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Direct Residential Real Estate in Oslo, Risk, Return and Comparison to the Equity Markets

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By

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Abstract

This thesis studies the nominal- and risk-adjusted returns from direct residential real estate investments in Oslo, for different dwelling types and areas, and compare with returns offered by OSEFX. We develop a hedonic regression model, to estimate individual home prices for each quarter between 2010 and 2020. We implement costs and compute different return series for each dwelling. We find that neither dwelling type or district in Oslo offers superior average asset returns, independent of cost structure. All dwelling types and districts offer lower variances and superior risk-adjusted asset returns, given a specific cost structure. We conclude that for a short-term horizon, the OSEFX are superior on both average and risk-adjusted returns. The long-term return to equity offers significantly higher average- and risk-adjusted returns.

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Contents

List of Abbreviations

BOU	Bond Ownership Unit
Co-ops	Cooperatives
CR(OX)	Cumulative Return on X
HP	Holding Period
ID	Identification number of a dwelling
LOG-TD	Logarithmic Time Dummy
LTD	Linear Time Dummy
ltv / ltvr	Loan-to-Value / Loan-to-Value Ratio
NaN	Not-a-Number
NCREIF	National Council of Real Estate Investment Fiduciaries
NPI	NCREIF Property Index
OSEFX	Oslo Børs Mutual Fund Index
PSR	Probabilistic Sharpe Ratio
ROA	Return on Asset (Appreciation of Asset)
ROE	Return on Equity
SOA	Samfunnsøkonomisk Analyse
SOU	Standard Occupied Unit
sqm	Square Meters
SR	Sharpe Ratio
StOU	Stock Ownership Unit
TBI	Transaction Based Index (NCREIF)

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α	Parameter for the time dummies
β_x	Parameters for the intercept, the logarithm of size, number of bedrooms and ownership type
γ	Parameter for the district dummies
δ	Parameter for the age dummies
∂	Parameter for the floor-level dummies
ε	Error term, residuals
$\bar{R}$	Sample mean returns
σ	Standard deviation
μ	True population mean
ρ	Skewness related to return series
φ	Kurtosis related to return series
τ	Tax rate
ϑ	Total tax expenses
D	Acquired debt when buying a dwelling
θ	Implicit rent
η	Quarterly living expenses
L	Yearly living expenses
λ	Transaction costs

1 Introduction and motivation

In Norway, 81.8% of the population are homeowners, according to Statistics Norway (2021c). In other wealthy European countries, such as Sweden, Denmark, Germany and Switzerland, these shares amount to 63.6, 60.8, 51.1 and 41.6%, respectively (Eurostat, 2021). According to Eurostat (2021), Norway rank within the top eight European countries based on share of homeownership.
If we look at Oslo alone, 75% of the population are homeowners (Statistics Norway, 2017).

A reason as of why this share is so high in Norway may be the “Norwegian housing model”, a model whose purpose is to facilitate homeownership for Norwegian citizens. Eiendom Norge (n.d.) states that homeownership is an important measure in order for Norway to reach UNs sustainability goals, by arguing that it reduces inequality, increases savings, labour activity and productivity. Cultural aspects, financial stability, and financial safety, together with strong subsidized political regulations have led residential real estate to be, by far, the largest asset and source of savings for Norwegian households (Eiendom Norge, n.d.).

In a recent study, Benedictow et al. (2020, p.12) state that the investment portfolio of Norwegian households to a large extent consists of housing investments. However, the level of investments in financial assets have increased a bit in recent years. They also conduct a comparison between the Norwegian housing market and the OBX (25 most liquid stocks on OSE), and the effect on wealth accumulation. Their findings present superior returns from stock investments compared to housing investments in Norway from 1996 to 2018. They argue that important considerations is the time of investment, as well as the geographical area for where you buy a house or apartment. These findings aroused our curiosity.

The discussion above proves that housing investments are of huge importance for a diverse group of people, and something 90 percent of Norwegians will have to relate to at some point in their lives (Benedictow et al., 2020, p.11). The real estate sector has an enormous impact on the overall macroeconomic state and the financial system, and vice versa. Essential in economic history is the events before, during and after the Global Financial Crisis of 2008, which was primarily triggered by a vulnerable housing market. Furthermore, the price of a property is highly affected by macroeconomic aspects such as the level of interest rates and debt, political regulations in terms of taxes and regulations, immigration and construction activity. These factors explain why the real estate sector is a frequently debated topic in the media, in the political scene, as well as throughout society.

There are frequently publications in the news related to housing returns in Norway. Researchers such as Larsen and Weum (2008), Delfim and Hoesli (2019) and Hill and Melser (2019) have done thorough work related to returns to homeownership. Many of these publications have conducted systematic research on the costs associated with homeownership and subsequently the returns to homeownership *net of costs*. However, we lack findings on the returns on equity (ROE), an aspect we find truly unique for this asset class due to the immense debt-to-equity ratios representing real estate investments in Norway. We believe that ROE is of high interest to private households and a measure that is superior to mutual fund- and stock market returns.

The abovementioned discussion has triggered our curiosity related to investments in residential real estate made by households and individuals, for the purpose of owning their own home. We want to examine if the Norwegian housing model have imposed private households less favourable returns, compared to that of renting and investing in mutual funds. More precisely, the objective of our thesis is:

Do the asset- and equity returns offered by direct, residential real estate investment in Oslo, from households and individuals' perspective, provide superior returns to mutual fund investments, from 2010 to 2020? Do we find the same conclusions regarding the risk-adjusted returns for both asset classes?

2 Theory and literature review

2.1 Literature review

Extensive studies have been made regarding real estate and its characteristics as an investment. We will in the following examine the findings of relevant literature and compare similarities and differences in their methodology to ours.

2.1.1 Findings of related studies

In contrast to our research question Larsen and Weum (2008) tested the efficiency of the housing market in Oslo (2008, p. 511), by applying the concept of informational efficiency testing that is based on the work of Fama (1970). They find clear evidence of time structure in both house price indices and returns in Oslo from 1991 to 2002. First, this implies that there is superior risk-return relationship over other asset classes. Second, there is seasonal patterns of returns, which makes it strategically smart to time the market entering. In relation to our research question, they find that housing assets showed higher appreciation and lower volatility than stocks (2008, p. 510), and further that capital gains from housing assets amounted to 12% per year. They argue that this relationship seems to be inconsistent with the idea that risk-return relationships apply across asset classes (2008, p. 514).

Delfim and Hoesli (2019) studies the role of real estate in mixed asset portfolios, using US data. They state that, based on the conclusion by Pagliari (2017), "low-risk investors would prefer direct real estate, while high-risk investors should focus on listed real estate due to leverage" (2019, p. 4). Regarding transaction costs for direct real estate, as reported by Steverman (2014), they find these to make up 6% for "round-trip" transactions (Delfim & Hoesli, 2019, p. 9). Regarding returns for stocks and real estate, the authors report geometric mean of 2.38% and standard deviation of 7.66% for U.S. stock returns (U.S. MSCI), and transactions-based mean return of 1.91 % and volatility of 4.43% for direct real estate (2019, p. 11). The calculations for real estate are based on data on NCREIF TBI and NPI indices.

Hill and Melser (2019) studies the risk, return and diversification characteristics of residential real estate investments in Sydney, Australia, from 2002 to 2016. They find that the average return to housing is significantly higher than for shares, and that different risk characteristics leads to superior risk-adjusted return for houses, as measured by the Sharpe ratio (2018, p. 113). Besides the interesting findings by Hill and Melser (2019) and their research method, we believe there is yet to be studied another side of returns and performance of housing that is crucial in describing real implications of the price appreciation and return dynamics in housing. This includes the extensive use of debt financing, or *leverage,* in such investments as opposed to other investments, which seriously shifts both risk and return for investors.

2.1.2 Differences and similarities in methodology

Larsen and Weum (2008) argue that "testing for efficiency requires three separate operations: the establishment of a price index; the establishment of a series of housing returns; and scrutiny of how the series behave" (Larsen & Weum, 2008, p. 511). We will incorporate step one and two into our methodology and perform hypothesis testing. To establish a price index, Larsen and Weum uses the Case-Shiller methodology for constructing a house price index (2008, p. 511). In contrast to our methodology, they use the repeated-sales regression method. Our econometric model is more comprehensive, in terms of more explanatory variables. Larsen and Weum (2008) uses the logarithm of realized prices as the dependent variable, while the right-hand side consist of "three additive terms: a city-wide price level, which shall be our index, a Gaussian random walk, and a classical noise term originating in the usual market imperfections" (Larsen & Weum, 2008, p. 511). Furthermore, they define the returns to housing as capital gains plus housing dividends (implicit rents), less interest payments, which in essence is the same way we think when constructing total returns. They use a data set like ours, with quarterly transactions related to dwelling sales in Oslo from 1991 to 2002. They also use the OSEAX index as a benchmark for stock market returns. OSEAX is broader than OSEFX, which we use, in terms of stocks included, and there is no limit to the weight of each constituent in OSEAX, whereas this limit is maximum 10% in OSEFX. However, in contrast, they only use transactions retrieved from OBOS, hence only focusing on cooperatives in their analysis. Our data set includes more characteristics and variables related to each transaction, compared to the data used by Larsen and Weum.

Hill and Melser (2019) constructs a hedonic price model to estimate prices, which in turn is used to calculate series of returns and to study risk-adjusted performance. They "estimate a hedonic generalized additive model (GAM) with smoothing spline effects for each of the variables in terms of how they change over time and space" (Hill & Melser, 2019, p. 122). This model allows the effect of the independent variables on price to be both non-linear and evolve over time and space, making it a more comprehensive model than our time-dummy hedonic model. The data they have used is perceived as similar to the one we use, however, different in terms of weight given to geospatial characteristics and sample size (611,304 observations). Their sample period is also larger, going from 2002 to 2016. Like our data set, theirs also consists of different characteristics related to each transaction and dwelling, allowing them to make use of their more comprehensive hedonic price model. In addition, we will refrain from the same authors analysis of diversification to different choices of portfolio size on both housing and stock investments.

2.2 Investing in real estate

There exist numerous ways of getting exposure to the real estate market. A natural first distinction would be to determine whether to invest directly or indirectly in real estate. Direct real estate investment would imply full ownership to the property and right to use it physically, as well as incurring the costs of owning the real estate directly. Indirect investment could be through an intermediary, listed equities, a fund or syndicate, or other investment vehicles. It typically requires less action, maintenance, and administration by the investor. We focus on direct investments.

We can divide real estate into four main categories: land, commercial, industrial, and residential properties (Corporate Finance Institute, n.d.). They all serve different purposes and comes with different degrees of utility to the investor. Most research on returns and portfolio allocation in real estate is studied from a professional investor's perspective, which typically will overlap several of the categories mentioned above. We narrow our scope down to residential real estate to private investors and households.

Within the category of residential real estate, we find different housing types and structures, ownership possibilities and tax implicational forms of ownership. In section 3.1.1 we will go into detail on the two former groups and justify limitations to our analysis. The Norwegian Tax Administration (2021a; 2021b) draws a separation between primary housing, secondary housing, and recreational homes. We will only refer to primary housing and exclude the two other groups, hence we proceed by focusing on direct, residential real estate investments to private investors and households.

2.3 Returns to real estate investments

The basic method to compute returns from period $t-1$ to t for any asset i, is to compute asset appreciation between $t-1$ and t and divide this by the initial price of asset i, at time $t-1$, hence, the returns, $r_{i,t}$, on asset i at time t, is

$$r_{i,t} = \frac{p_{i,t} - p_{i,t-1}}{p_{i,t-1}} = \frac{Asset\ gain_{t,t-1}}{Initial\ investment_{t-1}} \tag{1}$$

where, $p_{i,t}$ is simply the price of asset i at time t. This method will be our cornerstone to compute different time series of returns, for different stratums.

2.4 Sharpe ratio

To elaborate and compare the risk-adjusted returns to homeownership versus mutual fund investments, we will use the (ex post) Sharpe ratio (SR), which "efficiently summarizes the attractiveness of an investment in one single measure" (Sharpe, 1963), as cited in Hill and Melser (2019, p. 135). A higher ratio simply implies higher risk-adjusted return. It is a widely used measure to calculate risk-adjusted returns and evaluate performance of portfolios (Bailey & Lopez de Prado, 2012). Eq. 2 shows how to compute the Sharpe ratio for asset i,

$$Sharpe\ ratio = \frac{Excess\ returns}{Riskiness\ of\ returns} = \frac{r_i - r_f}{\sigma_i} \quad (2)$$

where r_i is the average return on asset i, r_f is the risk-free rate[1], and σ_i is the standard deviation of the returns, r_i.

A significant amount of research has focused on the Sharpe ratio, its strengths, and shortcomings. One of the issues frequently discussed is how to perform meaningful inference testing and comparison analysis. A usual concern emerges from the consensus on how returns from especially the stock market could be considered non-normally distributed, with negative skewness, and positive excess kurtosis. This in turn could affect the calculation and estimation errors of the Sharpe ratio (Bailey & Lopez de Prado, 2012). Research by Bailey and Lopez de Prado (2012) suggests a "new uncertainty-adjusted investment skill metric" called *Probabilistic Sharpe Ratio* (PSR), to be applied when dealing with returns assumed to be non-normally distributed. This concept can be employed to test the statistical significance of reported Sharpe ratios and show how maximizing the traditional metric could be suboptimal if sample length is small.

