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Analysis of house price dynamics using the price-to-rent ratio: evidence from the Oslo housing market

By

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Abstract

Housing prices in Oslo have risen significantly in recent decades, approaching historic levels. Specifically, in the last ten years, house prices in Oslo have experienced a remarkable appreciation of 90%, surpassing the 47% increase in rental prices. This paper aims to examine the long-run dynamics of house prices in Oslo by investigating the relationship between the price-to-rent ratio and relevant macroeconomic variables. A Johansen cointegration test and Vector error-correction model are applied to determine these relationships. The results provide evidence indicating the existence of a cointegrated relationship between the macroeconomic variables and the price-to-rent ratio. The estimated VECM suggests that real interest rate is the predominant driver, followed by population and disposable income. In the short-run, the price-to-rent ratio adjusts toward equilibrium with an adjustment speed of 28,52% per quarter. A shock to the debt-to-income ratio has the most significant effect on the price-to-rent ratio, while the ratio itself is the primary driver in determining its variability.

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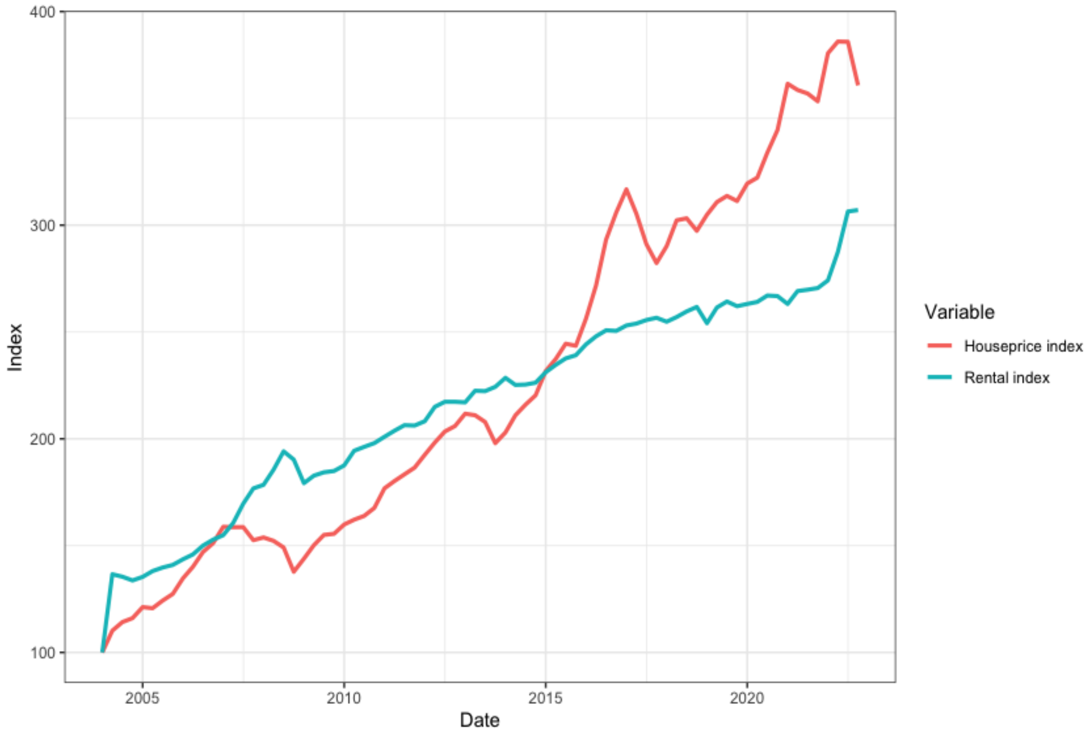
1. Introduction

The housing market is an intriguing market that has generated both economic enrichment and suffering. The market is an important asset class with substantial influence on the financial markets and the economy. This assertion has been validated by historical fluctuations, where the subprime/financial crisis in 2007 - 2008 was one of the most remarkable events, with a crash in both financial markets and house prices internationally. As observed in Figure 1, Norway was no exception either. With credit growth, reasonable fiscal policy, and an increased population in cities after the bank crisis in the early 90s, the increased Norwegian house prices also suffered a sharp and rapid decline but surprisingly quickly recovered (Grytten, 2009).

According to Eurostat (2021), the average proportion of individuals residing in households that own a home stood at approximately 70% among the EU countries in 2021, with other Scandinavian countries (excluding Norway) reporting an average of 63%. However, Norway’s homeownership rate significantly surpasses these averages. Calculations based on statistics from Statistics Norway (SSB) indicate that Norway’s homeownership share totaled 81.9%. The point is that investments and home ownership are more common in Norway compared to many other countries. The capital city of Oslo is no exception, with estimations indicating that nearly 74% of households in the city reside in their own homes. Once again, it can be emphasized that the housing market is central to the country's economy. In addition, Grindaker (2017) also suggests that a place of residence is considered the single most significant investment a household makes and constitutes as much as 2/3 of Norwegian households' total assets.

In recent years, Oslo has received much attention for its housing prices and development. Krakstad and Oust (2015) refer to an approximately 7% annual increase in housing prices over two decades, starting in 1992. The graph below illustrates the development of the housing market, which confirms this development with a significant increase in house prices in Oslo that has continued with an increase of 90% over the last ten years, surpassing the 47% growth observed in rental prices. Contributing to this phenomenon can be various macroeconomic factors, including income growth, low-interest rates, high debt accumulation, and population growth. Additionally, the psychology among the population also has its central part, where expectations of the economy can influence market supply and demand dynamics (Larsen, 2013). Furthermore, until 2015 there was a close alignment between house and rental prices, as depicted in Figure 1. However, a notable divergence emerged thereafter, with house prices exhibiting a substantial increase while rental prices lagged behind, following its earlier trend. The divergence has been attributed to the impact of the oil industry decline in 2015, with Oslo exhibiting less susceptibility compared to oil industry-dependent cities like Stavanger. Furthermore, the scientist from Statistics Norway (SSB) suggests that income growth and lower interest rate may act as mitigating factors, countering the effect of the industrial slowdown (Armstrong, 2016). The intersection of house prices and rental prices in 2015 could potentially be explained by an increase in demand for owning a house relative to renting due to individual's income growth and lower interest rate. These conditions contributed to enhanced purchasing power and reduced debt cost, thus influencing individuals to pursue homeownership rather than relying on rental accommodations.

Figure 1: House price vs Rental price



However, this analysis will narrow its focus to selected macroeconomic variables that may exert varying degrees of influence on house prices in Oslo. There are several examples of similar research-based analyses within this subject, which have contributed inspiration to both the methodology and the inclusion of macroeconomic variables that have proven to significantly contribute to explaining house prices.

1.1 Motivation

The background and motivation for analyzing the housing market's relationship to macroeconomic variables is the market's vital role in international financial markets and economies. To a certain degree, most individuals are affected by the housing market in one way, regardless of whether they own or rent a home. As previously mentioned, housing investments make up most of the household wealth in Norway. This implies that fluctuations in house prices and rents can cause imbalances and undermine global and local stability by affecting households' purchasing power, wealth, and, consequently, their demand for various goods. This makes it relevant for most individuals to investigate and try to understand the connection between macroeconomics and the housing market in the short- and long-run. Furthermore, such knowledge can provide valuable insight and information about how this market’s dynamics behave, contribute to more individuals identifying unstable and deviant behavior, and limit the impact of potential fluctuations. In addition, we hope to expand our academic knowledge of how these analyses and methodologies work and how to include and interpret significant fundamental factors in various analysis cases.

