + \varepsilon_t$$

Average Income and Rent Price are estimated to have a positive relationship with House Prices, while Lending Rate displays a negative relationship. The signs of the cointegrated coefficient are as expected from previous literature. All variables are interpreted as elasticities with respect to house prices as they are specified in logarithmic terms. Results are reported in Table 7.

The results suggest that Average Income is the predominant factor explaining house prices in Oslo, which are in line with the findings of Case & Shiller (2003) and the first part of our analysis. A one percent increase in average income is estimated to increase housing prices by three percent. Compared to the long-run elasticity of 1.7 found by Abelson et al., (2005) and 3.43 by McCarthy et al., (2002), the estimate for the Oslo market fall somewhere in between[10]. Jacobsen & Naug (2005) find a long-term income elasticity of 2.25 for the Norwegian market but insist that common findings range between 1.5 to 3.5. The effect of income in the long run for the Oslo market is in the upper bound of what is common among markets. According to Case & Shiller (2003), house price movement substantially being explained by income alleviates the suspicions of bubble tendencies.

The long-run elasticity of House Price with respect to Lending Rate and Rent Price is -0.38 and 0.36, respectively. Most papers use nominal interest rates instead of real lending (Jacobsen & Naug, 2005). Their findings suggest that a one percent increase in interest rates

[10] Definitions and number of included variables may vary between papers. Referencing to previous research is not meant as direct comparisons, but rather as adequate benchmarks.

is accompanied by a 3.5 percent decline in house prices, similar to the findings of 18 OECD countries in Annette (2005). Better comparable are the results of Dermani et al., (2016), which find the coefficient of real mortgage rate to be -0.57 in Sweden. Hence, the cointegrating coefficient is in the lower bound of what previous research has indicated. A possible explanation is that the real lending rate has been historically low during the sample period. As the lending rate is commonly adjusted by around 25 basis points (Norges Bank, 2022), a change in the variable would effectively imply a 12.5% adjustment if the rate today is 2%. These results suggest that if we consider Norges Bank's estimations of an increase from 2% in 2022 to 4% in 2024 in real lending rate, house prices would be reduced by approximately 9%, all other factors kept constant. Hence, we argue that it is important to consider the monetary policies in the estimation period when examining the coefficients. As expected, the cointegrated coefficient of rent price was the factor with the most negligible impact on house prices in the long run, as little evidence of the effect of rents on house prices has emerged from Norway. However, these results suggest a 1% increase in rent prices is followed by a 0.38% increase in house prices.

The House Price adjustment parameter is negative and significant at a 10% level, almost 5%. A negative Error Correction Term (ECT) is a requirement and thus expected. Otherwise, the process would not converge in the long run. An ECT of -0.125 is close to the findings in previous research (Jacobsen & Naug, 2005; Annette, 2005).

Table 7

Long-run dynamics

VEC-Model

Variable	Cointegrating coefficient
House Price	1.0000
Average Income	2.9391
Lending Rate	-0.3843
Rent Price	0.3635

6.3.2 Adjustment parameters – short-run (ECT)

We analyze the short-run adjustment parameters to estimate the behavior of house prices if they deviate from their long-run equilibrium. The model estimates an ECT in the house price equation of -0.125 per quarter. Meaning that house prices are converging 50% per year towards their equilibrium if diverging in the short run from the long-term trend implied by fundamentals. This adjustment coefficient is slower than the one found in Amundsen and Jansen (2013b) of -0.24, implying an overpriced market is prolonged. Suggesting the equilibrium price is restored two years after rather than one after a deviation from the house price equilibrium. However, these results align with the quarterly adjustment coefficient of 12 percent found in Jacobsen & Naug (2005). A prolonged adjustment process to equilibrium prices should be considered when evaluating monetary policies. Finanstilsynet (2021) addresses housing prices as one of the most critical vulnerabilities, with the Oslo market playing a pivotal role. A fair assumption is that policymakers will act more aggressively to prevent a house price disequilibrium when the adjustment process is estimated to be more lasting.