2.5 Tax implications

In principle, asset gains from housing investments are subject to taxes as many other asset classes. However, when looking at primary housing, there exists multiple tax exempts. The most important one states that asset gains from housing investments is exempt all taxes, if you have owned the dwelling for at least 12 months and lived in it 12 out of the last 24 months (The Norwegian Tax Administration, n.d.-e). As we, for most computations, rely on a holding period (HP) of 11 years, most of our return calculations is exempt taxes. When gains on housing investments is taxable, its taxed at the same rate as capital income (The Norwegian Tax Administration, n.d.-d). These rates vary from year to year, as presented in Table 6.

[1] We use an average annual bank deposit rate in the Norwegian market, available to private households, from Statistics Norway (2021a).

2.6 Financing aspects

Something that is truly unique to personal investments in housing is the immense loan-to-value (ltv) ratios. In 2015, the Ministry of Finance imposed severe regulation on Norwegian banks in relation to mortgage distributions to Norwegian citizens, due to very high debt levels. Among the regulations is a maximum debt-to-income ratio of 500% and a ltv-ratio of 85% (Ministry of Finance, 2021). Because the housing market in Oslo has experienced such high appreciation the past decade (Krogsveen, n.d.-b) and the favourable tax implications as mentioned in section 2.5, this feature of housing investments has led to immense ROE for Norwegian homeowners.

The same pattern is not found when studying personal investments in the stock market. Cint conducts a survey on behalf of Nordnet AB (2015) and find that only 0.6% of the Norwegian population leverage their stock and fund investments through a loan, where the stocks and funds are provided as collateral. Thus, we will focus on unlevered fund performance throughout our thesis, considering the prevalent conditions above.

3 Data description

In this section we will explain the process of collecting and adjusting our data to make robust models, analysis, and conclusions.

3.1 Data from Eiendomsverdi AS

We receive data on all real estate transactions in Oslo from 2010 to 2020 from Eiendomsverdi AS*,* Norway's largest provider and collector of real estate data and statistics, as can be seen on their website (https://eiendomsverdi.no). They provide data to Norwegian banks for the purpose of distribution of mortgages, they help real estate brokers and developers for the purpose of valuation of properties and land, and they provide statistics for Eiendom Norge*,* who, on a monthly basis, reports developments in the Norwegian real estate market. For each unique dwelling we were given statistics on dwelling identification (ID) number, sales date, district, sales price (final), acquired debt, asking price, form of ownership, year of construction, size of dwelling, floor level, number of bedrooms, and dwelling type.

3.1.1 Elaboration on dependent and independent variables

Our initial data set retrieved from Eiendomsverdi AS contained partial non-responses related to some of the explanatory variables. To avoid arbitrary choices, we have chosen a rather strict line when it comes to the cleaning process, somewhat similar to Takle (2012). In what follows we will go through the different variables in our data set from Eiendomsverdi AS, as well as limitations we made to each variable and the scope of these limitations.

The *dwelling ID number* is an identification number representing each unique dwelling. The raw data set from Eiendomsverdi AS contained data on 209,708 transactions, whereas 127,387 represented unique dwellings.

The *sales date* represents the time of registered sale of a dwelling. Our data set contains sales dates from Jan. 2nd, 2010, to Dec. 30th, 2020.

Our research area Oslo consists of 17 different *districts*, as represented in Fig. 1.

Fig. 1 *Overview of all districts in Oslo*[2]

The raw data set contain data on 18 different districts, as one observation is labelled with district "NULL" and represent a clear error. We remove this observation, and we are left with 209,707 transactions, of which 127,386 represent unique dwellings. Furthermore, to see if there is any dispersion in returns between districts, we separate the apartments into five broader districts, in line with Oslo kommune (n.d.), as presented in Table 1.

Table 1 *Separation of districts in Oslo into broader districts, in accordance with Oslo kommune (n.d.)*

Division	**Inner East**	**Inner West**	**Outer East**	**Outer West**	**Outer South**
Districts	Gamle Oslo Grünerløkka Sagene	St.Hanshaugen Frogner Sentrum	Bjerke Grorud Stovner Alna	Ullern Vestre Aker Nordre Aker	Østensjø Nordstrand Søndre Nordstrand

The *sales price (final)* is defined as the total price the buyer of a dwelling must pay less acquired debt, hence,

$$p_{i,t} = p_{i,t}^{TOT} - D_{i,t} \tag{3}$$

[2] From Oslo kommune, Plan- og bygningsetaten (2017)

where, $p_{i,t}$ is the final sales price, $p_{i,t}^{TOT}$ is the total price and $D_{i,t}$ is the acquired debt of dwelling i in period t. In our data set, some observations related to this variable are incomplete, and reported as Not-a-Number (NaN)-values. Out of 209,707 transactions, we remove 1,266 observations marked as NaN-values in the final sales price.

To remove other possible errors, we set limit values to a dwelling turnover in accordance with Takle (2012, p. 9). A dwelling turnover, $p_{i,t}^{TOT}$, is represented by its final sales price plus acquired debt, as presented in Eq. 3. Prior to 2005 Statistics Norway operated with a minimum dwelling turnover of 150,000 NOK. From 2005 to 2012 this level was 250,000 NOK, representing an increase of 67% over those seven years. We find it appropriate to set this value of 500,000 NOK, representing a 100% increase in limit values from 2012. By removing transactions with dwelling turnover less than 500,000 NOK we remove 37 transactions. After making the adjustments to the sales price variable we are left with 208,404 transactions, whereas 127,178 represent unique dwellings.

Acquired debt, $D_{i,t}$ of dwelling i in period t, is the debt that follows the property when you buy it, as presented in Eq. 3.

Asking price is the announcement price of a dwelling when advertised. Based on the adjustments above, our data set now contains 267 transactions with errors related to this variable. We do not use this variable in any of our econometric models and will leave these observations untouched.

In Norway you can own a dwelling through different *forms of ownership*. Below follows a further explanation, in line with Eiendomsrett (n.d.). After the adjustments made so far, 46.1% of the transactions represents “Selveier” [standard occupied unit] (SOU). SOUs represent full ownership of your own unit, and partly, or full, ownership of the building and lot, depending on dwelling type. 47.6% of the transactions represents “Borettslag” [cooperatives] (co-ops). Through co-ops you own a share of the housing cooperative, with a right to use your own apartment. 6.3% of the transactions represents “Aksjeleilighet” [stock ownership unit] (StOU). StOUs are like co-ops, the only difference being the fact that you own a share of the housing company, not a share in the cooperative. One transaction relates to an unknown ownership type, while two transactions relate to "Obligasjonsleilighet" [bond ownership unit] (BOU). BOUs is no longer a valid form of ownership in Norway (Anderssen, 2020).

We observe that many StOUs has different characteristics (bedrooms, floor level, etc.), but the same ID number. Thus, we delete the transactions related to StOUs, as we need to distinguish between ID numbers for our econometric model. We remove 13,110 transactions and we are left with 195,294 transactions, where 126,658 represents unique dwellings. We observe that out of 13,110 observations, only 520 represents unique IDs, confirming that many of the StOUs represented the same ID number. Out of the remaining transactions, we remove two transactions representing BOUs and one observation characterized as "unknown". We are then left with 195,291 transactions, where 126,656 represents unique dwellings. The fact that we are now left with only co-ops and SOUs, is in line with Takle (2012).

The *year of construction* is simply the construction year of the dwelling. According to Eurostat (2012, p. 39) this is "one of the most important price determining quality attributes". 629 transactions contain NaN-values in this variable, and 41 transactions had a construction year of «zero». After removing the abovementioned errors, we are left with 194,621 transactions, where 126,449 represents unique dwellings. We categorize the year of construction-variable into four age intervals, like Takle (2012, p. 24), where each $Age\ Interval_x$ is defined as,

$$Age\ Interval_x = \ 2020 - Age_i \tag{4}$$

and represent the age interval according to Table 2, for $x = 1, 2, 3, 4$. Age_i is the year of construction for dwelling i.

Table 2 *Age intervals of dwellings, in accordance with Takle (2012, p. 24)*

Variable	$\boldsymbol{Age\ I._{1}}$	$\boldsymbol{Age\ I._{2}}$	$\boldsymbol{Age\ I._{3}}$	$\boldsymbol{Age\ I._{4}}$
Interval	$< 10\ Y.$	$10 - 19\ Y.$	$20 - 34\ Y.$	$> 35\ Y.$

In Norway there exists multiple *dwelling types*, the most common ones being *houses* and *apartments* (Statistics Norway, 2021b). According to housing data service Virdi (2020), houses are simply detached, freestanding houses. Two-family houses, also called semi-detached houses, consists of two apartments in one freestanding house, either vertically or horizontally divided. Terraced houses are houses attached horizontally in a chain with other houses. We label semi-detached houses and terraced houses together as *small houses,* in line with Takle (2012, p. 8), and proceed with three dwelling types, namely apartments, houses, and small houses.

The *size of a dwelling* is usually defined as "PROM" [size in square meters (sqm) of the total living area], hereafter defined as *size* (Meglersmart, n.d.-b). Size is a very important measure as it is widely used for computing average sqm. prices for comparison reasons, for computation of taxable value of a dwelling, and lastly, a very important explanatory variable for all our econometric models. We remove 538 transactions containing NaN-values in the size variable. Table 3 shows the limit sqm. size for each dwelling type, in line with Takle (2012, p. 9), as well as the number of observations removed due to exceeding these limits.

Table 3 *Sqm. limit values of dwelling types, in accordance with Takle (2012, p. 9)*

Dwelling type	Min. sqm	Max. sqm	# of obs.
Apartments	15	250	239
Houses	50	500	197
Small houses	40	350	137

The abovementioned adjustments to the size variable leave us with 193,510 transactions, where 125,537 represents unique dwellings.

We remove *floor levels* greater than floor 15, as this only represents 61 transactions, and 40 unique dwellings. By looking at these 61 transactions we observed suspicious values to at least one of the relevant explanatory variables. Second, in order for us to make use of our hedonic model related to apartments, we remove 12,691 transactions containing NaN-values in the floor level variable related to apartments. 10 of the apartment transactions were represented by floor level “zero”, something we suspect is an error. Our data set now contains 180,748 transactions, where 120,075 represents unique dwellings.

We remove 10,149 transactions containing NaN-values in the *number of bedrooms* variable. As we are looking at returns to homeownership for private investors in primary residences, we set an upper limit to number of bedrooms to six. Based on our data set we observe that properties with more than six bedrooms are rare. Furthermore, these properties are often used for rental purposes, therefore representing secondary and special residences which is outside the scope of this research. Since Hill and Melser (2019, p. 119) removes dwellings with more than seven bedrooms, we find this to be a reasonable adjustment. We remove 194 transactions related to dwellings with more than six bedrooms.

3.1.2 Summary statistics – Eiendomsverdi AS

After the cleaning process we are now left with 170,405 transactions, a reduction of 18,74% (39,303) of the transactions from the initial data set. 114,406 represents unique dwellings, a reduction of 10.19% (12,981) unique dwellings from the initial data set.

Table 4 displays some summary statistics from our cleaned data set from Eiendomsverdi AS, and divides the sample by dwelling type, year, and the districts from Fig. 1. We can see that apartments comprises the larger part of dwelling types in the data, in line with Benedictow and Gran (2020). This structure has the smallest mean size, lowest mean price, but the highest prices per sqm., in line with our expectations and the typical dynamics of price and size relationships. The region with the most transactions is Grünerløkka, and the highest prices per sqm. are found in Frogner, Sentrum and St. Hanshaugen. During the period, the sqm. prices per year with all structures together, have almost doubled. These figures of sqm. prices are, not surprisingly, very similar to those reported by Oslo kommune (2020) in their price statistics. In sum, we spot few surprises in the summary statistics.