1.2 Research Question & Organization

The primary objective of this study is to analyze the relationship between macroeconomic variables and the dynamic nature of house prices in the Oslo housing market. The analysis focuses on using the price-to-rent ratio as the dependent variable, as it is widely acknowledged as a crucial metric for comprehending housing market dynamics. The price-to-rent ratio also holds significant importance as it contributes to explaining the variation observed in housing prices. The study aims to assess and estimate the long-run dynamics of house prices in Oslo by examining the relationship between the price-to-rent ratio and macroeconomic variables. Additionally, the research delves into the short-run relationship and examines the speed of adjustment toward the long-run equilibrium. The overarching research question this study aims to address is as follows:

I. Does a long-run cointegrated relationship exist between Oslo housing prices and macroeconomic variables?

II. What are the predominant macroeconomic variables that exert the most significant impact in the long-run dynamics of housing prices in Oslo?

The paper is organized as follows: In Section 2, we review previous research that is pertinent to the subject matter of our study. Section 3 presents a detailed description of the data and variables used in our analysis and any data transformations and adjustments made. Section 4 outlines the methodology employed in our study. This section covers the analytical framework and statistical techniques utilized to analyze the data and address our research question. In section 5, we discuss the empirical results obtained from our analysis. Finally, in section 6, we provide the conclusion of the study.

2. Literature review

2.1 Oslo Housing Market

In the media, news articles are constantly dealing with rising house prices in Norway, and house prices in the Oslo area have received much attention in recent years. According to Krakstad and Oust (2015), Oslo's house prices over a 20-year period had an average annual increase of 7 % from 1992-2012, with only a minimal decrease during the financial crisis in 2008 when the United States and other European countries were inflicted with fatal price reductions in the housing markets. The rise in Oslo's housing prices did not stop in 2012. From Lindquist et al. (2021) article, there appears to be a significant increase in Oslo's housing prices. The authors point out that in the ten years between 2010 and 2020, the general growth in Norwegian house prices has been estimated at close to 65%, with Oslo's house prices almost doubling in the same 10-year period. What factors influence this continuous growth?

Krakstad and Oust (2015) investigate this further in their research article. The article uses a vector error-correction model to define the long-run relationship between various relevant macroeconomic variables and house prices. They also use different ratios, where among other parameters, the price-to-rent ratio is a central part of the survey, as it will be in this thesis. The authors also write that their results indicate that Oslo house prices are overpriced in relation to what the macroeconomic variables would indicate.

2.2 Review of macroeconomic variables

Jacobsen and Naug (2005) research article is closer to this thesis area in a geographic way. While they focus on the Norwegian housing market, this article focuses on the capital city's housing market. They aim to explore which macroeconomic variables are the most significant drivers in the Norwegian housing market by applying an empirical model. To define the long-run relationship between the respective variables and house prices, they have constructed an error-correction model (ECM). The results from their models indicate that interest rates have a particularly strong influence on house prices. At the same time, it is proven that macroeconomic variables such as household income, unemployment, and construction are essential factors to consider in justifying the fluctuations in house prices.

Abelson et al. (2005) aim to model the Australian housing market's long- and short-run housing prices to determine the variations in real house prices. The authors write that to explore this, they use an error-correction model to analyze the relationship between house prices and the respective macroeconomic variables selected for the analysis. Moreover, they state that the most interesting findings suggest that, in a long-run perspective, both the housing stock and the stock market will have a negative effect on house prices. In contrast, both CPI and disposable income have a positive effect. They also mention that interest rates and unemployment significantly negatively impact house prices. However, their short-run results indicate a delayed adjustment to equilibrium, where the adjustment process is faster with increasing prices than with decreasing or flat prices.

In Al-Masum and Lee (2019) research article, they use several of the same variables that will be used in this thesis and also consider a specific large city as this thesis does. While this thesis focuses on Oslo's house prices, this research article deals with Sydney's prices. The authors aim to analyze the long-run relationship between macroeconomic variables and Sydney’s house prices by applying VECM and the cointegration test. Moreover, their findings suggest a long-run association between macroeconomic variables and house prices, where disposable income and the unemployment rate are the predominant variables. Additionally, they find no evidence that interest rates and the population are influencing house prices. However, they emphasize that there is little evidence that house prices significantly deviate from the macroeconomic variables indicating that a housing bubble has no strong presence.

Apergis (2003) is curious about the relationship between European Monetary Union (EMU) housing markets and various pertinent macroeconomic variables. In this research article, the authors have made the investigation even more specific by not focusing on all 15 countries in the EMU but primarily on the house prices in Greece. To examine this relationship, the authors are applying an error-correction vector autoregressive (ECVAR) model and variance decomposition to determine the impact of the different macroeconomic variables and which of these variables has the most influence on house prices in Greece. However, the results indicate an influencing relationship between house prices and specific variables, where interest rate and inflation have the most influence. Furthermore, they apply the impulse response function to analyze the dynamic behavior of macroeconomic variables. The result suggests that an increase in housing prices will be evident from a positive shock in employment and inflation. Conversely, they emphasize that housing prices will be reduced by a positive shock in the interest rate.

Gimeno and Martinez-Carrascal (2010), and Anundsen and Jansen (2013) are two different research articles that examine the relationship between household debt and house prices in Spain and Norway, respectively. Their respective analyses use the Vector error-correction model (VECM) to explore the long-run relationship between these two variables. Their results show that they get slightly different results during their analyses. However, in general, both conclude the same, where they find that credit debt and house prices are, in a long-run perspective, dependent on each other in that they both have a mutual influence relationship. Anundsen and Jansen (2013) describe this relationship as an increase in housing prices that will provoke credit growth. When there is a reciprocal relationship, this increase in debt will again result in potentially higher house prices. In addition, the authors point out that their analysis is based on Gimeno and Martinez-Carrascal (2010) but differs in that their analysis extends a little further, as they also follow the dynamics between house prices and credit debt from a short-run perspective.

The inspiration on which variables to include in this thesis is obtained from all the different Research papers we have used to build our analysis, and some of the most important ones are addressed in this literature review. However, the next section shows a more detailed description and justification for each variable.

2.3 Price-to-rent ratio

The variance decomposition method described by Campbell and Shiller (1988a; 1988b) and the two other articles below are incorporated into the literature review to exemplify one of several different methods to understand and assess the drivers of the price-to-rent ratio and investigate which variables that are the primary determinant of the fluctuations in the housing market. However, this method will not be applied in this thesis, just described in the literature review to show the importance of the price-to-rent ratio as a metric in the financial and housing markets.

In Campbell and Shiller (1988a; 1988b), the two academics present a renewed and expanded VAR framework within volatility tests. The framework investigates the time variation in corporate stock prices relative to dividends and the underlying macroeconomic factors that may influence the condition. To explore these movements in stock prices, they apply a present value model, a log dividend-price ratio model that reflects the rational expectation regarding the present value of future dividend growth rates and discount rates. The authors write that the model can be considered a dynamic version of Gordon growth model in that Campbell and Shiller (1988a) account for the stock returns risk premium by applying a free constant term as representation. This allows their model to concentrate solely on capturing the dividend-price ratio dynamics. Furthermore, by combining the expression with a VAR model, they decompose the movements in the log dividend-price ratio into three components expected future discount rates, expected future dividend growth, and an unexplained factor Campbell and Shiller (1988a; 1988b). This framework was initially introduced as a valuation model for the stock market. However, as we shall see, this approach has been applied to several asset classes, including the housing market and commercial real estate.

Campbell et al. (2009) use the same method Campbell and Shiller (1988a; 1988b) explain. However, now they apply the dynamic Gordon growth model to analyze the variation in the rent-price ratio in the American housing markets. They use a variance decomposition on the rent-price ratios, which divides the relationship into three components future expected rent growth, housing premia, and real interest rates. The model indicates that all three variables influence the ratio, but housing premia may be the major contributing variable to the volatility of rent-price ratios. At the same time, these three covariances contribute to stabilizing fluctuations in the relationship between rent and price.

Kishor and Morley (2015) propose a modified present-value model of the price-rent ratio. The authors emphasize that their study differs from Campbell et al. (2009) in using the price-rent ratio, not the dividend-price ratio. Furthermore, they consider expected rent growth and housing return as latent variables and do not apply a VAR model for estimation. However, the findings from the variance decomposition indicate that expected housing return drives most of the price-rent ratio variation.