Table 8 *Short-run dynamics*

VEC-Model					
Dependent variable	**House Price**				
ECT	-01254*				
Explanatory variables		Lag 1	Lag 2	Lag 3	Lag 4
	ΔHP	0.4063**	0.0093	-0.2963*	0.2208
	ΔAI	65.9091	-21.6672	-145.4316	106.3170
	ΔRP	-0.3015	0.1525	0.1820	-0.1765
	ΔLR	0.0639**	0.0122	0.0179	-0.0058

6.3.3 Short-run parameters

Lagged values of the house price equation are presented in Table 8. The first and third lag of house prices is significant at 1% and 10%, respectively. The first lag of the real lending rate is significant at the 5% level. These results suggest a delayed relationship exists between house prices in previous periods and a lagged response of lending rates to house prices.

Short-run dynamics are further examined through Impulse Response Functions (IRF) and Variance Decomposition (VD).

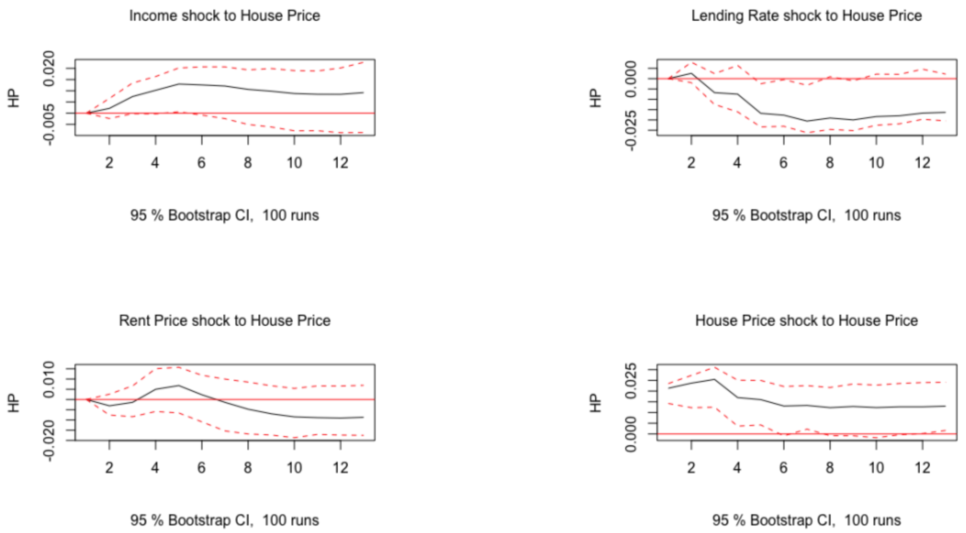
6.3.4 Impulse Response Functions

The effect on the house prices of a one standard deviation shock in the fundamental variables is examined through impulse response functions. We examine the house price behavior for the next 12 quarters after a shock occurs, i.e., over three years. An immediate observation is that the functions do not converge back to zero but rather tend to stabilize at a new level. This is opposed to what we would expect from a standard VAR model but is considered normal in VEC models (Kilian & Lütkepohl, 2017). A shock that declines over time towards zero is considered transitory, whereas the effects remaining in the system over time are characterized as permanent. The confidence intervals are derived from bootstrap with 100 simulations, and the axis is specified in integers. Results are presented in Figure 2.

Income and lending rate shocks have the greatest effects on house prices. The direction of the shocks is as expected and consistent with previous literature. Both shocks have a steep impact on house prices in the first quarter before supposedly stabilizing after approximately two years. Income has a permanent and positive effect of around 1%, and the lending rate has a negative and permanent effect of just below 2%. Worth noting is the initial steep decline in house prices after the shock to the lending rate, before gradually increasing and stabilizing at the end of the three years. The overshooting is not an indication of a house price bubble, according to Jacobsen & Naug (2005). Due to the high transfer costs and non-liquidity of housing compared to other asset classes, we argue that emphasis should be put on the permanent effect of a shock to fundamentals rather than short-term fluctuations in the first periods by households and investors.

The results from rent price shock to house price might seem counterintuitive. The IRF suggests a slight decrease in house prices in the first two quarters, before a sharp increase followed by another decline and stabilizing at around -0.5% after three years. A possible explanation is the minor effects found of rent prices on house prices. Another important implication is that IRFs (and VD's are) are difficult to interpret accurately. Hence confidence bands should always be computed and considered (Runkle, 1987). It is generated orthogonalized impulse responses to overcome the assumption that all the error terms of all other equations in the VAR system are held constant. Thus, the ordering of the variables is important. As suggested by Brooks (2014), the variables are ordered based on which variables are more likely to follow rather than precede the others, according to financial theory.