Table 4 *Summary statistics of cleaned data set from Eiendomsverdi AS*

			Apartments		Price (NOK)		Size (sqm)		Total Price / Size		Bedrooms	
By	**Group**	**# of obs.**	**Mean**	**Std**	**Mean**	**Std**	**Mean**	**Std**	**Mean**	**Std**	**Mean**	**Std**
Structure	Houses	7,595	0	0	9,305,161	4,731,152	191	61	49,348	19,266	3.78	0.97
	Apartments	148,976	1	0	3,655,512	1,948,377	66	24	58,789	20,180	1.79	0.76
	Small houses	13,834	0	0	6,338,986	3,125,825	133	40	48,211	17,345	3.26	0.77
Years	2010	13,823	0.878	0.328	2,703,675	1,746,026	77	42	37,868	10,099	1.96	0.94
	2011	14,918	0.870	0.336	3,031,587	1,927,790	77	42	42,245	11,607	1.98	0.96
	2012	14,781	0.871	0.335	3,330,906	2,023,120	78	42	45,946	12,366	1.99	0.94
	2013	14,596	0.863	0.344	3,427,407	2,031,390	78	42	47,675	12,960	2.00	0.96
	2014	14,920	0.875	0.331	3,472,717	2,036,716	77	40	48,746	12,816	1.99	0.94
	2015	16,197	0.875	0.330	3,914,465	2,239,685	77	42	54,759	14,236	1.99	0.95
	2016	14,958	0.877	0.328	4,517,460	2,489,277	77	42	63,649	17,608	2.00	0.96
	2017	14,526	0.874	0.332	4,916,454	2,727,869	77	42	68,579	18,143	2.02	0.96
	2018	15,681	0.875	0.331	4,899,037	2,838,797	77	41	68,049	18,497	2.02	0.96
	2019	17,359	0.873	0.333	5,155,476	3,093,098	78	42	71,208	19,127	2.02	0.95
	2020	18,646	0.883	0.321	5,393,720	3,124,426	77	41	75,386	20,490	2.01	0.95
Districts	Alna	11,715	0.870	0.336	2,818,571	1,211,824	76	31	41,255	12,508	2.04	0.93
	Bjerke	7,351	0.859	0.348	3,533,227	1,812,157	76	34	49,601	15,282	2.21	0.86
	Frogner	17,711	0.982	0.135	5,481,143	3,180,165	79	41	72,193	20,768	1.87	0.82
	Gamle Oslo	17,538	0.982	0.134	3,322,254	1,690,545	61	20	61,124	18,940	1.71	0.75
	Grorud	5,572	0.853	0.354	2,753,616	1,335,314	79	35	38,968	11,670	2.17	0.87
	Grünerløkka	21,468	0.990	0.101	3,480,486	1,540,957	59	20	63,684	18,330	1.63	0.72
	Marka	59	0.000	0.000	8,259,237	3,370,517	181	72	46,948	13,483	3.53	1.28
	Nordre Aker	8,420	0.736	0.441	5,602,062	3,497,804	91	52	63,469	17,623	2.27	1.10
	Nordstrand	10,648	0.696	0.460	4,933,480	3,347,887	97	57	51,612	14,924	2.35	1.06

	Group	# of obs.	Apartments		Price (NOK)		Size (sqm)		Total Price / Size		Bedrooms	
			Mean	**Std**	**Mean**	**Std**	**Mean**	**Std**	**Mean**	**Std**	**Mean**	**Std**
	Sagene	17,616	0.997	0.052	3,588,323	1,529,788	58	19	65,616	18,825	1.57	0.69
	Sentrum	303	1.000	0.000	3,123,362	1,264,407	46	19	72,833	19,445	1.17	0.45
	St. Hanshaugen	12,180	0.994	0.080	4,152,467	1,932,796	66	26	67,577	19,047	1.73	0.74
	Stovner	5,149	0.678	0.467	3,172,340	1,434,489	98	42	34,937	9,790	2.48	1.08
	Søndre Nordstrand	6,397	0.564	0.496	3,186,786	1,352,453	99	42	35,058	9,706	2.60	1.04
	Ullern	7,233	0.770	0.421	6,110,359	3,372,960	104	55	61,947	17,533	2.42	1.07
	Vestre Aker	8,553	0.636	0.481	6,863,111	4,346,999	123	68	57,202	16,350	2.74	1.16
	Østensjø	12,492	0.814	0.389	3,523,269	1,839,219	79	36	47,060	12,440	2.12	0.87
Total		170,405	0.874	0.332	4,125,171	2,626,049	77	42	57,510	20,209	2.00	0.95

3.2 Data from Oslo Børs

We download time series of prices of the Oslo Børs Mutual Fund Index (OSEFX) from Euronext (2021). We choose the OSEFX index for two reasons. First, we believe the index work as a representative and alternative investment opportunity in contrast to real estate to private investors and households. Second, the index comprises a generalized method of capturing returns from what is commonly known as "investing in the stock market" in Norway, as it is focused on the Norwegian market. It is used as a benchmark by many Norwegian mutual funds, as can be seen on e.g., Morningstar's website (https://www.morningstar.no/).

In line with the length of our data set on real estate transactions from Eiendomsverdi AS, we adjust the date range of the data from year start 2010 to year end 2020, with quarterly intervals, thus reducing the number of observations from 5,325 to 44. The index is adjusted for dividend payments.

3.3 Other data

3.3.1 Rental price data

The returns to homeownership ought to include the avoided cost of renting, or the *implicit rent* which is another term used by e.g., Larsen and Weum (2008). We import monthly data of rental market prices in the period 2010 to 2020 from Oslo kommune (2021). The prices are given for different dwelling sizes, in terms of number of rooms. Originally, there are 725 observations for five different city districts, but we use the average of these five as a measure for Oslo in total. The data provides average monthly prices per year from 2010 to 2014, and monthly prices per quarter for the span between 2015 and year-end 2020. Where there are missing observations per quarter, we will assume the yearly average to be a proxy for those quarters. For all prices that are given monthly we multiply by three to obtain quarterly figures. Table 5 provide summary statistics of the quarterly rental prices.

***Table 5** Summary statistics of quarterly rental prices (NOK) in Oslo, based on data set from Oslo Kommune (2021).*

Year	#obs.	1 room	2 rooms	3 rooms	4 rooms	5+ rooms
2010	4	20,521	27,498	34,480	44,749	52,708
2011	4	21,225	28,827	36,693	47,117	57,934
2012	4	23,053	30,342	38,582	49,603	60,375
2013	4	23,822	31,522	40,253	51,487	61,319
2014	4	23,887	32,296	41,116	50,980	61,080
2015	4	25,454	33,830	42,376	52,951	62,958
2016	4	27,011	35,662	44,456	56,688	65,698
2017	4	28,360	36,917	45,507	56,853	66,271
2018	4	28,464	37,564	46,418	58,434	67,153
2019	4	29,308	37,965	46,205	58,318	69,155
2020	4	29,583	38,243	47,322	59,636	68,745
Total	44	25,517	33,697	42,128	53,347	63,036

3.3.2 Living expenses

On behalf of Huseierne, Samfunnsøkonomisk Analyse (SOA) have annually developed a report presenting a housing cost index for houses and apartments in Oslo (Benedictow & Gran, 2020). This cost index includes costs related to real estate taxes, regional fees, electricity use, interest expenses, insurances related to the dwelling type, and maintenance costs. They incorporate the best possible estimates for each cost component, considering changes in laws and regulations during the sample period. They give a thorough explanation as of what is included in the different cost elements. They sum up the average of all cost elements for both dwelling types and incorporate this into a single measure for living expenses, for both apartments and houses in Oslo, for each year.

We get data on yearly living expenses in Oslo based on a reference 70 sqm. apartment from SOA through Benedictow and Gran (2020), and for a 120 sqm. house from Huseierne, through Gyldenskog, K., via e-mail correspondence on the 31st of May 2021. These cost estimates are presented in Table 6, as absolute numbers.

3.3.3 Tax rates

We retrieve the yearly tax rates from The Norwegian Tax Administration (n.d.-a) and assign the correct tax rate to each observation based on the quarter and year of observation. The tax rates are presented in Table 6 below.

3.3.4 Risk-free rates

As an approximation of using an appropriate measure of the risk-free rate available to private investors and households, we choose a series of annual average bank deposit rates in the Norwegian market from Statistics Norway (2021a), instead of the more common government bonds and treasury bills, due to private investors unavailability to invest in the latter. The figures are presented as percentages in Table 6.

3.3.5 Loan-to-value ratios

In order to elaborate on the ROE we needed estimates on average ltv-ratios throughout our sample period. For the years 2016 to 2020 we get ltv-ratios from The Financial Supervisory Authority of Norway, through Sørlie, K., via e-mail correspondence on the 27th of April 2021. These rates include collateral and represents ltv-ratios where the purpose is housing investments. For 2015 and 2014 we retrieve data from The Financial Supervisory Authority of Norway (2014; 2016). We could not obtain data for 2010 to 2013, so we decide to use the average of the ltv-ratios for 2014 to 2020 for those years. The rates are presented as percentages in Table 6.

__Table 6__ Summary statistics of yearly cost estimates and expenses

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Yearly living expenses apartments, $L_{Y,a}$	76,734	82,530	83,430	89,095	88,857	83,084	83,769	86,976	91,419	103,712	87,905
Yearly living expenses houses, $L_{Y,h}$	125,463	130,884	134,339	138,418	137,016	129,402	127,842	136,811	146,624	165,266	142,411
Tax rates, τ_t	28%	28%	28%	28%	27%	27%	25%	24%	23%	22%	22%
Risk-free rates, R_t^f	2.09%	2.36%	2.40%	2.26%	2.13%	1.41%	0.85%	0.80%	0.82%	1.02%	0.70%
Ltv-ratios, $ltvr_t$	70%	70%	70%	70%	71%	76%	67%	66%	68%	70%	69%

4 Testable hypotheses

The Oslo housing market has experienced great appreciation the past ten years, with Krogsveen announcing a staggering 100% return to homeowners the past decade (Krogsveen, n.d.-b). Statistics Norway (n.d.) argues that the returns to homeownership has differed depending on dwelling type, with apartments experiencing an increase in value of 78.9% from 2010 to year-end 2019. For smaller houses and houses, the return amounts to 58.2% and 51.0%, respectively. With the dispersion between return to apartments and houses in mind, can we conclude that returns to apartments outperform mutual funds' investments, while returns to houses do not? Do real estate investments outperform mutual funds' investments, independent of dwelling type or is the returns from mutual funds' investments outperforming real estate investments overall? Questions like this indicates that we want to conduct a two-sample one-sided Welch test with the following null- (H_0) and alternative (H_A) hypothesis,

$$H_0: \mu_1 - \mu_2 = 0 \rightarrow \mu_{\bar{R}_1} - \mu_{\bar{R}_2} = 0 \rightarrow \mu_{\bar{R}_1 - \bar{R}_2} = 0$$

$$H_A: \mu_1 - \mu_2 > 0 \rightarrow \mu_{\bar{R}_1} - \mu_{\bar{R}_2} > 0 \rightarrow \mu_{\bar{R}_1 - \bar{R}_2} > 0$$

hence, we want to conclude that the difference in the sample means of real estate returns, $\bar{R}_1$, and OSEFX, $\bar{R}_2$, is statistically significantly greater than zero, i.e., the mean real estate return is greater than the mean mutual fund return. μ_i is a parameter representing the true population mean under the null hypothesis.

The Welch test is a version of the Student t-test. It relaxes on the assumption of homogeneity of variance in the samples, as opposed to the Student t-test (Ahad & Yahaya, 2014, p. 888). As we assume the variances of real estate returns and OSEFX returns are not equal, we find this test appropriate. Ahad and Yahaya (2014, p. 893) find that Welch test seemed robust regardless of the group sizes and group variances, but only under the assumption of a normal distribution in a setting with homogenous variances. The test statistic, t_{stat}, is given as,

$$t_{stat} = \frac{(\bar{R}_1 - \bar{R}_2) - (\mu_1 - \mu_2)}{\sqrt{\frac{\sigma^2_{R_1}}{N_1} - \frac{\sigma^2_{R_2}}{N_2}}} \tag{5}$$

where, $\bar{R}_1$ and $\bar{R}_2$ is the sample means of real estate- and OSEFX returns, respectively. $(\mu_1 - \mu_2)$ is the hypothesized difference in the population means under the null hypothesis. σ_{R_1} and σ_{R_2} is the sample standard deviations of real estate- and OSEFX returns. N_1 and N_2 is the sample size of real estate- and OSEFX returns, respectively (Ahad & Yahaya, 2014, p. 889).

We use a two-sample, F-test to find answers to whether the variance of housing returns ($\sigma^2_{R_1}$) differ significantly from the variance of OSEFX returns ($\sigma^2_{R_2}$). The null hypothesis (H_0) states that the two series of returns come from normal distributions with the same variance, while the alternative hypothesis (H_A) states that they come from normal distributions where returns to real estate offer lower variances than that of OSEFX, hence,

$$H_0: \sigma^2_{R_1} = \sigma^2_{R_2}$$

$$H_A: \sigma^2_{R_1} < \sigma^2_{R_2}$$

The F-statistic is given as,

$$F_{stat} = \frac{\sigma^2_{R_1}}{\sigma^2_{R_2}} \tag{6}$$

Modern portfolio theory, and Markowitz (1952) suggests that investors should focus on maximizing expected return for a given level of risk, i.e., the investor will choose the portfolio with lower risk if the expected return is the same. We build on this assumption when we compare risk-adjusted returns to real estate versus the OSEFX, by comparing the Sharpe ratios offered by the two investments. We test the statistical significance of Sharpe ratios by applying Mertens (2002) approximation of normally distributed Sharpe ratios, referred to in Bailey and de Prado (2012). They find that skewness and kurtosis related to returns does not affect the point estimate of the Sharpe ratio, but it affects its statistical significance, through impact on the standard deviation of the estimated Sharpe ratio, $\hat{\mathfrak{R}}$. This can be observed in Eq. 7,

$$\hat{\sigma}_{\hat{\mathfrak{R}}} = \sqrt{\frac{1}{n-1}\left(1 + \frac{1}{2}\hat{\mathfrak{R}}^2 - \rho\hat{\mathfrak{R}} + \frac{\varphi - 3}{4}\hat{\mathfrak{R}}^2\right)} \tag{7}$$

where, $\hat{\sigma}_{\hat{\mathfrak{R}}}$ is the standard deviation of $\hat{\mathfrak{R}}$, ρ is a measure of the skewness, and φ is a measure of the kurtosis related to the series of returns. One cannot compare Sharpe ratios without considering the estimation errors, and taking the skewness and kurtosis into account. We observe that high positive skewness, ρ, will reduce the standard errors of $\hat{\mathfrak{R}}$, while high positive excess kurtosis[3], φ, will increase the standard deviation. By using $\hat{\sigma}_{\hat{\mathfrak{R}}}$, we are able to provide a de-inflated estimate of the Sharpe ratio, given in probabilistic terms as,

$$\hat{PSR}(SR^*) = Z\left[\frac{(\hat{\mathfrak{R}} - SR^*)}{\hat{\sigma}_{\hat{\mathfrak{R}}}}\right] \tag{8}$$

where $\hat{PSR}(SR^*)$ is the estimated Probabilistic Sharpe Ratio, given the benchmark SR^*. Z is the cumulative distribution function of the standard normal distribution (Bailey & de Prado, 2012, p. 9). We set $SR^* = SR^{OSEFX}$, to compare the Sharpe ratios offered by real estate investments to that of OSEFX. We are then able to test the significance of the estimated Sharpe ratios, $\hat{\mathfrak{R}}$, compared to the benchmark SR^{OSEFX} using a standard Z-test, with

$$Z_{stat} = \frac{(\hat{\mathfrak{R}} - SR^{OSEFX})}{\hat{\sigma}_{\hat{\mathfrak{R}}}} \tag{9}$$

We conduct a one-sided right-tailed test, to see if the estimated Sharpe ratios of real estate returns are equal to that of OSEFX (H_0) or that the Sharpe ratio of real estate returns are greater than that of OSEFX (H_A), hence,

[3] Skewness equal to zero, and kurtosis equal to three represents a normal distribution, hence explaining the expression "excess kurtosis".

$$H_0: \hat{SR} = SR^{OSEFX}$$

$$H_A: \hat{SR} > SR^{OSEFX}$$

The alternative hypotheses for the Welch and Z-test will vary for the return series presented in section 6.3.2, where further explanation will follow. For all tests we use a 5% significance level, thus we reject H_0 if the corresponding $p - value$ is lower than 5%.