3. Data- and variable description

In this empirical analysis, the pertinent data to answer the provided research questions are obtained from the statistical banks of various institutions, either directly from their public catalog of published statistics or with the assistance of contact individuals at the respective institutions. The data was collected from Boligbygg Oslo KF, Eiendom Norge, the Welfare Administration (NAV), the Norwegian Central Bank (Norges Bank), Bloomberg Terminal, Statistics Norway (SSB), and Finans Norge. Due to the different frequencies for the various variables, the data sample had to be limited to a time period where figures for all variables were available. Therefore, the sample period is from Q1 2004 to Q4 2022, which corresponds to 76 observations in total. The variables are elaborated in more detail in the justification and description down below.

3.1 Dependent variable

This thesis will use the price-to-rent ratio to assess house prices in Oslo. The price-to-rent ratio is derived by dividing the house price index by the rental index. The price-to-rent ratio is a modified version of what is often used in the financial markets, namely, a price-to-earnings ratio. Applying this estimate aims to gain a more comprehensive understanding of whether the housing market is moving in step with the fundamental values and can also provide an indication of whether the housing market is over- or underpriced. This is a way of revealing potential bubble trends by exploring whether the fundamental value, the object's earning capacity, reflects the object's market price (Grytten, 2009). What can be complex with this constructed variable is that, for example, population growth affects both house prices and rental prices since they are close substitutes, meaning both alternatives can fill the same need. This may indicate that other macroeconomic forces also play a central role (Larsen, 2013). This may also be a possible limitation in these analyses, in that the different macroeconomic variables can potentially influence both the price and rent similarly and provide no reflections in the price-to-rent ratio.

After contacting Eiendom Norge, we were sent their house price index in a monthly structure. The rent values were extracted from Boligbygg Oslo KF, representing the average rental price for tenancies signed in Oslo's private rental housing market during the current quarter. The housing price index is converted by taking the average for every three months to produce quarterly figures to facilitate the computation of the price-to-rent ratio. The market rent has been converted to a quarterly index with starting value of 100 beginning in the first quarter of 2004, equal to the house price index.

3.2 Independent variables

Stock Index

The OSEBX index is included in the analysis to shed light on whether there is a relationship between the Norwegian stock market and the housing market in the Oslo area and to what extent house prices are possibly affected by such a relationship. When Abelson et al. (2005) try to explain the fluctuations in house prices in Australia, they find indications that the stock market can indirectly affect house prices. However, it should be emphasized that the effects the results provide are relatively weak. Their analysis uses the All-Ordinaries index, a stock market index consisting of Australian companies listed on the Australian Securities Exchange (ASX). Based on this, it has been chosen to use OSEBX, a similar index that consists of Norwegian companies listed on the Oslo Stock Exchange. The index was obtained as a quarterly index-based series using faculty Bloomberg Terminal access.

Expectation

Psychology and individuals' expectations of their own and the country's economy are often not given the significant weight they should be. Shiller (2007) believes that individuals think that market psychology drives the housing market and shows tendencies toward herd mentality in that individuals measure the psychology and actions of others, which makes change difficult. Shiller (2007) also concludes that the opinions of individuals regarding long-run decisions shape short-run actions, but it is not easy to quantify as they often are unexpressed. Vague expectations and perceptions about property value drive increases in consumption, finances, and prices. The coordination problem of psychological expectations plays a crucial role in the strong momentum of house price increases as investors struggle to change their expectations and coordinate the timing (Shiller, 2007). Therefore, using this variable in the analysis will be interesting. We have chosen to use the expectation barometer constructed by Finans Norge and Kantar TNS but extracted from Finans Norge website. The barometer of expectation provides insight into Norwegian household's expectations for the country and their own economy, where the barometer should reflect an individual's future demand. According to Finans Norge, this estimate is based on a quarterly survey with the same questions from its inception in 1992 to the present day. The primary indicator used in this thesis can be broken down into five sub-indicators that measures the expectation of household's for both their own and the country's economy for the past and upcoming year, as well as major purchases. For this thesis, we have extracted Q1 2003 – Q4 2022.

Population

Jacobsen and Naug (2005) express in their research article that the total population can have an effect on the overall housing supply and housing demand, which can impact the market's housing prices. However, their model later denied the effect as it did not get significant results. When Capozza et al. (2002) explore the dynamics of real house prices, they do not necessarily find evidence that population is one of the main factors in house price fluctuations but can have a certain impact together with other macroeconomic variables. Because of what we know about economic theory and the population's possible influence on supply and demand, we have extracted the population in Oslo from the SSB database quarterly, which provides the population at the commencement of the quarter from 2004Q1 – 2022Q4.

Disposable Income & Unemployment Rate

A higher disposable income enhances housing affordability, while higher unemployment rates reduce housing demand and drive prices down. Jacobsen and Naug (2005) argue that the disposable income that the households expect will influence the demand side for housing. Furthermore, they express that a very central part of the expectations for income depends on the development of the labor market. This means that a reduction in unemployment can lead to an expectation of an increase in wage growth and hence increased willingness to pay and reduced uncertainty among households. This reasoning is given weight as the results from their analysis prove that unemployment and disposable income are two of the most significant drivers of house prices (Jacobsen & Naug, 2005). This is further proven when both Al-Masum and Lee (2019) and Abelson et al. (2005) also find that the variables disposable income and unemployment have considerable influence on the housing market and are therefore considered in the analysis. Disposable income and unemployment are extracted from SSB national account quarterly and the NAV database monthly and converted to quarterly by taking the average for every three months, respectively.

Real Interest Rate

According to the Monetary policy strategy (Norges Bank, 2021), the economy is regulated through monetary policy and its central instruments. The real interest rate is one of the most critical tools to adjust economic imbalances. Furthermore, it is emphasized that strong growth in property prices, rapid debt build-up, significant risk-taking, and high consumption can be shown by low levels of interest rates over time. According to economic theory, Aastveit and Anundsen (2018) write that lower housing demand and reduced house prices can become a reality due to higher interest rates and the opposite in the case of a downward adjustment of interest rates. Both Abelson et al. (2005) and Jacobsen and Naug (2005) can conclude that their results are consistent with economic theory when they test the influence of interest rates on long-run developments in house prices with significant results. For this thesis, the quarterly interest rate on outstanding loans to households extracted from SSB and adjusted for inflation, where the Fisher equation is applied. Monthly CPI-ATE obtained from SSB has been used as an inflation target after being converted to quarterly data by taking the average for every three months.

Household debt

Household debt and house prices are often mentioned in the same setting. Jacobsen and Naug (2004) describes a complex relationship between the housing market and household debt where they both influence each other, where higher house prices can lead to taking on higher debt which can further develop imbalances in the economy where increases in interest and costs of the debt can lead to significant reductions in household consumption, uncertain serviceability and significantly increased financial risk. According to Gulbrandsen (2023), Norwegian households' debt burden has increased continuously since the 1990s, resulting in the total stock of Norwegian households' debt reaching record levels. Lindquist et al. (2017) also add that household debt is one of the most critical sources of Norwegian economic vulnerability. Household debt is, therefore, an exciting and essential variable to define in the analysis. In other previous research in the field, Mian et al. (2017) find strong correlations between real house price growth and household debt. In this thesis, the *debt-to-income ratio* will be employed as a measure to quantify the level of household debt. This ratio can provide an improved reflection of Norwegian household's ability to service debt and their purchasing power, thereby providing a better picture of their demand in the housing market in relation to household debt (Torstensen, 2016). The data extracted for the household debt was originally reported monthly in the SSB database and showed the domestic loan debt per household at the end of each month. However, it has been converted to quarterly figures by taking the average for every three months.