Figure 2: *Impulse Response Functions*



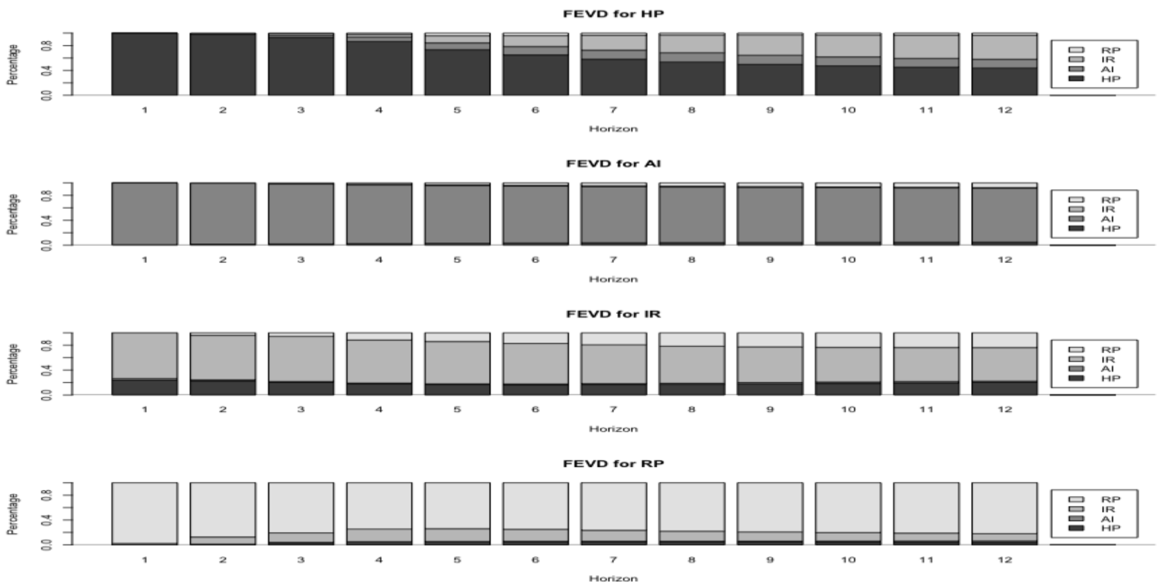
6.3.5 Variance Decomposition

To supplement the IRF, which traces the effect of a shock to each fundamental on the house price, the VD contributes information about the corresponding importance of each fundamental in affecting the forecast error variance in the system. Results are reported in Figure 3.

The results suggest house prices are mainly explained by itself the first two quarters. However, fundamentals tend to explain increasingly more of the variation the more extended the horizon. We observe that income is the factor explaining most of the fundamentals within the first year before the lending rate gradually explains more of the house prices. These results are in line with the expectations as they make economic sense. The lending rate arguably serves as the discount rate for housing valuation, which means the negative effect is enhanced the longer the horizon.

Moreover, the effect of an income increase will decay further into the future due to the time value of money. Rent prices tend to explain increasingly more moving towards the third estimation year, though contributing a small part of the variance. The variable can be interpreted as the growth factor for an investor purchasing a home to rent it out. Hence, an increased contribution further into the horizon is in line with expectations.

Figure 3*: Variance Decompositions*



6.3.6 Predictions

Prediction of future house prices is beyond the scope of this dissertation. However, the graphs serve as a reference point to the accuracy of the VEC Model and whether it finds housing overvalued based on fundamentals as of 2020.

Figure 4 displays the forecasting accuracy of the model for the previous twelve quarters, i.e., the period from 2018 to 2020. The out-of-sample forecast is created by discarding the past three years of observations and estimating the model on the sub-sample, including the period 2003 to 2017. The fitted line is displayed as a one-period ahead forecast together with the true time series. We observe that the model can capture both the timing and direction of fluctuations of the true value adequately in the first periods. However, there seems to be a delayed response to the spike in house prices following the outburst of the pandemic. This may be because the average income dropped in the first quarters of 2020 due to layoffs. The lending rate plunged in the second quarter of the same year, which one can tell from the model and true house prices reacted quickly and strongly.