5 Methodology

In the following, we will present the methodology used to compute returns to homeownership. First, we present the econometric models we use to compute property prices based on the cleaned data set from Eiendomsverdi AS. Based on this model we compute quarterly asset returns given three different cost structures. Finally, we elaborate on the ROE given the most relevant cost structure for private households. We will construct regression models and in turn indices for apartments, houses, and small houses. Furthermore, we arrange the apartments into five districts, as elaborated in Table 1. From now on, we will refer to these eight models, or property sets, as stratums. «Stratification is nothing else than separating the total sample of houses into a number of sub-samples or strata» (Eurostat, 2013, p. 38). Using stratifications is preferred over "a straightforward application of hedonic regression to the whole data set" (Eurostat, 2013, p. 159)

5.1 Regression analysis

5.1.1 Hedonic regression model

"The hedonic regression method recognizes that heterogeneous goods can be described by their attributes or characteristics" (Eurostat, 2013, p. 50). This method is a preferred method for compiling and computing property price indices for different dwelling types (Eurostat, 2013, p. 158). Hill and Melser (2019) uses this technique to compute returns to homeownership in Sydney. Wass (1992) and Lillegård (1994), cited in Takle (2012, p. 14), confirms that Statistics Norway have been using this method when computing house price indices and returns in Norway since 1992.

As a first step we use the hedonic regression model to compute estimated dwelling prices. The estimated prices are a function of a fixed number of characteristics representing each dwelling. To decide on the optimal regression model, that is which explanatory variables to include and the form of these variables, we will present our approach using the apartment model. This is because apartments represent 87.42% of the observations in our data set, and we observe that the arguments and conclusions regarding apartments are transmittable to the other stratums. However, the explanatory variables in the remaining models will differ slightly based on different evaluations of relevance and attributes in those stratums.

Apartment model

A fully linear time-dummy (LTD) regression model, as inspired by Eurostat, (2013, p. 50) can be represented as follows,

$$\hat{p}_{i,t}^{LTD} = \beta_0 + \beta_1 S_i + \beta_2 B_i + \beta_3 O_i + \beta_4 F_i + \sum_{t=1}^{T} \alpha_t \times D_{i,t} + \cdots \sum_{k=1}^{K} \gamma_k \times D_{i,k} + \sum_{a=1}^{A} \delta_a \times D_{i,a} + \varepsilon_{i,t} \quad (10)$$

where, $\hat{p}_{i,t}^{LTD}$ is the estimated price of apartment i, at time t, using the LTD method. β_0 is the intercept term and represents the overall price level and is held constant throughout the sample period. β_1 is the slope coefficient of the size, S_i. β_2 is the slope coefficient of number of bedrooms, B_i. β_3 is the slope coefficient of the ownership type, O_i, a dummy variable taking the value "0" if apartment i have ownership type SOU, and value "1" if apartment i is of ownership type "co-ops". β_4 is the slope coefficient of the floor level, F_i. α_t is a slope coefficient of the dummy variable $D_{i,t}$, where $D_{i,t}$ will take the values "0" or "1" depending on quarter t, for $t = 1,2, \ldots ,43$. γ_k is the slope coefficient of the dummy variable, $D_{i,k}$, where $D_{i,k}$ will take values "0" or "1", depending on $k = 1,2, \ldots ,16$ districts. δ_a, for $a = 1,2,3$, measures the effect of age on the estimated price, where age intervals are represented by dummy variables $D_{i,a}$. $\varepsilon_{i,t}$ is the error term. We make sure to leave out one dummy variable for each explanatory variable, to prevent perfect multicollinearity.

When running the LTD regression model from Eq. 10 we estimate 4,271,212 apartment prices, one for each quarter of our sample period (44), for 97,073 unique apartments. We discover multiple concerns related to this model. First, 12,985 of the estimated apartment prices are negative. Second, we observe a positive skewness of 2.5991 and an immense kurtosis of 22.0844 related to the distribution of observed (actual) prices, $p_{i,t}$. For the observed sizes, S_i, the same metrics are 1.4735 and 7.4436. Preferably, the skewness and kurtosis ought to be

0 and 3, respectively, representing a normal distributed variable. A histogram displaying these relationships is presented in Appendix 1. Third, from the OLS assumptions we know that the residuals should be normally distributed, with an expected mean of zero, and constant variance (homoskedasticity). However, when looking at the plot of residuals on estimated prices, as presented in Appendix 2 (a), we observe heteroskedasticity in the residuals, i.e., there seems to be a pattern indicating increased residuals when the estimated values increase. This is a problem that often occurs in data sets with a large range of values.

As the size of an apartment is highly relevant in determining the price, we try a log transformation on both the dependent variable, $\hat{p}_{i,t}^{LTD}$, and the explanatory variable, S_i, from the LTD regression model in Eq. 10, in order to solve the abovementioned problems. This transformation will imply that the effect of size on price is non-constant and elastic, in line with Takle (2012, p.16). We get a logarithmic time-dummy (LOG-TD) hedonic regression model,

$$\ln \hat{p}_{i,t}^{LOG-TD} = \beta_0 + \beta_1 \ln S_i + \beta_2 B_i + \beta_3 O_i + \sum_{t=1}^{T} \alpha_t \times D_{i,t} + \sum_{k=1}^{K} \gamma_k \times D_{i,k} + \cdots \sum_{a=1}^{A} \delta_a \times D_{i,a} + \sum_{f=1}^{F} \partial_f \times D_{i,f} + \varepsilon_{i,t} \tag{11}$$

where, $\ln \hat{p}_{i,t}^{LOG-TD}$ is the estimated logarithmic price of dwelling i, in period t. β_1 is the slope coefficient of the logarithm of size, S_i. We also adjust the floor level variable to be a dummy variable instead of a continuous one. ∂_f is the slope coefficient of the dummy variable, $D_{i,f}$, where $D_{i,f}$ will take values "0" or "1", depending on whether $f = 1,2, \ldots, 18$ different floor levels. The other variables and slope coefficients are explained below Eq. 10. Are we able to see improvements in the model related to our concerns from the LTD model?

First, the nature of taking the logarithm assures us that we get solely non-negative price estimates. Second, by looking at Appendix 3 (a) it seems like the logarithm of the observed (actual) prices, $\ln p_{i,t}$, is approximately normally distributed. The skewness and kurtosis related to $\ln p_{i,t}$ is -0.1400 and 4.8007, respectively. This represents a major improvement compared to the distribution of $p_{i,t}$, in terms of normality. Appendix 3 (b) displays the histogram of the logarithm of observed sizes, $\ln S_i$. This variable is also considered more normally distributed, as compared to the simple S_i. The skewness and kurtosis related to $\ln S_i$ is -0.0260 and 3.5968, respectively. Third, by looking at the plot of residuals on estimated logarithm of prices, as presented in Appendix 2 (b), we see that the patterns related to the residuals now look more normally distributed, thus having signs of homoskedasticity.

We look for further improvements in the LOG-TD model from Eq. 11 by first making the bedroom variable a dummy variable. Neither of the bedroom dummies proved to be statistically significant. Second, as we believe the effect of district on the estimated price will vary based on time t, and that the effect of size on the estimated price will vary based on district, we try to include interaction terms between district and time (quarter sold), and district and size. Due to size limitations of our data set, this additional feature proved no statistical significance on most of the interaction terms. We decide to keep the bedroom variable a continuous one and not include any interaction terms. Table 7 presents summary statistics from the hedonic models for apartments, as represented in Eq. 10 and 11.

Table 7 *Fit statistics of hedonic regression models*

	$Eq.X$	$\#obs.$	$\#coeff.$	R^2	$\bar{R}^2$
$\hat{p}_{i,t}^{LTD}$	$Eq.$ 10	148,976	66	0.7956	0.7955
$\hat{p}_{i,t}^{LOG-TD}$	$Eq.$ 11	148,976	83	0.8090	0.8089

A log transformation of price and size improves the R^2 slightly from our initial LTD model (Eq. 10), from 0.7956 to 0.8090. This improvement alone could easily be neglected, however, by using the LOG-TD model (Eq. 11) - we get solely non-negative price estimates, improvement in the assumption of normally distributed residuals, and the variables $\ln p_{i,t}$ and $\ln S_i$, and a better effect of size on estimated prices, hence we stick to the LOG-TD model as presented in Eq. 11.

House model

For the different stratifications we made some adjustments from the LOG-TD model in Eq. 11. For the house model we remove the type of ownership variable, as co-ops represents a very small fraction of the house set. We remove floor level, as this variable contained a lot of NaN-values in the house stratum. By removing this variable, we can use observations containing partial non-responses, thus maximizing the data availability from the house stratum. We use the following LOG-TD model when estimating prices on houses,

$$\ln \hat{p}_{i,t}^{LOG-TD} = \beta_0 + \beta_1 \ln S_i + \beta_2 B_i + \sum_{t=1}^{T} \alpha_t \times D_{i,t} + \sum_{k=1}^{K} \gamma_k \times D_{i,k} + \cdots \sum_{a=1}^{A} \delta_a \times D_{i,a} + \varepsilon_{i,t} \qquad (12)$$

where the variables and slope coefficients are explained below Eqs. 10 and 11.

Smaller house model

For the smaller houses we remove only the floor level variable from Eq. 11, following the same arguments as for the house model. We are left with the following model for estimating prices on smaller houses,

$$\ln \hat{p}_{i,t}^{LOG-TD} = \beta_0 + \beta_1 \ln S_i + \beta_2 B_i + \beta_3 O_i + \sum_{t=1}^{T} \alpha_t \times D_{i,t} + \sum_{k=1}^{K} \gamma_k \times D_{i,k} + \cdots \sum_{a=1}^{A} \delta_a \times D_{i,a} + \varepsilon_{i,t} \qquad (13)$$

where the variables and slope coefficients are explained below Eqs. 10 and 11.

District models for apartments

For the apartments in the different districts, we have used the apartment model from Eq. 11, but of course excluded the district variable from the regression. The inputs for this model is based on the stratums defined by different districts, hence we have the following model for estimating prices in five different districts,

$$\ln \hat{p}_{i,t}^{LOG-TD} = \beta_0 + \beta_1 \ln S_i + \beta_2 B_i + \beta_3 O_i + \sum_{t=1}^{T} \alpha_t \times D_{i,t} + \sum_{a=1}^{A} \delta_a \times D_{i,a} + \cdots$$
$$\sum_{f=1}^{F} \partial_f \times D_{i,f} + \varepsilon_{i,t} \quad (14)$$

where the variables and slope coefficients are explained below Eqs. 10 and 11.

As the estimated dwelling prices are given as $\ln \hat{p}_{LOG-TD}^{i,t}$, we find it useful to transform the price back to nominal prices, by using the exponential, hence,

$$e^{\ln \hat{p}_{i,t}^{LOG-TD}} = \hat{p}_{i,t}^{LOG-TD}$$

5.1.2 Alternative regression models

An alternative to hedonic regression method is called the *repeat-sales method*, initially proposed by Bailey, Muth and Nourse (1963) as stated in Eurostat (2013, p. 66). A natural distinction between the two methods, is that the latter only makes use of repeated sales observations, i.e., the same dwelling must be sold more than once, while the hedonic model makes no such limitation. Furthermore, the repeated sales method is much less data intensive, as the only inputs needed are the price, sales date, and addresses (Eurostat, 2013, p. 66). As we have received a data set containing data on numerous characteristics, we want to make the best use of this data, thus developing a hedonic model (Eurostat, 2013, p. 57).

The repeat sales method is used by e.g., Larsen and Weum (2008). They argue that the repeat-sales method in their case will not be reduced qualitatively by sample selection bias, which is usually a concern to the repeat-sales method (Eurostat, 2013, p. 13). Gatzlaff and Ling (1994) and Clapp and Giaccotto (1998), as cited in Eurostat (2013, p. 74), overcome the sample selection bias problem by combining the repeat sales method with an assessment-based method, a method that relate "actual sale prices to assessed values" (Eurostat, 2013, p. 13). However, this method is not an econometric method, and is much less data intensive, thus making it inappropriate for our purpose.