Table 1: Summary of the data

Variables	Obs.	Mean	Std. Dev	Min	Max
Price-to-rent	76	1,0191	0,1732	0,7241	1,3917
Real interest rate	76	0.0340	0.0121	0.0086	0.0676
Unemployment rate	76	3,5004	1,1941	1,9333	9,1333
Population	76	622 233	58 606	521 886	707 531
Debt-to-income	76	154 711	1.0446	1849711	10.0243
Disposable income	76	300 859	75 622	184 953	469 249
Expectation	76	32478	15.229	-36.80	31.1682
Stock Index	76	590.85	278.93	193.77	1261.35

4. Methodology

4.1 Stationarity

The first step in making our model is to check if the data variables are stationary. The characteristic of a stationary series consists of constant mean, constant variance, and constant autocovariance for any specific lag (Brooks, 2019, p. 437). When working with non-stationary data, you may encounter spurious regressions. Using such regressions violates the assumptions of OLS and can lead to inaccurately high R^2 and wrongly significant coefficients, resulting in incorrect conclusions. This is because t-ratio and F-ratio statistics will diverge from their normal distribution since the typical premise for statistical analysis is violated (Brooks, 2019, p.438). In the case of Oslo house prices, it is essential to ensure that the time series is stationary since there are several trends and seasonal effects that can alter the variance of the series.

While several methods exist for testing unit roots, the Augmented Dickey-Fuller test is currently the most widely used method for determining whether there is a unit root. As described by Brooks (2019, p. 450), the ADF-model contains the following components:

$$\Delta y = \psi y_{t-1} + \sum_{i=1}^{p} \alpha_i \Delta y_{t-i} + u_t \quad (1)$$

We test that Ho: $\psi =$ vs HA: $\psi < 0$.

The ADF-test is conducted by regressing the Δy on lagged variable y_t, this allows for the absorption of dynamic patterns in the dependent variable, preventing autocorrelation in the error-term. The null hypothesis is if the series contains a unit root (non-stationary), while the alternative hypothesis assumes that the series contains no unit root (stationary). When utilizing a Vector error-correction model (VECM), a requirement is that the variable under consideration is non-stationary and becomes stationary by taking the first difference. Once the variables are integrated in the same order, the cointegration analysis can be carried out to investigate the long-run relationship and the equilibrium among the variables. Typically, if a non-stationary series y_t requires being differenced (d) times to achieve stationarity, it is considered to be intergraded of order (d) (Brooks, 2019, p. 446).

Moreover, when utilizing an ADF-test, selecting an appropriate lag length for the dependent variable is important. Obtaining accurate estimation can depend on selecting the appropriate number of lags. With insufficient lags, the model risks missing important relationships and patterns in the data. However, the model may become overfit if we use more lags. Considering that we are working with quarterly data, utilizing four lags could be a suitable choice (Brooks, 2019, p. 450). However, it is worth exploring different lags to compare the outcomes. Hence, we will employ the Akaike information criteria (AIC), which is an information criterion that aids in selecting the optimal lag length of the test. Using the expression given by Brooks (2019, p. 360):

$$AIC = \ln(\hat{\sigma}) + \frac{2k}{T} \qquad (2)$$

Where the residual of variance is represented by σ^2, k denotes the number of coefficients estimated, and T represents the number of observations. It is important to acknowledge that no criterion is considered to be superior to others. However, it is worth noting that AIC is not consistent and often tends to favor larger models, meaning that AIC often selects models with more parameters, potentially leading to overfitting (Brooks, 2019, p. 361).

4.2 Cointegration and Vector error-correction model (VECM)

When using the differencing method, non-stationarity series should be handled carefully to prevent information loss. Differencing the series can potentially conceal the relationship between the variables by removing important long-run relationships. To avoid missing important relationships, it is essential to thoroughly evaluate the differenced series and consider employing alternative techniques. Cointegration and VECM are viable alternatives for determining long-run relationships between the variable under consideration when analyzing non-stationary series. In financial theory, there are many instances in which at least two variables are believed to have a long-run relationship. One example can be the theory of purchasing power parity (PPP), which suggests that the exchange rate between two currencies should be equal to the price of identical goods across different countries. These variables are considered to be related in the long-run, with deviations from the equilibrium being corrected over time to restore purchasing power parity (Brook, 2019, p. 480). Furthermore, if two variables contain one unit root I (1), it is defined as cointegrated if a linear combination of them is stationary (Brook, 2019, p. 457).

There are several methods available for identifying cointegrated relationships such as Engle and Granger's two-step method. However, there are a number of issues with this method, the most significant being that it requires us to treat the variables in an asymmetrical fashion by classifying one as the dependent variable and the other as the independent variable (Brook, 2019, p. 464). The Johansen´s cointegration test addresses this issue. This test helps you to handle multivariate datasets with multiple non-stationary variables and can reveal dynamic relationships among variables over time, which can be particularly important when trying to gain insight into the housing market. Therefore, in this thesis, we will employ Johansen's cointegration test. The Johansen's method is based on VAR with k lags, demonstrated by Johansen (1988), where we have a set of g variables ($g \geq 2$), it is assumed that the variables are integrated in order one and accounts for the potential of cointegration between the variables. The model is presented as (Brooks, 2019, p. 474):

$$yt = \beta_1 \; y_{t-1} \; + \cdots + \; \beta_k \; y_{t-k} + u_t \qquad (3)$$

In addition, the VAR (2) must be transformed into a Vector error-correction model (VECM), using the derivation given by Brooks (2019, p. 474). The model is presented in equation 4:

$$\Delta y_t = \Pi \mathrm{y}_{\mathrm{t-k}} + \Gamma_1 \, \Delta y_{t-1} + \Gamma_2 \, \Delta y_{t-2} + \cdots + \Gamma_{k-1} \, \Delta y_{t-(k-1)} + u_t \; (4)$$

$$\text{Where } \Pi = \left(\sum_{i=1}^{k} \beta_i \right) - I_g \quad \text{and} \quad \Gamma_{\mathrm{i}} = \left(\sum_{j=1}^{i} \beta_j \right) - I_g$$

Where Π is a long-run coefficient matrix and I_g denotes the identity matrix. Computing the cointegration test and the implantation of the Johansen test depends on determining the rank of the matrix Π through its eigenvalues (Brooks 2019, p. 474). When the rank of matrix Π is zero, it indicates the absence of a long-run relationship and cointegration. On the other hand, if we have at least one cointegrated relationship ($1 \leq \Pi < g$), it indicates the presence of *r* cointegrated vector, which implies the existence of a long-run relationship. In such cases, Π can be rewritten as:

$$\Pi = \alpha\beta` \quad (5)$$

Where matrix β gives the cointegration coefficient and gives insight into the variable´s long-run relationship and α represents the coefficient for speed of adjustment (Brook, 2019, p. 476-477). Furthermore, a linear combination $\beta`\mathrm{y_t}$ is stationary, and each *r* row of $\beta`y_t$ is a cointegration long-run relationship (Bjørnland & Thorsrud, 2015, p. 264). Assuming that g = 3 (three dependent variables) and r = 2 (cointegrating vectors), we have two linear relationships between the three variables, then the VECM can be written in matrix form as:

$$\begin{pmatrix} \Delta y_{1,t} \\ \Delta y_{2,t} \\ \Delta y_{3,t} \end{pmatrix} = \begin{pmatrix} \mu_1 \\ \mu_2 \\ \mu_3 \end{pmatrix} = \begin{pmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \\ \alpha_{31} & \alpha_{32} \end{pmatrix} \begin{pmatrix} \beta_{11} & \beta_{21} & \beta_{31} \\ \beta_{12} & \beta_{22} & \beta_{32} \end{pmatrix} \begin{pmatrix} y_{1,t-1} \\ y_{2,t-1} \\ y_{3,t-3} \end{pmatrix} + \begin{pmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \\ \varepsilon_{3,t} \end{pmatrix} \quad (6)$$

Using equation (4), we can now extend the framework to a VAR (k), resulting in the following model:

$$\Delta y_t = \mu + \alpha\beta`\mathrm{y_{t-1}} + \Gamma_1 \Delta y_{t-1} + \Gamma_2 \Delta y_{t-2} + \cdots + \Gamma_{k-1} \Delta y_{t-(k-1)} + u_t \quad (7)$$