The fan chart provides a prediction of house prices for the next three years with a shaded area displaying the confidence interval. The prediction is based on forecasts of all fundamental variables for the following periods. These results suggest house prices are not overpriced based on fundamentals and weaken the suspicion of a housing bubble in the market. Conversely, the model suggests house prices will continue their positive trend for the next three years as of 2020.

Figure 4: *Comparision of true and fitted House Prices*

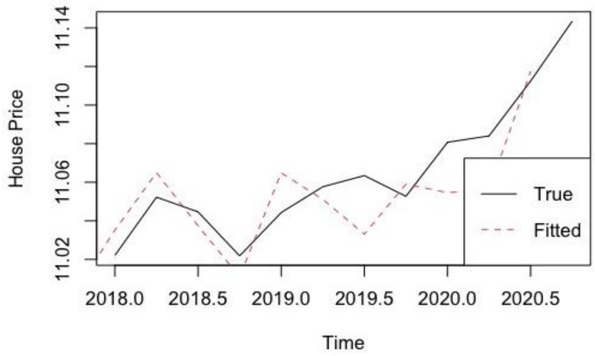
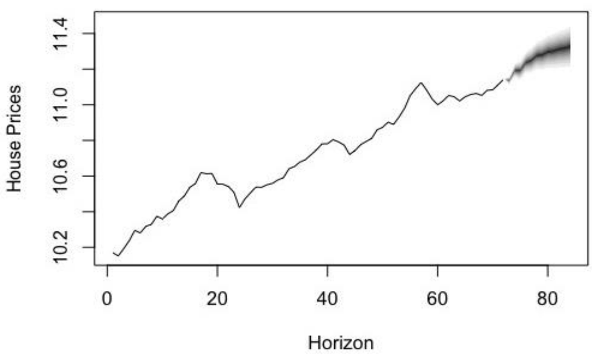


Figure 5: *Fan chart for predicted House Prices*



6.3.7 Robustness checks

The multivariate Portmanteau test for autocorrelation was performed on the VEC Model with four lags. There is no doubt that the errors suffer from serial correlation as the null hypothesis of zero autocorrelation is rejected at the 1% level. The issue could be resolved by extending the lag length to nine, however, at the cost of an over-parameterized model. The test results of both four and nine lags are presented in Table A5 in the Appendix.

There is no evidence of heteroskedasticity in the model. The ARCH[11] test was specified, with ten lags used for the multivariate test statistic. A p-value of 1 means we cannot reject the null

[11] Autoregressive Conditional Heteroskedasticity

hypothesis that the residuals exhibit no serial correlation. Meaning there is no clustered volatility in the model. Results can be found in Table A5 in the Appendix.

The multivariate Jarque-Bera test is conducted on the residuals of the model. The test is calculated using standardized residuals by Cholesky decomposition of the variance-covariance matrix for the centered residuals. The null hypothesis being a joint hypothesis of the skewness and the excess kurtosis being zero is rejected at the 5% level with a p-value of 0.025. This is most likely caused by the presence of structural breaks previously discussed. However, normality is not rejected at the 1% level, and the test is defined such that the ordering of the variables may alter the test results. Results are presented in Table A5 in the Appendix.

7.0 Conclusion

Real house prices in Oslo have increased by approximately 165% in the eighteen-year period between 2003 to 2020. The spectacular increase has raised concerns of a possibly existing housing bubble due to the adverse repercussions a bubble bursting would have on the economy. The OLS estimation finds several factors which possibly affect the pricing of the Oslo housing market. Despite statistical limitations, we obtain sufficient explanatory power and significant coefficients supported by economic theory.

The VECM examines the short- and long-run dynamics of the predominant factors found to explain house prices. The long-run results suggest that average income and lending rate as the main predictors of price movement. Contrary to international research, we find little evidence of rent prices affecting the Oslo market. Furthermore, the model predicts the prices to keep increasing in the foreseeable future. Thus, the suspicion of a housing bubble is alleviated due to pricing being sufficiently explained by fundamentals.