5.2 Implementation of costs related to housing investments

In this section we will go through how we incorporate the relevant costs for different dwellings and type of ownership, to give estimates of returns *net of costs*. Implementing the relevant costs is not a straightforward procedure, as they are influenced by a lot of different factors.

5.2.1 Transaction costs buyer

When buying a dwelling you will in most cases face *stamp duty* ($Stamp\ duty_i$) (Huseierne, n.d.). These are the same independent of dwelling type but differ with the form of ownership. Co-ops is exempt from the stamp duty (Kartverket, 2021a), while SOUs face a stamp duty of 2.5% (Kartverket, 2021b), hence for SOUs we have,

$$Stamp\ duty_{i,t} = 2.5\% \times (\hat{p}_{i,t}^{LOG-TD} + D_{i,t}) \tag{15}$$

where, $\hat{p}_{i,t}^{LOG-TD}$ is the estimated price of dwelling i at time t using our preferred regression models (Eqs. 11, 12, 13, and 14), and $D_{i,t}$ is the acquired debt that follows dwelling i at time t. Huseierne (n.d.) argue that there exist some exempts from the stamp duty for SOUs, for instance in the cases of heritage. However, due to the complexity in terms of identifying such transactions, we neglect the exempts for SOUs in our research.

Kartverket (2021c) provided us with the *registration fees* ($Fees_i$) associated with the purchase of dwellings. Furthermore, Osloadvokatene (n.d.) states that most individuals buy *home-buyer-insurance* ($Insurance_i$). Anderssen et al. (2015, p. 8) states that HELP Forsikring is the largest distributor of home-buyer-insurances in Norway, and we therefore use their prices (HELP Forsikring, n.d.). Appendix 4 represents the figures related to each cost component when buying different dwelling types, with different ownership types. The total transaction costs, $\lambda_{i,t}^{B}$, for a buyer of a dwelling i, at time t, is then the sum of the relevant costs associated to that specific dwelling, hence,

$$\lambda_{i,t}^{B} = Stamp\ duty_{i,t} + Fees_i + Insurance_i \tag{16}$$

5.2.2 Transaction costs seller

The complexity of transaction costs related to selling a dwelling is even more comprehensive compared to buying. There are some fixed costs related to public documentation, but most costs depend on personal preferences and choices. You can freely choose between numerous broker agencies, you can sell the dwelling completely by yourself, or you can choose a solution were a professional, in most cases a lawyer, will help you with the public documentation and contract negotiations.

Värderingsdata (2018), a comparable service provider in Sweden to Eiendomsverdi AS, referred to in Strømnes (2019), have analyzed real estate transactions in Sweden and conclude that using a broker will increase the selling price of a dwelling. Carl O. Geving, CEO of Norges Eiendomsmeglerforbund, further argues that we would expect the same pattern in Norway, and states that the amount of private sales is close to zero (Strømnes, 2019). Therefore, we assume throughout this thesis that all sales goes through a broker agency. Stamsø (2011, p. 17) states that in 2010 the average *broker commission* ($Commission_i$) in Norway was close to 2% of the dwelling price. Delfim and Hoesli (2019, p. 9) uses a 2% broker fee in the US. Edvardsen (2021) argues that average commission is somewhere between 1-3.6%. Given the appreciation of the Norwegian real estate market (Krogsveen, n.d.-b; Statistics Norway, n.d.) the past ten years, there is no reason as of why the broker commission rate should have increased, hence we use Stamsø's (2011) predictions of 2%. By doing so we have implicitly assumed that the broker will be paid by commission, not by an hourly rate. The rate of 2% is assumed to be independent of dwelling type, form of ownership, and time of sale. The minimum commission is set to NOK 40,000,-, in accordance with real estate agency Krogsveen's price list (n.d.-a).

$$Commission_i = \max\left(40{,}000\ ,\ 2.0\% \times \left(\hat{p}_{i,t}^{LOG-TD} + D_{i,t}\right)\right) \tag{17}$$

Anderssen et al. argues that 80% of home-sellers will buy a *home-seller-insurance* ($Insurance_i$) (2015, p. 22). Meglersmart (n.d.-a) and Pedersen (2021) coincide in their estimates of this insurance, and we proceed further by using the latter.

Based on a list of expenses provided by Krogsveen (n.d.-a), we were able to match the costs related to *public documentation* ($Documentation_i$) according to dwelling type and form of ownership.

Eierskiftegebyr ($Fees_i$) is a fee associated with the change in ownership of a dwelling that only applies to co-ops (EiendomsMegler1, n.d.). This is a fee compensating the co-ops for the additional work associated with a change in ownership. The Ministry of Local Government and Modernisation (2016) states that this fee varies a lot between co-ops, but the maximum amount is four times a legally fixed fee, called "rettsgebyr" [court fees]. Appendix 5 presents these court fees for the years 2010-2020, collected from The Norwegian Tax Administration (n.d.-c). By adding VAT to these fees[4], and taking the average over the whole sample period, we set a fee of NOK 4,858,-, for all co-ops, independent of dwelling type.

Appendix 6 presents the figures related to each cost component when selling different dwelling types, with different ownership forms. The total transaction costs, $\lambda_{i,t}^S$, for a sale of a dwelling i, at time t, is then the sum of the relevant costs associated to that specific dwelling, hence,

$$\lambda_{i,t}^S = Commission_i + Insurance_i + Documentation_i + Fees_i \qquad (18)$$

5.2.3 Living expenses

Households will face numerous *living expenses* when owning a dwelling, as introduced in section 3.3.2 To incorporate the right amount of living expenses to each unique dwelling for each quarter, we divided the yearly living expenses by four, and adjusted them for size of the dwelling according to the reference sizes of an apartment and a house of 70 and 120 sqm., respectively. For apartments, the quarterly living expenses $\eta_{i,t}$ for apartment i at time t is,

$$\eta_{i,t} = \frac{L_{Y,a}}{4} \times \frac{S_i}{70} \qquad (19)$$

[4] The permission to include value added tax (VAT) can be seen in (Ot.prp. nr. 30 (2002-2003), p. 123) as referred to in Prop. 36 L (2018-2019, p. 28)

where $L_{Y,a}$ is the yearly living expenses for apartments, as presented in Table 6
For houses, the quarterly living expenses $\eta_{i,t}$ for house i at time t is,

$$\eta_{i,t} = \frac{L_{Y,h}}{4} \times \frac{S_i}{120} \tag{20}$$

where, $L_{Y,h}$ is the yearly living expenses for houses, as presented in Table 6.

Benedictow and Gran (2020) lacked research related to living expenses for small houses. As this dwelling type have similarities to apartments, as elaborated in section 3.1.1, we have used an apartment of 70 sqm. as a reference, thus the quarterly living expenses $\eta_{i,t}$ for small house i at time t is,

$$\eta_{i,t} = \frac{L_{Y,a}}{4} \times \frac{S_i}{70} \tag{21}$$

where, $L_{Y,a}$ is the yearly living expenses for apartments, as presented in Table 6.

5.2.4 Implicit rent

For the purpose of finding the correct implicit rent rates we use rental price data, as elaborated in section 3.3.1 We allocate the correct quarterly rent for each unique dwelling simply by matching the rent for each quarter of our sample period with the size, in terms of number of bedrooms, of the dwelling. That way, a dwelling with 5 rooms is allocated higher implicit rent for a given quarter than another dwelling with less rooms for the same quarter. We denote the implicit rent for dwelling i at time t as $\theta_{i,t}$.

5.3 Assessing the returns to housing investments

Based on our hedonic regression models from Eqs. 11, 12, 13 and 14, and the elaboration of the relevant costs from section 5.2 we compute four different series of quarterly returns, for each stratum. These four series is the ROA with cost structures $No\ Costs$ (NC), $Total\ Costs$ (TC) and $Smoothed\ Costs$ (SC), as well as the ROE with cost structure SC. The return computations are inspired by

Hill and Melser (2019, p. 125) and The Norwegian Tax Administration (n.d.-b). The procedures below are repeated eight times, one for each stratum. We will base our calculations on the estimated prices from our LOG-TD models, $\hat{p}_{i,t}^{LOG-TD}$, but for the sake of convenience we will refer to these estimates as $\hat{p}_{i,t}$ from now on, hence,

$$\hat{p}_{i,t}^{LOG-TD} = \hat{p}_{i,t} \tag{22}$$

5.3.1 Housing returns with no costs, NC

The quarterly returns when excluding costs, ROA (NC), is simply the asset gains for a quarter, divided by the initial price at the beginning of the quarter, as stated in Eq. 1. We proceed by using the following notation,

$$ROA_{i,t}^{c} = \frac{\hat{p}_{i,t} - \hat{p}_{i,t-1}}{\hat{p}_{i,t-1}} \tag{23}$$

where, $ROA_{i,t}^{c}$ is the ROA on dwelling i, at time t, for a given cost structure c. $\hat{p}_{i,t}$ is the estimated price of dwelling i, at time t. To present the ROA (NC), we have

$$ROA_{i,t}^{NC} = \frac{\hat{p}_{i,t} - \hat{p}_{i,t-1}}{\hat{p}_{i,t-1}} \tag{24}$$

where, $ROA_{i,t}^{NC}$ is the ROA on dwelling i, at time t, given the cost structure NC.

We computed the aggregated gains or losses over the sample period, in principle the fundamental price development, for each unique dwelling as,

$$CROA_{i,t}^{NC} = \left(\frac{\hat{p}_{i,t} - \hat{p}_{i,0}}{\hat{p}_{i,0}}\right) \tag{25}$$

where, $\hat{p}_{i,0}$ is the estimated original price of dwelling i at time t. $CROA_{i,t}^{NC}$ displays the cumulative return offered from period 0 to t for dwelling i, with cost structure NC.

5.3.2 Housing returns with total costs, TC

To elaborate on a short-term strategy households might choose, we compute quarterly ROA given a buy-and-sell strategy each quarter (TC). This strategy implies that you will, among other costs, face full transaction costs each quarter. $ROA^{TC}_{i,t}$ is the ROA on dwelling i, at time t, given the cost structure TC, hence,

$$ROA^{TC}_{i,t} = \frac{(Net\ asset\ gain_{t,t-1}) \times (1 - tax\ rate) - Living\ exp. + Impl.\ rent}{Purchase\ price\ asset\ i\ at\ t-1}$$

$$ROA^{TC}_{i,t} = \frac{(\hat{p}_{i,t} - \lambda^S_{i,t} - \lambda^B_{i,t-1} - \hat{p}_{i,t-1}) \times (1 - \tau_t) - \eta_{i,t} + \theta_{i,t}}{\hat{p}_{i,t-1}} \tag{26}$$

where, $\lambda^S_{i,t}$ is the total transaction costs when selling at time t, $\lambda^B_{i,t-1}$ is the total transaction costs when buying at time $t-1$, $\eta_{i,t}$ is the quarterly living expenses from $t-1$ to t, $\theta_{i,t}$ is the implicit rent from $t-1$ to t, and τ_t is the tax rate on capital gains at time t. By buying and selling each quarter the asset gain from period $t-1$ to t are no longer tax exempt due to a holding period of less than 12 months. Calculations of taxable net asset gains follows that of The Norwegian Tax Administration. (n.d.-b).

We compute the cumulative ROA, $CROA^{TC}_{i,t}$, for each unique dwelling as,

$$CROA^{TC}_{i,t} = \frac{\hat{p}_{i,t} - Cumulative\ Net\ Costs^{TC}_{i,t} - \hat{p}_{i,0}}{\hat{p}_{i,0}} \tag{27}$$

$$where,$$

$$Cumulative\ Net\ Costs^{TC}_{i,t} = \sum_{t=0}^{t} \lambda^S_{i,t} + \lambda^B_{i,t-1} + \eta_{i,t} + \vartheta_{i,t} - \theta_{i,t} \tag{28}$$

$$and,$$

$$\vartheta_{i,t} = (\hat{p}_{i,t} - \lambda^S_{i,t} - \lambda^B_{i,t-1} - \hat{p}_{i,t-1}) \times \tau_t \tag{29}$$

where, the $Cumulative\ Net\ Costs^{TC}_{i,t}$ displays the sum of the cost elements , $\lambda^S_{i,t}$, $\lambda^B_{i,t-1}$, $\eta_{i,t}$ and $\vartheta_{i,t}$, net of the implicit rent $\theta_{i,t}$ for a dwelling i at any point t, hence, it is the total net costs you have faced from time 0 to time t. $\vartheta_{i,t}$ is the tax expenses related to dwelling i at time t. $CROA_{i,t}^{TC}$ displays the cumulative return offered from period 0 to t for dwelling i, with cost structure TC.

5.3.3 Housing returns with smoothed costs, SC

To elaborate on a long-term strategy that households most likely chose, we compute quarterly ROA given a buy-and-hold strategy (SC). We assume that you will buy the dwelling in Q1 of 2010 ($t = 0$) and sell in Q4 of 2020 ($t = T$). The computation of quarterly returns with such a buy-and-hold strategy and holding period is inspired by Hill and Melser (2019, p. 125).