The VECM model now incorporates information regarding the long-run and short-run dynamics among the variables in y_t. In the long-run, $\beta`y_t$ determines the relationship between the variables, whereas, in the short-run, there can be deviations of the variables from their equilibrium values (Bjørnland & Thorsrud, 2015, p. 265). To determine the number of cointegrated vectors of matrix Π, Johansen (1988, 1995) presents different approaches. These are the trace test and maximum eigenvalues (Bjørnland & Thorsrud, 2015, p. 265), which can be expressed as:

$$\lambda_{trace}(r) = -T \sum_{i=r+1}^{g} \ln(1 - \hat{\lambda}_i) \qquad (8)$$

and

$$\lambda_{max}(r, r+1) = -T \ln(1 - \hat{\lambda}_{r+1}) \qquad (9)$$

In the setting of the null hypothesis, r represents the amount of cointegrated vectors, while $\hat{\lambda}_i$ denotes the estimated eigenvalue. The H0 is that the cointegrated vectors are lower than or equivalent to *r*, which applies to both the trace test and the maximum eigenvalue test. The trace test evaluates the H1 of having greater than *r* cointegrated vectors. On the other hand, the H1 for the maximum eigenvalues test implies the presence of *r+1* cointegrated vectors (Brook, 2019, p. 475)[1].

After investigating the relationship between our dependent and independent variables, this thesis will utilize the impulse response function (IRF) and variance decomposition to deepen our understanding of this relationship. The IRF analysis will provide valuable insight into the dynamic behavior and magnitude of the relationship between the variables. Additionally, variance decomposition will enable us to determine the relative contributions of each independent variable to explain the variation in our dependent variables, allowing us to identify the drivers of house prices.

[1] *In the case where the calculated test statistic exceeds the critical value, the H0 that r cointegrated vector exist is rejected, instead accept the H1 of having r+1 cointegrated vector for the maximum eigenvalues and greater than r cointegrated vectors for trace test (Brook, 2019, p.476)*

5. Results and Analysis

5.1 Regression analysis

Our initial aim was to examine the relationship between the price-to-rent ratio and key macroeconomic variables. Following that, we sought to enhance our model by including additional variables, namely Expectation and Stock Index, to see whether further improvements could be achieved. Table 2 presents the results of multiple regression analysis utilizing three different models. Model 1 consists of the key macroeconomic variables that were first considered for our analysis. The results indicate that the real interest rate, debt-to-income ratio, and lnDisposable income are statistically significant at a 1% level, with a positive sign. Additionally, lnPopulation displays statistical significance at the 5% level, but with a negative sign, contrary to what we anticipated. From an economic standpoint, population growth increases housing demand, resulting in housing prices to rise. However, our results suggest that an increase in population might contribute to a higher demand for rental properties, which causes rental prices to rise faster than house prices. This can be due to reduced affordability among individuals living in Oslo as well as those who migrate to the city. Furthermore, the unemployment rate does not show statistical significance.

In Model 2, the additional variables are introduced, resulting in only the real interest rate and unemployment rate exhibiting statistical significance at the 10% level among the macroeconomic variables. Only the stock index shows statistical significance at a 1% level among the additional variables, but the effect appears to be very marginal. Interestingly, population now switches to a positive sign, but the result is insignificant, suggesting it can have a certain effect together with other variables, as explained by Capozza et al. (2002).

Moving on to Model 3, we re-estimate Model 1 using the independent variables that displayed statistical significance. These variables maintain their respective significance levels of 1% and 5%, with an adequate adjusted R^2 of 78.6%. Therefore, Model 3 is utilized to construct the Vector error-correction model (VECM), which is represented by the following equation:

Log(Pt/Rt) = $\alpha + \ \beta 1\ real\ interest\ rate + \beta\ lnPopulation + \beta 2\ Debt\ to\ income + \ \beta 3\ lnDisposable\ income + \varepsilon$ (10)

Table 2: Multiple regression with Log(P_t/R_t) as dependent variable

Independent variables	Model 1	Model 2	Model 3
Real interest rate	-5.125(1.057)***	-2.343(0.915)*	-5.470(1.026)***
Unemployment rate	0.010(0.008)	0.012(0.006)*	
LnPopulation	-3.401(1.058)**	1.865(1.155)	-3.166(1.046)**
Debt-to-income	0.115(0.031)***	-0.047(0.035)	0.104(0.030)***
LnDisposable income	1.223(0.307)***	-0.575(0.368)	1.163(0.305)***
Expectation		0.0003(0.000)	
Stock Index		0.0005(0.000)***	
Adjusted R^2	0.788	0.874	0.786

*Notes: The provided table presents the results of the three multiple regression models with the price-to-rent ratio as the dependent variable. In Model 1, all the macroeconomic variables are included as independent variables. Model 2 extends the model by incorporating additional independent variables, namely, Expectation and Stock Index. Lastly, Model 3 consists of only the significant variables identified in Model 1. The corresponding standard errors are in brackets. The significance level are denoted by ***,**, and *, representing the 1%, 5% and 10%, respectively.*

5.2 Unit root test

The order of integration plays a crucial role in the analysis of Johansen´s cointegration test, which assumes that the variables being tested are integrated in the same order, typically I (1). This assumption is fundamental for the validity of the test, as it ensures that the variables have a long-run relationship. Table 3 represents the results of the ADF test in level form and the first difference. From the result, we can see that price-to-rent ratio and disposable income are stationary after taking the first difference at a 1% significance level, and the remaining variables are stationary at a 5% significance level after taking the first difference. Based on the findings, we can infer that the variables are integrated in order one, allowing us to proceed with the cointegration test.

Table 3: Unit root test

	Augmented Dickey-Fuller test with trend	
Variables	Test-Statistical	
	Level	First difference
ln(P/R)	-2.433	-4.124***
Real interest rate	-2.894	-4.002**
LnPopulation	1.412	-3.893**
Debt-to-income	-3.148	-3.480**
LnDisposable income	-3.078	-4.659***

*Notes: The presented table displays the result of the ADF-test where the price-to-rent ratio is the dependent variable, with the null hypothesis tested in the presence of a unit root. The table includes the test statistic, which measures the significance of the test. The significance levels are denoted by ***, **, and *, representing the 1%, 5%, and 10% levels, respectively.*

5.2.1 Johansen Cointegration test

To proceed with the Johansen test, we must determine the optimal lag to include in our model. The choice of lag length is essential as it can impact the results of the Johansen test. To determine the optimal lag length for our model, we employ VAR selection, which automatically tests the lag length using four different information criteria. These criteria are the Akaike information criterion (AIC), Hannan-Quinn criterion (HQ), Schwarz criterion (SC), and Final prediction error (FPE). The AIC and FPE suggest that the appropriate lag length is 4, while HQ and SC suggest 3 and 2. The results are presented in Table 1.1 in the Appendix. Thus, considering that we have quarterly data, we determine that employing 4 lags is the most optimal choice for our analysis. Consequently, the Johansen test will be conducted with 3 lags (k-1). The Johansen trace and maximum eigenvalue tests are displayed in Table 4.