Consistent with previous research, the adjustment coefficient is found to be 12.5%. This suggests that prices will restore their equilibrium state in two years after a deviation from price equilibrium. The effect of shocks in average income and lending rate affect house prices quickly and permanently, with indications of overshooting in the lending rate. It is argued that the overshooting is not an indication of a housing bubble. Moreover, the average income is found to provide the most information on house prices in a one-year horizon, whereas the lending rate contributes more in a longer horizon. Rent prices were found to explain a modest part of the variation.

The results suggest that house prices in Oslo are well explained by its fundamental factors. Based on the solid relationship, we argue that the pricing of the market does not indicate tendencies of a bubble.

Limitations and further research

A restricted sample period at disposal caused the exclusion of arguably important factors explaining the housing prices in Oslo. Among others, the debt-to-income ratio was excluded to prohibit an overparameterized VEC model. A more rigorous analysis would include a larger sample and thus facilitate the inclusion of more variables. Moreover, construction costs are considered an important factor explaining house prices in previous literature but was excluded from the analysis due to lack of available data.

The structural changes in some fundamentals may have affected the relationship with house prices during the investigation period. To strengthen the analysis, further research could try to model for these effects. Due to the lack of evidence regarding rent prices in this study, the inclusion of other variables could be yielding for later research.

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Appendix

Table A1

OLS Regression Results on changes in house prices

Independent Variable(s)	Model 1	Model 2	Model 3
Average Income			
Housing Starts			
Lending Rate			
Δ Unemployment			
Unemployment Rate			
Δ Population		+*	
Rent Price			-**
OSEBX			
Expectations			
Debt-to-Income			+**
R^2	.003	.193	.185

Note. *, **,*** Indicates the reject of the null hypothesis at a 1,5 and 10% significance level. Model 1 represents a simple regression of Δhouse prices on average income. Model 2 a multiple regression with the inclusion of *HS, MR, ΔUnemployment rate, Unemployment rate* and *population increase.* Model 3 is multiple regression with the inclusion of all significant variables from Model 2 with the addition of *Rent price, OSEBX, Expectations* and *Debt-to-Income ratio.*

Table A2

OLS Regression Results on changes in house prices

Independent Variable(s)	Dependent Variable	Δ House Price
Δ Average Income		-***
Δ Housing Starts		
Δ Mortage Rate		
Δ Unemployment		
Δ Population		
Δ Rent Price		
Δ OSEBX		
Δ Expectations		
Δ Debt-to-Income		-***
R^2		.320

Note. *, **,*** Indicates the reject of the null hypothesis at a 1,5 and 10% significance level.

Table A3

Robustness Tests

	Test statistics			
	Testing for	**Test stat**	**Critical Value**	**Decision**
Breusch- Godfrey	Autocorrelation	39.753	18.307	**Reject H_0**
White´s test	Heteroscedasticity	39.646	49.802	**Not reject H_0**
Jarque-Bera	Normality	2.991	5.991	**Not reject H_0**

Note. All decisions regarding the rejection of the null hypothesis have conducted on a 5 percent significance level.

Table A4

OLS Regression Results with Newey-West´s HAC.

Independent Variable(s)	Model 3
Average Income	+***
Housing Starts	
Lending Rate	-**
Unemployment Rate	
Rent Price	+*
OSEBX	+***
Expectations	
Debt-to-Income	+**
R^2	.960

Table A5

Robustness Tests

Robustness test on VAR

Test	**Lag**	**Null hypothesis**	**P-value**	**Decision**
Portmanteau	4	No autocorrelation	0.00	Reject H_0
Portmanteau	9	No autocorrelation	0.07	Not reject H_0
ARCH	10	Heteroscedastic residuals	1.00	Not reject H_0
Jarque-Bera		Normality	0.025	Not reject H_0

Table A6

Tests for Structural breaks

Chow test			
Dependent variable	**Independent variable**	**P-value**	**Decision**
HP	RP	0.00	Reject H_0
HP	AI	0.00	Reject H_0
HP	LR	0.00	Reject H_0

Note. All decisions on the rejection of the null hypothesis is conducted at a 5 percent significance level. Rejection of the null hypothesis states the existence of structural breaks in the time series.