Asset returns, SC

$ROA_{i,t}^{SC}$ is the ROA on dwelling i, at time t, given the cost structure SC, hence,

$$ROA_{i,t}^{SC} = \frac{(Net\ asset\ gain_{t,t-1}) - Living\ exp. + Impl.\ rent}{Purchase\ price\ asset\ i\ at\ t-1}$$

$$ROA_{i,t}^{SC} = \frac{\left(\hat{p}_{i,t} - \frac{\lambda_{i,T}^{S}}{HP \times \#Q} - \frac{\lambda_{i,0}^{B}}{HP \times \#Q} - \hat{p}_{i,t-1}\right) - \eta_{i,t} + \theta_{i,t}}{\hat{p}_{i,t-1}} \quad (30)$$

where, $\lambda_{i,T}^{S}$ is the total transaction costs for selling at time T (Q4 of 2020), $\lambda_{i,0}^{B}$ is the total transaction costs for buying at time 0 (Q1 of 2010), HP is the holding period in years, $\#Q$ is the number of quarters in a year. This way, the transaction costs related to buying, $\lambda_{i,0}^{B}$, and selling, $\lambda_{i,T}^{S}$, a specific dwelling is "smoothed" out throughout the sample period, by dividing with $HP * \#Q$. Due to the favourable tax implications for housing investments, you will not face any taxes given this HP.

We compute the cumulative ROA, $CROA_{i,t}^{SC}$, for each unique dwelling as,

$$CROA_{i,t}^{SC} = \frac{\hat{p}_{i,t} - Cumulative\ Net\ Costs_{i,t}^{SC} - \hat{p}_{i,0}}{\hat{p}_{i,0}} \quad (31)$$

$$where,$$

$$Cumulative\ Net\ Costs^{SC}_{i,t} = \sum_{t=0}^{t} \frac{\lambda^{S}_{i,T}}{HP \times \#Q} + \frac{\lambda^{B}_{i,0}}{HP \times \#Q} + \eta_{i,t} - \theta_{i,t} \qquad (32)$$

where, the $Cumulative\ Net\ Costs^{SC}_{i,t}$ displays the sum of the cost elements , $\frac{\lambda^{S}_{i,T}}{HP \times \#Q}, \frac{\lambda^{B}_{i,0}}{HP \times \#Q}, \eta_{i,t}$ net of the implicit rent $\theta_{i,t}$ for a dwelling i at any point t, hence it is the total net costs you have faced from 0 to time t. $CROA^{SC}_{i,t}$ displays the return offered from period 0 to t for dwelling i, with cost structure SC.

Equity returns, SC

$ROE^{SC}_{i,t}$ is the ROE on dwelling i, at time t, given the cost structure SC, hence,

$$ROE^{SC}_{i,t} = \frac{(Net\ asset\ gain_{t,t-1}) - Living\ exp. + Impl.\,rent}{Equity\ invested\ in\ asset\ i\ at\ t-1,\ given\ ltvr_0}$$

$$ROE^{SC}_{i,t} = \frac{\left(\hat{p}_{i,t} - \frac{\lambda^{S}_{i,T}}{HP \times \#Q} - \frac{\lambda^{B}_{i,0}}{HP \times \#Q} - \hat{p}_{i,t-1}\right) - \eta_{i,t} + \theta_{i,t}}{\hat{p}_{i,t-1} \times (1 - ltvr_0)} \qquad (33)$$

The only difference from the computation of $ROA^{SC}_{i,t}$ in Eq. 30 is that we must adjust for the equity invested in asset i at $t-1$, given the ltv-ratio at time 0, hence,

$$\hat{p}_{i,t-1} \times (1 - ltvr_0) \qquad (34)$$

The cumulative ROE, $CROE^{SC}_{i,t}$, is computed in the same way as in Eq. 31, however, adjusted for the equity invested in dwelling i at time 0, hence we get,

$$CROE^{SC}_{i,t} = \frac{\hat{p}_{i,t} - Cumulative\ Net\ Costs^{SC}_{i,t} - \hat{p}_{i,0}}{\hat{p}_{i,0} \times (1 - ltvr_0)} \qquad (35)$$

The $Cumulative\ Net\ Costs^{SC}_{i,t}$ are the same as in Eq. 32.

5.3.4 Computation of mean returns and indices

For each of the four series of returns (Eqs. 24, 26, 30, 33), we compute the mean of the quarterly returns, $\bar{R}_t$ for all dwellings, at time t, hence

$$\bar{R}_t = \frac{1}{I}\sum_{i=1}^{I} ROX^c_{i,t} \tag{36}$$

$$such\ that,$$

$$\bar{R}_1 = \frac{1}{I}(ROX^c_{1,1} + ROX^c_{2,1} + \cdots + ROX^c_{I,1})$$

$$\bar{R}_2 = \frac{1}{I}(ROX^c_{1,2} + ROX^c_{2,2} + \cdots + ROX^c_{I,2})$$

$$and\ so\ on\ \ldots$$

where, I is the number of dwelling IDs within the stratum. $ROX^c_{i,t}$ represent the four series of returns, where X is either A or E. $ROX^c_{1,t}$ is the return on one specific dwelling at time t, $ROX^c_{2,t}$ is the return on another specific dwelling at time t, and so on. This resulted in four series of 44 mean quarterly returns, $\bar{R}_t$ for each stratum.

We compute the mean cumulative returns, $\overline{CR}_t$, following the same arguments as for $\bar{R}_t$ in Eq. 36, hence,

$$\overline{CR}_t = \frac{1}{I}\sum_{i=1}^{I} CROX^c_{i,t} \tag{37}$$

where, $CROX^c_{i,t}$ is the cumulative return calculations from Eqs. 25, 27, 31 and 35. This results in four additional series of 44 mean cumulative returns, $\overline{CR}_t$, for each stratum. To display the indexes related to the mean cumulative returns $\overline{CR}_t$, we simply add 1 to each element in $\overline{CR}_t$, such that the initial value of Q1 of 2010 equals 1 instead of 0.

To compute a price index for Oslo properties at an aggregated level, independent of dwelling type we create an “aggregated mix-adjusted RPPI”, “calculated as the weighted average of indices for each stratum” (Eurostat, 2013, p. 38). The weighted average quarterly returns for Oslo properties, $\bar{R}_t^{s,TOT}$, is computed as follows,

$$\bar{R}_t^{s,TOT} = \sum_{m=1}^{3} (w_m \times \bar{R}_t^{s}) \tag{38}$$

$$such\ that,$$

$$\bar{R}_1^{s,TOT} = (w_1 \times \bar{R}_1^{s}) + (w_2 \times \bar{R}_1^{s}) + (w_3 \times \bar{R}_1^{s})$$

$$\bar{R}_2^{s,TOT} = (w_1 \times \bar{R}_2^{s}) + (w_2 \times \bar{R}_2^{s}) + (w_3 \times \bar{R}_2^{s})$$

$$and\ so\ on\ \ldots$$

where, w_m is the weight assigned to apartments (1), houses (2) and small houses (3) and $\bar{R}_t^{s}$ is the mean quarterly return at time t from Eq. 36.

We compute the weighted average mean cumulative returns for Oslo properties, $\overline{CR}_t^{s,TOT}$, following the same arguments as for $\bar{R}_t^{s,TOT}$ from Eq. 38, hence,

$$\overline{CR}_t^{s,TOT} = \sum_{m=1}^{3} (w_m \times \overline{CR}_t^{s}) \tag{39}$$

where, $\overline{CR}_t^{s}$ is the mean cumulative return at time t as represented in Eq. 37.

To represent the average quarterly return over the sample period, we used the arithmetic mean return, $\bar{R}^{s}$, in the following way:

$$\bar{R}^{s} = \frac{1}{T} \sum_{t=1}^{T} \bar{R}_t^{s} \tag{40}$$

5.4 Riskiness and risk-adjusted returns to housing investments

We compute the excess returns at time t, by subtracting the quarterly risk-free rate, R_t^f[5] from the mean of the quarterly returns at time t, $\bar{R}_t^c$ hence,

$$ER_t^c = \bar{R}_t^c - R_t^f \tag{41}$$

where, ER_t^c is the excess return at time t given the cost structure c. We computed the arithmetic mean excess returns, $\overline{ER}^c$, over the sample period, as

$$\overline{ER}^c = \frac{1}{T}\sum_{t=1}^{T} ER_t^c \tag{42}$$

To get a measure of the riskiness of the four return series we first compute the standard deviation of the 44 quarterly returns, $ROX_{i,t}^c$, for each unique dwelling i and cost structure c, represented by σ_i^c. We then computed the arithmetic mean standard deviation, $\bar{\sigma}^c$, of all unique dwellings i, for each of the four return series, where,

$$\bar{\sigma}^c = \frac{1}{T}\sum_{t=1}^{T} \sigma_i^c \tag{43}$$

and used this as a measure of the riskiness of the returns. We were then able to present four different Sharpe ratios, SR^c as,

$$SR^c = \frac{\overline{ER}^c}{\bar{\sigma}^c} \tag{44}$$

[5] See the "risk free rates" in Table 6 above. The quarterly rates are these figures divided by 4.

5.5 Returns, riskiness, and risk-adjusted returns to OSEFX

The OSEFX data, as elaborated in section 3.2, is first transformed from daily to quarterly prices. The quarterly returns, R_t^{OSEFX}, follow the foundation of Eq. 1, and is calculated as

$$R_t^{OSEFX} = \frac{p_t - p_{t-1}}{p_{t-1}} \quad (45)$$

The cumulative returns, CR_t^{OSEFX}, is defined as,

$$CR_t^{OSEFX} = \prod_{t=1}^{T}(1 + R_t^{OSEFX}) \quad (46)$$

Given the fact that we want to compare this index and its returns against variations of housing returns, where the latter also include costs elements – the question of whether we should incorporate direct costs estimates to the OSEFX returns becomes relevant. We choose not to do so, and instead hold as an assumption, that the private investor can easily replicate the returns offered by the index net of costs. However, we incorporate the effect of tax on realized returns by investing in OSEFX, which is not tax-exempt in the same way as housing investments. To compare the returns offered by OSEFX with the different real estate returns we need to adjust the OSEFX returns according to the relevant strategy. In our analysis of the buy-and-sell strategy (short-term) with cost structure TC, we multiply each element of the quarterly OSEFX returns with $(1 - \tau_t)$, hence,

$$R_t^{OSEFX\,(TC)} = \frac{(p_t - p_{t-1}) \times (1 - \tau_t)}{p_{t-1}} \quad (47)$$

The cumulative returns, $CR_t^{OSEFX\,(TC)}$ is calculated as in Eq. 46, with R_t^{OSEFX} replaced with $R_t^{OSEFX\,(TC)}$.

When considering the tax expense in the buy-and-hold strategy (long term) with cost structure SC, we treat $R_t^{OSEFX\,(SC)} = R_t^{OSEFX}$. For the cumulative returns,

$CR_t^{OSEFX\,(SC)}$, we need to adjust for the tax expenses time of realization of the asset in Q4 of 2020, hence we adjust the last observation in CR_t^{OSEFX} such that,

$$CR_{Q4,2020}^{OSEFX(SC)} = ((1 - CR_{Q4,2020}^{OSEFX}) \times (1 - \tau_{Q4,2020})) + 1 \qquad (48)$$

where $CR_{Q4,2020}^{OSEFX(SC)}$ is the cumulative quarterly return in Q4 of 2020, given the long-term strategy. For all other quarters, we have that $CR_t^{OSEFX(SC)} = CR_t^{OSEFX}$.

Relevant to the discussion above, is the implicit rent, $\theta_{i,t}$, which increases the real estate returns (Eq. 26, 27, 30, 31, 33 and 35). We assume that private households need a place to live in Oslo, independent of the choice between owning or renting. As a consequence, the implicit rent can be interpreted as an indirect cost of investing in OSEFX, as this will impose households to rent. This makes comparison of the two asset classes net of costs more reasonable.

In terms of comparing the ROE of real estate investments and OSEFX we use the findings from Nordnet AB (2015), who conclude that mutual fund and stock investments by private investors are rarely indebted in the same way as real estate investments. Consequently, we make no difference between ROA and ROE offered by OSEFX.

6 Results and analysis

In section 5.1.1 we explained why the LOG-TD model is the most appropriate for our purpose. We will in the following present outputs and interpretations from these models. Furthermore, summarize the different cost figures and present results and conduct analysis based on the four quarterly and four cumulative return series we computed, for each stratum.

6.1 Hedonic regression models – outputs and interpretation

Appendix 7 and 8 displays all the variable names ($Variable$), their corresponding dummy values (D), coefficients estimate ($Estimate$), standard errors (SE), test statistics ($tStat$), and p-values ($pValue$), from the eight hedonic models represented by Eqs. 11, 12, 13 and 14. By looking at Appendix 7, in the apartment model, we observe that all the slope coefficients are proven to be statistically significantly different from zero (5% sign. level), except for the "2010Q2" variable, represented by the dummy variable $D_{i,t}, for\ t = 1$. In the house model only the slope coefficient representing the dummy variable for "Region_Nordstrand", that is $D_{i,7}$, for $k = 7$, is not proven to be statistically different than zero. In the small house model there are some extra variables that cannot be concluded to be statistically significantly different than zero, i.e., some variables have a corresponding $pValue$ less than 0.05. These results are considered positive for our preferred model, as almost every slope coefficient estimate is proven to have a significant impact on the estimated prices.