Table 4: Johansen cointegration test

Null hypothesis	Trace Statistic	Critical value for significant levels		
		10 %	5%	1%
r ≤ 4	6.32	7.52	9.24	12.97
r ≤ 3	17.70	17.85	19.96	24.60
r ≤ 2	33.04	32.00	34.91	41.07
r ≤ 1	67.51***	49.65	53.12	60.16
r = 0	121.08***	71.86	76.07	84.45

Null hypothesis	Max eigenvalue statistic	Critical value for significant levels		
		10 %	5%	1%
r ≤ 4	6.32	7.52	9.24	12.97
r ≤ 3	11.38	13.75	15.67	20.20
r ≤ 2	15.35	19.77	22.00	26.81
r ≤ 1	34.47***	25.56	28.14	33.24
r = 0	53.57***	31.66	34.40	39.79

*Note: The significance levels are denoted by ***, **, and *, representing the 1%, 5%, and 10%.*

Starting with the first hypothesis, where we test for the presence of cointegration (r = 0), we see that the test statistic for trace and maximum eigenvalue exceeds the 1% significance level. As a result, we reject the null hypothesis, indicating at least one cointegration. Moving on to the second test, comparing r ≤ 1 against the alternative hypothesis r >, both test statistics are greater than the 1% significance level, leading us to reject the null hypothesis. However, at rank 2, we fail to reject the null hypothesis in both tests at all significance levels. Therefore, we conclude that there are at least two cointegrated vectors. The results of estimating the VECM model with two cointegration vectors are displayed in Table 5. Notably, only one ETC coefficient was found to be statistically significant and with a negative sign. To enhance the clarity and interpretation of the findings, we have chosen to focus on a VECM model with one cointegration vector.

Table 5: Result of the error-correction term with two cointegrated vector

	Ln(P/R)	*Real interest rate*	*LnPopulation*	*Debt-to-income ratio*	*LnDisposable income*
$ECT_{t-1}(\alpha)$	-0.260(0.121) *	0.067(0.019) **	0.002(0.006)	2.551(1.242)*	-0.284(0.154)
$ECT_{t-2}(\alpha)$	1.021(1.407)	-0.771(0.226) **	0.119(0.071)	-1.709(14.422)	-0.649(1.790)

*Notes: The table presents the estimated coefficient for the model´s speed of adjustment (α), indicating how quickly the model restores its equilibrium with two cointegration vector. The corresponding standard errors are in brackets. The significance levels are denoted by ***, **, and *, representing the 1%, 5%, and 10% levels, respectively.*

5.3 Results from VECM

5.3.1 Long-run dynamics

Proceeding to analyze the cointegration vectors presented in Table 6, they offer valuable insight into the long-run relationship between the macroeconomic variables and the price-to-rent ratio. The logarithmically transformed variables in the analysis will be interpreted as elasticities relative to the price-to-rent ratio. The estimated cointegration coefficient vectors can be expressed as:

$$\text{Ln(Pt/Rt)} = -7.31\ real\ interest\ rate - 4.45\ lnPopulation + 0.303\ Debt\ to\ income + 4.04\ lnDisposable\ income + \varepsilon_t \qquad (11)$$

Importantly, most of the variables have the anticipated sign, except for population, and are not in line with our theoretical explanation, as we explained earlier. However, the long-run elasticity of the price-to-rent ratio with respect to population is -4.45. Despite this, we cannot ignore the fact that population is one the primary long-run determinants of house prices in our results. However, the finding of Anundsen and Jansen (2013) indicate that population has no significant effect on house prices. In examining the price-to-rent ratio, we have identified that real interest rate are the predominant variable in the long-run. Our findings indicate that in the long-run, a one-unit increase in the real interest rate is associated with a 7.31% decrease in the house price. Jacobsen and Naug (2005) reported a decline in house prices ranging from 2.25 to 3.25% in response to an increase in nominal rate. They also found a 4.19% impact on house prices due to changes in real interest rates. The authors also noted that it is more common to achieve better model performance when using nominal rate rather than real interest rate. However, our results align to some extent with the findings of Abelson et al. (2005), who reported an average decrease of 5.4% in house prices for a 1% increase in the real interest rate. When estimating the elasticity of disposable income with respect to the price-to-rent ratio, we found that a 1% increase in disposable income leads to a 4.04 increase in house prices in the long-run. Al-Masum and Lee (2019) obtained a relatively higher estimate for the disposable income of 7%, while Jacobsen and Naug (2005) determined a long-run elasticity of disposable income of 2.25%. They also mentioned that it is more common to observe income elasticity between 1.5 and 3.5%.

Our analysis also suggests a positive long-run relationship between price-to-rent ratio and the debt-to-income ratio, resulting in a 0.303% increase in house prices corresponding to a one-unit increase. The result indicates that debt-to-income ratio exhibits the smallest effect among the other macroeconomic variables in the long-run.

Table 6: Coefficient in the VECM

	Ln(P/R)	*Real interest rate*	*LnPopulation*	*Debt-to-income ratio*	*LnDisposable income*
Cointegrated Coefficient (β)	1	-7.31115	-4.45203	0.30323	4.04037

Note: The cointegrated vectors represent the long-run dynamic.

5.3.2 Error-correction model & short-run dynamics

In the short-run, the price-to-rent ratio may deviate from its long-run equilibrium. However, there is a process in place that gradually brings the ratio back towards equilibrium. This process is captured by the error-correction term (ETC), which represents the speed of adjustment and reflects the extent to which deviations from the long-run equilibrium are corrected in the short-run. With values ranging between 0 and -1 to ensure a valid and meaningful interpretation of its dynamics, this criterion needs to be fulfilled. While our focus will be on analyzing the price-to-rent ratio, we will also examine the other variables' ECT for completeness. However, we can observe that the price-to-rent ratio stratifies the aforementioned criteria; it indicates a convergence from short-run dynamics toward long-run equilibrium. The estimated results of the error-correction term using a single cointegration vector are presented in Table 7. In cases where we observe positive or negative ECT that is not statistically significant, it implies an absence of substantial adjustment toward long-run equilibrium. Thus, the disequilibrium cannot be corrected to its equilibrium in the long-run.

Table 7: Result of Error-correction term with one cointegrated vector

	Ln(P/R)	*Real interest rate*	*LnPopulation*	*Debt-to-income ratio*	*LnDisposable income*
$ECT_{t-1}(\alpha)$	-0.2852(0.118)**	0.059(0.019)***	0.0008(0.006)	-0.3618(0.156)**	3.032(1.238)**

*Notes: The table presents the estimated coefficient for the model´s speed of adjustment (α), indicating how quickly the model restores its equilibrium with one cointegration vector. The corresponding standard errors are in brackets. The significance levels are denoted by ***, **, and *, representing the 1%, 5%, and 10% levels, respectively.*

The analysis reveals a statistically significant and negative error-correction term for the price-to-rent ratio, indicating a speed of adjustment of 28,52% per quarter toward equilibrium from a state of disequilibrium. The observed speed of adjustment can be considered relatively high within the context of this study. This implies that any deviation from the long-run equilibrium in the price-to-rent ratio is corrected at a relatively rapid pace in the short-run. The negative sign signifies that the adjustment process aims to reduce the deviation and bring house prices closer to equilibrium. Specifically, if the price-to-rent ratio deviates by 1% from its long-run relationship, house prices are expected to decrease or increase by approximately 28.52% in the same quarter. Our findings can also be aligned with prior studies conducted in Spain by Gimeno and Martinez-Carrascal (2010), where they reported an adjustment coefficient of 28% for house prices with an annual interpretation. Similarly, Abelson et al. (2005) observed a comparable error-correction term of 21% per quarter. In the Norwegian market, Anundsen and Jansen (2013) found a quarterly ETC of 24%, which is also closely aligned with our results. However, in contrast, Jacobsen and Naug (2005) reported a slower adjustment coefficient of 12% per quarter.

The estimated coefficient for disposable income is found to be statistically significant and negative, indicating a speed of adjustment of 36.18% per quarter toward long-run equilibrium. This suggests that any deviations from the equilibrium in disposable income will be corrected relatively quickly in the short-run. On the other hand, the coefficient for the population is not statistically significant, implying that changes in population may have limited influence on the adjustment process towards the long-run equilibrium. In addition, the ECT for real interest rate and debt-to-income ratio are statistically positive, indicating that these variables do not converge their equilibrium.