For the different districts, represented in Appendix 8, there are different estimates that cannot be proven to have a statistically significant effect on the estimated price. The reason for this may be that there exist very few observations in some of the stratums matching the relevant variable. This makes sense as almost every slope coefficient for the apartment model is proven to have an impact on the estimated apartment price, and this is by far the largest stratum. Furthermore, there might be a big dispersion in the observed prices for some districts, causing a less robust model. The Outer South model represents the districts Østensjø, Nordstrand and Søndre Nordstrand, areas that represent big dispersion in observed values. As we see from this model (Appendix 8), 13 variables cannot be proven to have a statistically significant effect on the estimated prices. This may relate to both problems mentioned above.

An elaboration of the effect the slope coefficient estimates have on the estimated price is necessary. Recall the models we used from Eqs. 11, 12, 13 and 14. First, if sqm., S_i (continuous, logarithmic) increases by one percent, the expected estimated price, $E(\hat{p}_{i,t})$, will increase by $\beta_1$percent, holding all other coefficients constant. By looking at the apartment model outputs in Appendix 7, we observe that the slope coefficient of $\ln S_i$ is 0.76469, hence, if S_i increases by 1%, the effect on the estimated price, $\hat{p}_{i,t}$, will be 0.76469% Let's say an apartment costs NOK 10,000,000,- with size 100 sqm. Then, if the size were to increase by 1%, i.e., an increase of 1 sqm, the effect on the estimated price would be an increase of NOK 76,469,-.

Second, if the number of bedrooms (continuous), B_i, increases by one unit, then the expected estimated price, $E(\hat{p}_{i,t})$, will increase by $100 \times \beta_2$ percent, holding all other coefficients constant. For apartments, the effect of adding an extra bedroom will result in an increase in the estimated price of $100 \times 0.01314\% = 1.314\%$.

For the dummy variables (O_i, $D_{i,t}$, $D_{i,k}$, $D_{i,a}$, $D_{i,f}$), e.g., going from period 2010Q1 to period 2010Q2, that is $D_{i,1}$ goes from 0 to 1, then the expected estimated price, $E(\hat{p}_{i,t})$, will increase/decrease by $100 \times (e^{\alpha_1} - 1)\%$. The effect of time passing from 2010Q1 to 2010Q2 (look up dummy variable 1 in the "D" column of Appendix 7 for apartments) will result in an increase of the estimated apartment price of $100 \times (e^{0.0088} - 1)\% = 0.8838\%$, thus representing the quarterly asset gain between 2010Q1 and 2010Q2. Another example could be a change in ownership type from SOU to co-ops. This would have an effect of $100 \times (e^{\beta_3} - 1)\% = 100 \times (e^{-0.13987} - 1)\% = -13.05\%$ on the estimated apartment price. This result is somewhat misleading, as it would be rather impossible to change ownership type from a SOU to a co-op, once you have bought an apartment with ownership type SOU. Therefore, it represents the average lower value, or price level, represented by investing in a co-op- instead of a SOU apartment. These interpretations will be the same for the other models in Appendix 7 and 8 as we only have three types of variables, which is continuous logarithmic, continuous and categorical (dummy).

As presented in Table 8 we observe that our LOG-TD model fits the data very well, for each stratum. The R^2 varies to some extent based on the different models, ranging from 0.7103 for the Outer South stratum, to 0.8577 for the small houses stratum.

Table 8 *Logarithmic-Time-Dummy Hedonic model fit statistics, for each stratum*

Logarithmic-Time-Dummy Hedonic Regression Model								
Stratum	Apartments	Houses	Small houses	Inner East	Inner West	Outer East	Outer West	Outer South
$\#obs.$	148976	7595	13834	56033	29789	24758	17200	21196
$\#Coeff.$	83	64	65	68	68	68	68	68
R^2	0.8090	0.8382	0.8577	0.7314	0.8481	0.7215	0.8196	0.7103
$\bar{R}^2$	0.8089	0.8368	0.8570	0.7311	0.8478	0.7207	0.8189	0.7094
$RMSE$	0.2096	0.1915	0.1790	0.2396	0.1939	0.1745	0.1932	0.2025

6.2 Assessing costs related to housing investments

The costs associated with buying a dwelling differs based on the dwelling types, with apartments having the smallest average transaction costs, as presented in Table 9. This is because many apartments have ownership type “co-op”, which has remarkably lower transaction costs, with an average of 0.2%. This contributes to an average transaction cost when buying of 1.49% for apartments. Houses and small houses do not have as many co-ops relative to SOUs, hence their average cost estimates for buying are biased towards SOUs, with average rates of 2.52% and 1.91% respectively. The reason as of why buying a co-op represent significantly lower transaction costs is mainly because these ownership types are exempt the stamp duty of 2.5% of the total price of a property.

Table 9 Average cost rates per asset turnover for buyer and seller. Yearly average living expenses and implicit rents. All estimates as percentage of estimated price. See section 5.2

	Apartments			Houses			Small houses		
	SOUs	Co-ops	Avg.*	SOUs	Co-ops	Avg.*	SOUs	Co-ops	Avg.*
Cost buyer	2.77	0.2	1.49	2.66	0.12	2.52	2.68	0.13	1.91
Cost seller	2.61	3.24	2.93	2.52	2.77	2.52	2.62	2.78	2.67
Liv. exp.	2.21	2.89	2.55	2.60	3.02	2.61	2.69	3.31	2.88
Impl. rent	4.08	4.08	4.08	2.95	2.95	2.95	4.00	4.00	4.00
Tot. costs**	7.59	6.33	6.96	7.78	5.91	7.74	7.99	6.22	7.46

*Average (avg.) cost rates computed as weighted average of SOUs and co-ops for each dwelling type.
** Summation of *Cost buyer*, *Cost seller* and *Liv. exp.*

When selling a dwelling the average cost rates are quite similar, ranging from 2.52% for houses to 2.93% for apartments. One thing to worth notice, is the fact that there are higher costs associated with selling a dwelling with ownership type co-op, for all dwelling types. Even though insurances $(Insurance_i)$ usually are lower for co-ops, this ownership type face higher costs related to public documentation fees $(Documentation_i)$, and fees associated with change of ownership $(Fees_i)$.

Hill and Melser (2019, p. 125) find that the total transaction costs for buying and selling a property in Sydney averages at 6.5%, independent of dwelling type and without taking into account form of ownership. Based on our calculations we find rates, on average to be 4.42% for apartments, 5.04% for houses, and 4.58% for smaller houses. The reason as of why this rate might be lower for Oslo might be the fact that when buying a dwelling in Sydney you will face a stamp duty of 4%, much higher than what you will face in Oslo. Delfim and Hoesli (2019, p. 9) finds that total transaction costs for buying and selling a property in the US makes up about 6%, where the buyer amounts for 2% and seller 4%, independent of dwelling type. The fact that their costs related to seller are higher than that of buyer is somewhat in line with our estimates.

Unlike the costs associated with buying and selling a dwelling, that only occurs at one specific time, the living expenses are yearly costs, and distributed quarterly in our calculations. The fact that the average living expenses between ownership types for each dwelling type differs is a strange finding. This is most likely caused by weights of each ownership type, especially for houses and smaller houses. There might be a random component related to for example size of the properties, causing average yearly living expenses of co-ops to be higher than that of SOUs. The living expenses when owning a house or a smaller house is also higher than for apartments. This makes sense as these dwelling types are often larger in size compared to apartments, and the latter might benefit from economies in scale in terms of sharing the regional fees, electricity use, insurance- and maintenance costs, in line with findings of Larsen and Weum (2008, p. 516). Hill and Melser (2019) uses spending by households on maintenance, insurances and rates together with depreciation costs in order to quantify the amount of living expenses. They conclude that apartments face average living expenses of 1.8% per annum, while the rate for houseowners is 1.2%. These rates are considerably lower than ours, with apartments facing average living expenses of 2.55% per annum, and houses 2.61% per annum. This may be due to the fact that we have incorporated more living expenses into this measure, as elaborated in section 3.3.2, and that there can be economic price differences between Sydney and Oslo.

The average implicit rent per annum is the same independent of ownership type, because these rates are computed based on the number of bedrooms in a dwelling. We find that the implicit rent for apartments is 4.08% per annum, while for houses and smaller houses it is 2.95% and 4.0% respectively. A premium yield for apartments is in line with expectations, and results by e.g., Hill and Melser (2019, p. 134). They find that the rental yield for apartments in Sydney averages at 4.48% per annum, while for houses the same rate is 3.68%. Larsen and Weum (2008, p. 512) assume that the implicit rent for co-op-apartments, can be set to 5.0% annually, with reference to work by Case and Shiller (1989). Global Property Guide (2018) argues that, as of 2018, the average rental yield for "residential properties in Oslo range from 3.1% to 4.6%". To conclude, we find our rates to be well in line with market figures and research estimates.

6.3 Comparison of returns to housing investments and OSEFX

Let us now turn to the return series we computed. We will draw links to other relevant research and studies where suitable, and at the same time keep in mind that comparing with other countries where there might be different sample periods and methods used might be misleading.

6.3.1 Housing returns with no costs (NC)

Fig. 2 (a) displays the quarterly ROA from owning a property in Oslo (blue line) and OSEFX (red line). The graph displays greater variance in returns for OSEFX, than that of Oslo properties. The returns of OSEFX ranges between -24.83% in Q1 of 2020, to 18.05% in Q3 of 2010. The returns to homeownership in Oslo ranges from a maximum quarterly return in Q3 of 2016 of 8.23%, to -4.30% in Q3 of 2017.

Fig. 2 *Quarterly (a) and cumulative (b) ROA (NC). Oslo properties and OSEFX.*

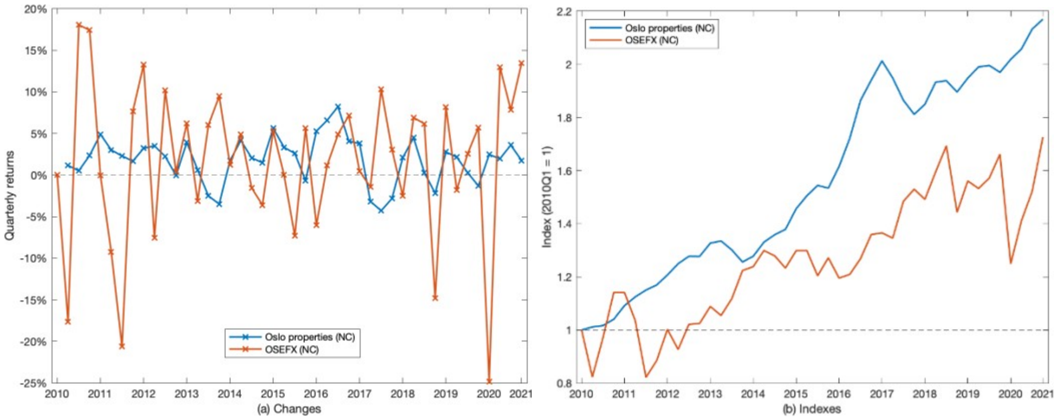


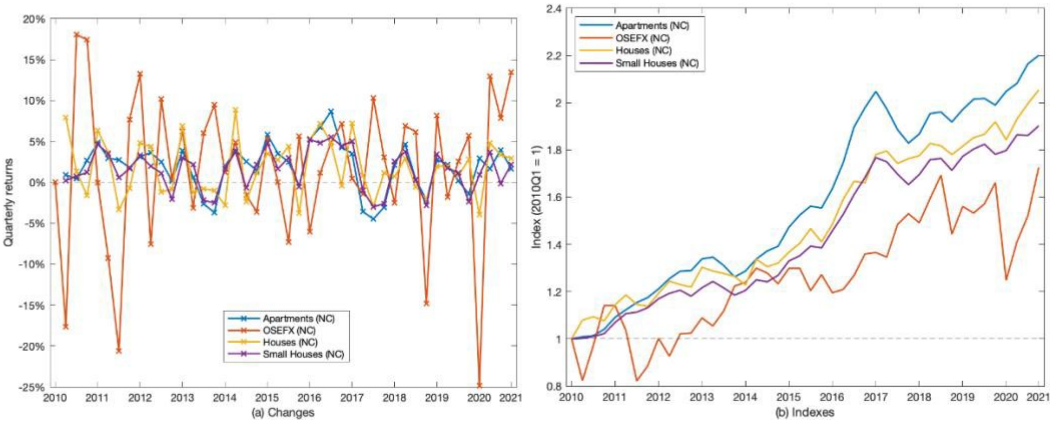
Fig. 2 (b) displays the cumulative price development for Oslo properties (blue line) and OSEFX (red line). Oslo properties, as a weighted average between apartments, houses, and smaller houses, have experienced an immense 116.98% increase over the eleven-year period from 2010 to year end 2020. The same figures for OSEFX are 72.62%. Oslo properties experienced an increase in value of approximately 40% from 2010 to 2013, followed by a decline during 2013 and a surge in value from 2014 to year end 2016. Jacobsen and Naug (2005) argues that the level of interest rates as well as the construction of new houses are two key factors in relation to real estate appreciation. During the time from year end 2014 to year start 2016 the central bank of Norway, Norges Bank (2021), reduced their *sight deposit rate* (policy rate) from 1.50% to 0.50%. Furthermore, the level of completed new builds went down from 2014 to 2015 and increased a bit in 2016 (Lund, 2020, p. 13). These findings might explain the immense surge in property value from 2014 to year end 2016.