Moving on to examining short-run relationships, the findings are presented in Table 8. Examining the lagged values for our dependent variable in relation to the macroeconomic variables, we observe that only the third lag of the price-to-rent ratio is statistically significant. Additionally, the first and second lag of the real interest rate are significant at 10% and 1% levels, respectively. These findings suggest that the price-to-rent ratio is negatively influenced by its own previous value and has a negative relationship with the real interest rate delayed by one period, but there is a positive relationship in the second lag. For further examination, the analysis delves deeper into the dynamics by employing the impulse response function and variance decomposition.

Table 8: Short-run dynamics

Variables	Lag 1	Lag 2	Lag 3
ΔLn(P/R)	-0.045(0.1349)	-0.188(0.133)	-0.297(0.1305)*
$\Delta Real\ interest\ rate$	-1.553(0.7631)*	2.730(0.760)***	-0.876(0.6559)
$\Delta Lnpopulation$	-1.847(2.7325)	2.516(3.375)	-2.386(2.7812)
$\Delta Lndisposable\ income$	0.608(0.6858)	1.034(0.813)	0.231(0.5727)
ΔDebt-to-income ratio	0.022(0.0755)	0.091(0.0984)	0.016(0.0702)

*Notes: The corresponding standard errors are in brackets. The significance levels are denoted by ***, **, and *, representing the 1%, 5%, and 10% levels, respectively.*

5.3.3 Impulse response function

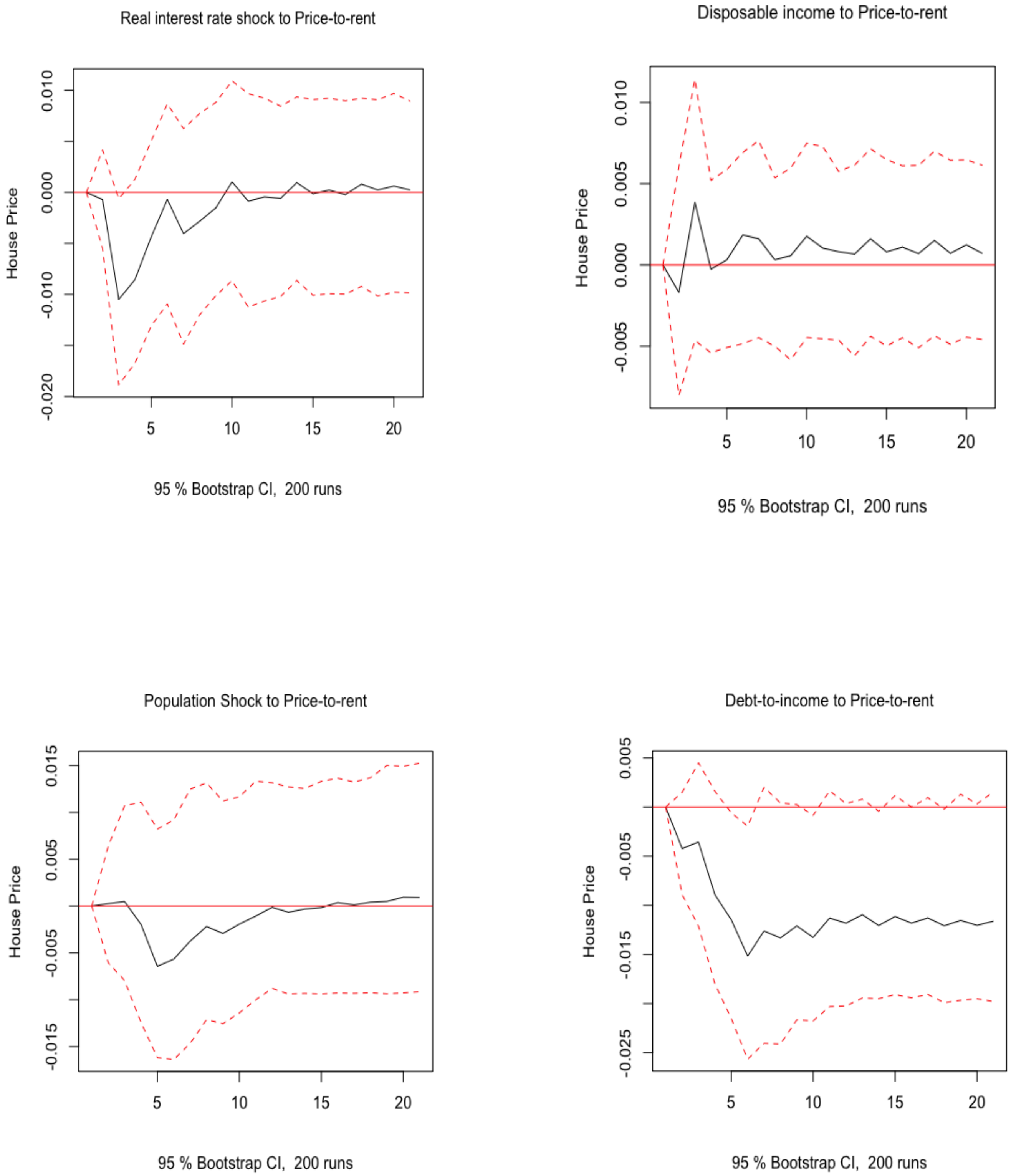
In a VAR model, the impulse response function illustrates how the dependent variable in the system respond to a shock in each of the variables. Therefore, one unit shock is added to the error term for each variable in each equation individually, and the effects on the VAR system over time are captured (Brooks, 2019, p. 423). The IRFs are performed to simulate one standard deviation shock in the macroeconomic variables to see the effect on the price-to-rent ratio. We investigate the dynamics of house prices using the price-to-rent ratio over the next 20 periods, corresponding to a period of 5 years. Our orthogonalized IRF is derived from the VECM and is displayed in Figure 2.

In the first panel of Figure 2, we analyze the impact of a shock in the real interest rate on the price-to-rent ratio. The shock occurs around period 1, leading to a rapid decline in the subsequent period. Notably, the observed effect of the shock on the price-to-rent ratio shows a negative impact in period 3. Furthermore, we can see an increase until period 5, followed by a stabilization phase starting around period 10, which eventually converges back towards zero. However, as market forces act to restore equilibrium, a shock to the real interest rate leads to an endogenous price adjustment. Therefore, the effect of the shock on the price-to-rent ratio can either increase or decrease by this price adjustment. From the figure, we can observe that the effect is nearly zero, indicating that the house and rental prices tend to move in the same direction in response to a shock in the real interest rate.

When examining the response of the price-to-rent ratio to a shock in disposable income, we find that our dependent variable initially experiences a negative effect in the first two quarters, although the magnitude of this effect is very low. However, in the third period, we can see a positive effect, indicating that an increase in disposable income on the price-to-rent ratio is 0.005%, which is also close to zero. One explanation for this can be the differential adjustment between house and rental prices in response to a shock in disposable income. Rental prices may adjust more quickly compared to house prices to a shock of disposable income, resulting in a smaller overall impact on the price-to-rent ratio. Despite the small effect, the impact remains positive, albeit close to zero, suggesting a short-run and relatively minimal influence on our dependent variable. Thirdly, we observe that a shock in population starts to have an effect in the third period, resulting in a negative effect on the price-to-rent ratio. The effect is relatively negligible, at approximately 0.006%. However, it is consistent with the sign identified in our previous findings.

Lastly, we analyze the effect of a shock in the debt-to-income ratio on the price-to-rent ratio. In the final panel, we can see a sharp response to the shock from periods 1 to 6 of roughly -0.015%. While the statistical significance is marginal, the impulse response function demonstrates a more prominent effect than the preceding two variables, despite having the opposite sign. This negative effect persists over time and gradually becomes permanent. This negative effect can be due to a decline in purchasing power and its implications for housing affordability. Individuals` housing affordability decreases as the debt-to-income ratio increases, reflecting a higher debt burden in relation to income. As a result, the demand for housing declines, leading to a fall in housing prices, while rental prices may be less strongly affected by the debt-to-income ratio. Thus, the price-to-rent ratio experiences a decline as housing prices decrease more compared to rental prices.

Figure 2: Impulse response function



5.3.4 Variance decomposition

In order to further investigate our model, we will conduct a variance decomposition, which is also based on VECM. The result from the variance decomposition analysis will be beneficial as it helps us to explain how much of the variability in the price-to-rent ratio is explained by each macroeconomic variable. Furthermore, it enables us to determine how much of the variation in the dependent variable is caused by their own shock, as well as how much is due to shocks from other variables. (Brook, 2019, p. 424). Table 9 provides the results of the variance decomposition. The analysis reveals that the price-to-rent ratio´s variability is primarily driven by its own shock, which accounts for 100% to 87.52% across the 20 periods examined. From periods 1 to 5, it is evident that a shock in the real interest rate explains a small portion of the variability in the price-to-rent ratio, contributing up to 2.86% of the variation. However, as time proceeds, the impact of this shock gradually fades, indicating a weaker long-run effect. Furthermore, it is observed that a shock in population also has a stronger effect in the short-run before gradually diminishing and accounts for up to 0,82% of the variation of price-to-rent ratio. However, it exhibits the weakest effect on the variation compared to the other variables. Conversely, the analysis shows that the debt-to-income ratio and disposable income progressively account for a larger share of the variation in the price-to-rent ratio as the time period extends.

Table 9: Variance decomposition

Period	Price-to-rent ratio	Real rate	Population	Debt-to-income	Disposable income
1	1.000	0.000	0.000	0.000	0.000
2	0.9884	0.000	0.000	0.0077	0.0037
3	0.9633	0.0251	0.000	0.0073	0.0040
4	0.9465	0.0286	0.0007	0.0191	0.0049
5	0.9315	0.0229	0.0059	0.0315	0.0079
6	0.9119	0.0184	0.0081	0.0493	0.0120
7	0.9029	0.0162	0.0082	0.0568	0.0156
8	0.8936	0.0146	0.0078	0.0657	0.0180
9	0.8881	0.0134	0.0077	0.0707	0.0199

10	0.8818	0.0127	0.0073	0.0768	0.0211
11	0.8800	0.0118	0.0069	0.0794	0.0217
12	0.8777	0.0111	0.0065	0.0828	0.0216
13	0.8773	0.0105	0.0061	0.0845	0.0213
14	0.8761	0.0100	0.0057	0.0872	0.0207
15	0.8763	0.0094	0.0054	0.0885	0.0201
16	0.8757	0.0090	0.0052	0.0906	0.0193
17	0.8760	0.0086	0.0049	0.0918	0.0185
18	0.8754	0.0082	0.0047	0.0937	0.0177
19	0.8756	0.0078	0.0045	0.0949	0.0170
20	0.8752	0.0075	0.0043	0.0965	0.0163

5.3.5 Diagnostic test for VECM

In our diagnostic tests for the VECM, we employed three tests: the Portmanteau test for serial correlation, the ARCH-test for heteroscedasticity, and Jarque-Bera for normality. These tests were conducted using 4 lags, and the results are presented in Table 10. The results of the serial correlation tests show that the p-value is lower than the 5% significance level, leading us to reject the null hypothesis of no serial correlation. This implies the presence of autocorrelation in the residuals, indicating that the errors are not random. Regarding heteroscedasticity, the p-value associated with the test is below the 5% significance level. Therefore, we fail to reject the null hypothesis of no conditional heteroscedasticity. This suggests that the variance of the error is not constant over time. Lastly, the normality test for the residuals yields a very small p-value. Based on the results, we reject the null hypothesis and conclude that the residuals are not normally distributed.

Table 10: Diagnostics of VECM

Test	P-Value	H0	Conclusion
Portmanteau	2.981E-05	No serial correlation	Reject H0
ARCH	0.3167	No conditional heteroscedasticity	Fail to reject H0
Jarque-Bera	1.9212E-11	Normally distributed	Reject H0

6. Conclusion

Over the past decades, housing prices in Oslo have risen substantially and are approaching historic levels. However, there were downturns observed during the financial crisis and again in 2017-2018, which can be attributed to the delayed effect of the oil crisis in 2015. However, in the last ten years, house prices in Oslo have experienced an appreciation of 90%, surpassing the 47% increase observed in rental prices. This thesis aimed to understand the long-run relationship between macroeconomic variables and house prices in the Oslo housing market, with the price-to-rent ratio as the dependent variable from 2004 to 2022, measured quarterly. To determine whether cointegrated relationships exist between the price-to-rent ratio and the macroeconomic variables and to identify which of the macroeconomic variables has the most significant impact on the long-run dynamics of housing prices in Oslo, a Vector error-correction model and the Johansen cointegration test were applied.

At first, we examined three different regression models to determine the most suitable model for explaining the price-to-rent ratio in the Oslo housing market. Based on our analysis, we concluded that Model 3 provides the most appropriate representation. We obtained acceptable explanatory power with coefficients that were statistically significant. Therefore, we proceeded to construct our Vector error-correction model (VECM) based on Model 3, incorporating the independent variables real interest rate, population, debt-to-income ratio, and disposable income. Importantly, we find that the unemployment rate is insignificant in explaining the price-to-rent ratio of the Oslo housing market.

Based on our analysis, we find evidence indicating the existence of a cointegrated relationship between the macroeconomic variables and the price-to-rent ratio in the long-run. The estimated VECM shows an evident long-run relationship between the real interest rate, population, debt-to-income ratio, and disposable income in explaining house prices in Oslo. Furthermore, the results of the cointegrated coefficients in the VECM suggest that the real interest rate is the predominant macroeconomic variable in explaining the price-to-rent ratio in Oslo in the long-run, followed by population and disposable income, although the population has the opposite sign.

The short-run dynamics of house prices in Oslo are also examined through the VECM. The estimated model indicates that the price-to-rent ratio adjusts towards equilibrium with a speed of adjustment of 28,52% per quarter, suggesting a relatively quick correction of any deviation from the long-run equilibrium in the short-run. This implies that changes in the real interest rate, disposable income, and debt-to-income ratio result in a transition to a long-run equilibrium with price-to-rent ratio.

The results of the impulse response function indicate that a shock in the debt-to-income ratio has the most significant effect on the price-to-rent ratio in the short-run. On the other hand, the effect of a shock in the real interest rate, population, and disposable income is negligible and quickly diminishes. These findings suggest the presence of a differential adjustment between house and rental prices in response to a shock in the independent variables. From the variance decomposition, we find that the price-to-rent ratio itself is the primary driver of its variability. The real interest rate and population have a greater effect on the variation in the short-run. Over time, disposable income and debt-to-income have an increasing effect in explaining the variability of the price-to-rent ratio, with the latter having the most significant effect.

6.1 Limitation and further research

Our study has a restricted sample period of 76 observations, which increases the risk of not fully capturing enough of the underlying movements when working with a small sample size. This limitation can affect the reliability of our results. Additionally, the VECM suffers from autocorrelation and heteroscedasticity, but we were able to address them by increasing the lag orders to 9 and 6, respectively. Another limitation of our study is the conversion of our initial monthly data to quarterly data. During this data aggregation process, there is a possibility of losing important patterns or information, which may result in losing valuable insight. Moreover, due to limited data access, we were unable to obtain important variables such as building stock, which could have served as a significant supply and demand factor in the Oslo housing market. Lastly, certain variables were omitted from our VECM that could have potentially affected the model and enhanced its performance. These limitations should be carefully considered when interpreting our findings.

To further investigate this topic, it would be interesting and beneficial to determine whether the Oslo housing market exhibits indications of being overpriced or underpriced, which could indicate the existence of a housing bubble.

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8. Appendix

Table1.1: VAR lag order selection criteria

lag	AIC	HQ	SC	FPE
1	-41.2805	-40.9029	-40.3319	1.18243e-18
2	-42.5887	-41.8963	-40.8496	3.22984e-19
3	-42.9071	-41.9001	-40.3775	2.41007e-19
4	-43.1698	-41.8481	-39.8497	1.94727e-19