The Oslo real estate market saw a big decline in value in 2017. “Boliglånsforskriften”, which was carried out in 2015 (Ministry of Finance, 2021), limited households’ ability to raise mortgages and thus buying properties, and the level of newly completed builds increased from 2016 levels. These factors might explain the decline in prices in that period. From 2017 to 2019 the population growth in Oslo increased (Lund, 2020, p. 13), and at year start 2020 the policy rate was decreased to a record breaking 0% (Norges Bank, 2021), factors that might explain the increase in value from 2019 to year end 2020. Furthermore, we observe that by 2019, the decline in value from 2017 is recouped, well in line with findings of Lund (2020, p. 13). The patterns related to Oslo properties follows what Krogsveen (n.d.-b) and Housing Lab (2019) publishes, amongst others.

The OSEFX experienced more volatility, with major variance in returns from 2010 through 2012, with steady appreciation following the years up to 2018. From this point on the volatility once again increased and peaked at the Covid-19 outburst in 2020. Based on these plots we find modest evidence indicating that Oslo properties might have experienced greater appreciation, with lower volatility than the OSEFX.

We illustrate the diversity of price trends across dwelling types in Fig. 3 (a) and 3 (b). As we observe from the quarterly returns (a), the returns to different dwellings are highly correlated. In the period 2016 to 2018, apartments (blue line) offered both the highest and lowest quarterly returns, while smaller houses (purple line) saw a bit less volatility in the returns. Furthermore, houses seemingly has the highest volatility.

Fig. 3 *Quarterly (a) and cumulative (b) ROA (NC). Dwelling types and OSEFX.*

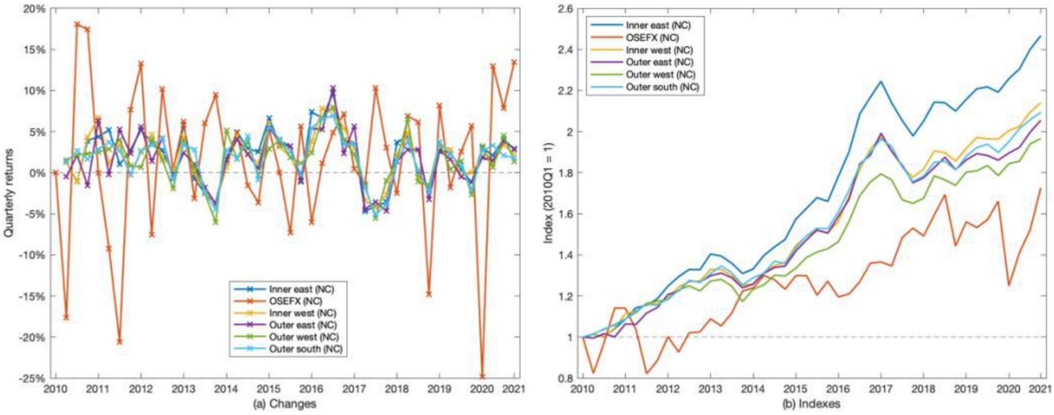


From Fig. 3 (b) we observe that all dwellings outperform the OSEFX on a cumulative basis. One thing worth noticing is that the decrease in value in 2017 was bigger for apartments compared to houses and smaller houses. During the sample period, apartments, houses and smaller houses experienced an increase in value of 120.06%, 105.41% and 90.22%, respectively. These are rates somewhat higher than Statistics Norway (n.d.). Furthermore, we see that the dispersion in the cumulative returns offered by the different dwelling types versus the OSEFX is smaller for small houses and houses, than for apartments.

As we observe from Fig. 4 (a), the quarterly returns in different districts for apartments in Oslo[6] are highly correlated. However, when looking at the cumulative plots we observe that it is the Inner East district, i.e., Gamle Oslo, Grünerløkka and Sagene, which experience the greatest appreciation, with an immense 146.70% returns over the sample period. Outer West, that is the districts of Ullern, Vestre- and Nordre Aker have experienced the lowest appreciation, with 96.61% cumulative returns over the sample period. This may be due to the fact that these areas are already considered to be very expensive, while areas such as Grünerløkka and Sagene have experienced an enormous increase in popularity over the sample period. However, all apartment owners in every district of Oslo can look back on superior price development compared to that of OSEFX (red line).

[6] Remember, whenever different aspects of districts are mentioned, e.g., Inner West, Inner East etc. this only applies to apartments, and not houses and small houses.

Fig. 4 *Quarterly (a) and cumulative (b) ROA (NC), for apartments. Districts and OSEFX.*



Based on the discussions above we find evidence that the real estate market in Oslo, when not considering any costs, have experienced greater appreciation from 2010 to 2020, with lower volatility than that of the OSEFX. Larsen and Weum (2008) finds similar conclusions for their research on Oslo apartments between 1991 and 2002. Table 10 presents summary statistics for the ROA (NC) series, for all stratums.

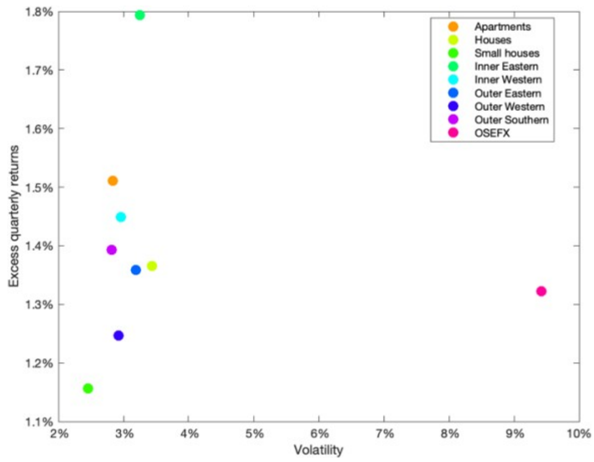
Table 10 *Return characteristics for ROA (NC), for all stratums*

Stratum	Returns	Volatility	Excess return	Sharpe ratio	Skewness	Kurtosis
Apartments	0.0189	0.0284	0.0151	0.5318	-0.3313	3.0897
Houses	0.0174	0.0344	0.0137	0.3972	0.2039	2.1066
Small houses	0.0154	0.0245	0.0116	0.4714	-0.2945	2.1161
Inner East	0.0217	0.0325	0.0179	0.5518	-0.2592	2.7147
Inner West	0.0183	0.0296	0.0145	0.4887	-0.0625	2.5353
Outer East	0.0174	0.0319	0.0136	0.4256	-0.0234	3.0478
Outer West	0.0163	0.0293	0.0125	0.4258	-0.4440	3.5096
Outer South	0.0177	0.0282	0.0139	0.4937	-0.6543	2.9864
OSEFX	0.0169	0.0942	0.0132	0.1404	-0.8522	3.7315

By looking Table 10, and the plots of the volatility and excess return for each dwelling type and area as presented in Fig. 5, we observe that the returns to homeownership are represented by remarkably lower volatility and more or less equal excess quarterly returns (except for the Inner East district) for all stratums except Outer West (apartments) and small houses, compared to that of OSEFX. This results in superior risk-return relationship (Sharpe ratios) for real estate investments compared to that of OSEFX (0.1404).

In the decision of where to invest in real estate, a household with no preferences as of where to live should take the findings represented in Fig. 5 into consideration, as the Inner East region offers higher excess returns, without compromising on the volatility. Hill and Melser (2019, p.134) find that the mean ROA (NC) for apartments and houses is 1.34% and 1.61% respectively, somewhat lower than our estimates. The volatility related to these return metrics in Sydney is also lower than what we find for Oslo. Larsen and Weum (2008, p. 514) find that apartments (co-ops) had a typical quarterly return of almost 3%, whereas the OSEAX yielded 1.2% quarterly, in the period between 1991 and 2002.

Fig. 5 *Risk-return relationship for ROA (NC), for all stratums*



Can we conclude that the returns to homeownership have offered significantly higher returns compared to OSEFX? We perform two-sample, one-sided Welch tests in order to test whether the difference in the sample means related to real estate returns (μ_{R_1}) and OSEFX returns (μ_{R_2}) is statistically significantly greater than zero. From Table 11 we cannot conclude that any of the mean real estate returns, for all stratums, are statistically significantly higher than the mean returns offered by OSEFX. Furthermore, we use a two-sample, left-tailed, F-test to find answers to whether the variance of housing returns ($\sigma^2_{R_1}$) differ significantly from the variance of OSEFX ($\sigma^2_{R_2}$). By looking at Table 11 we observe that for all stratums we can conclude that real estate investments offer statistically significantly lower variances in the returns than that of OSEFX.

Table 11 *Summary test statistics, ROA (NC), for all stratums.*

	Welch test of difference in mean quarterly returns $H_0: \mu_{R_1} - \mu_{R_2} = 0$ $H_A: \mu_{R_1} - \mu_{R_2} > 0$			F-test of equal variances $H_0: \sigma^2_{R_1} = \sigma^2_{R_2}$ $H_A: \sigma^2_{R_1} < \sigma^2_{R_2}$		
Stratum	$tStat$	$pValue$	$Reject\ H_0?$	$FStat$	$pValue$	$Reject\ H_0?$
Apartments	0.1050	0.4584	No	0.0909	0	Yes
Houses	0.0079	0.4969	No	0.1331	0	Yes
Small houses	-0.1326	0.5525	No	0.0678	0	Yes
Inner East	0.2900	0.3865	No	0.1191	0	Yes
Inner West	0.0636	0.4748	No	0.0991	0	Yes
Outer East	0.0038	0.4985	No	0.1149	0	Yes
Outer West	-0.0706	0.5280	No	0.0967	0	Yes
Outer South	0.0269	0.4893	No	0.0898	0	Yes

We find the results from the Welch tests partly surprising. Based on the patterns related to all dwelling types and areas as presented in Fig. 2, 3 and 4, one would expect to be able to conclude that mean returns to homeownership are greater than those of OSEFX, at least for some stratums. One reason as of why we fail to reject H_0 using the Welch test, is that we computed the mean returns using an arithmetic average. In a setting where volatility is high, something we have proven for the OSEFX, this way of computing averages might be misleading. The conclusions regarding the volatility of housing returns compared to that of OSEFX is in line with what we would expect looking at Fig. 2, 3 and 4.

Next, based on a one sided, right tailed Z-test, using the Sharpe ratio of OSEFX ($SR^{OSEFX} = 0.1404$) as a benchmark, we conclude that the Sharpe ratios for all stratums except the Outer West district offer statistically significantly higher risk-adjusted returns compared to OSEFX. With a p-value of 0.0505 for the test of the Outer West Sharpe ratio, we are not far off from concluding that this rate is also significantly higher than that of OSEFX. The reason as of why we fail to reject the null hypothesis for the Outer West Sharpe ratio is because of the negative skewness and the very high kurtosis, as seen in Table 10, causing the standard error of the estimated Sharpe ratio, $\hat{\sigma}_{\widehat{SR}}$, to increase, thus decreasing the Z_{stat} .

Table 12 *Test statistics, Sharpe ratios and Probabilistic Sharpe ratios, ROA (NC), for all stratums*

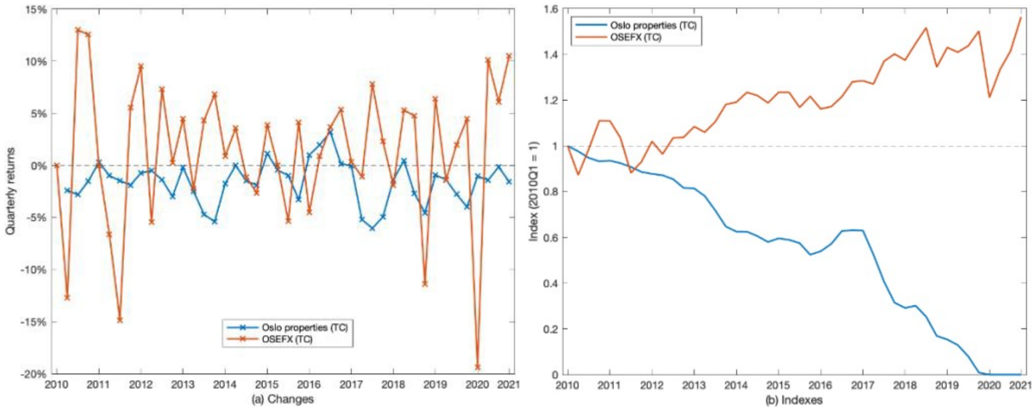
Hypoteses	H_0: $\hat{S}R = SR^{OSEFX}$			H_A: $\hat{S}R > SR^{OSEFX}$		
Stratum	$\hat{\mathfrak{R}}$	σ_{SR}	Z_{stat}	$PSR(SR^{OSEFX})$	$pValue$	$Reject\ H_0$?
Apartments	0.5318	0.1755	2.2308	0.9872	0.0128	Yes
Houses	0.3972	0.1496	1.7162	0.9569	0.0431	Yes
Small houses	0.4714	0.1671	1.9809	0.9762	0.0238	Yes
Inner East	0.5518	0.1721	2.3904	0.9916	0.0084	Yes
Inner West	0.4887	0.1615	2.1561	0.9845	0.0155	Yes
Outer East	0.4256	0.1601	1.7812	0.9626	0.0374	Yes
Outer West	0.4258	0.1741	1.6397	0.9495	0.0505	No
Outer South	0.4937	0.1833	1.9280	0.9731	0.0269	Yes

Our findings coincide to some extent with findings of Larsen and Weum (2008). We both find superior risk-return relationship for the housing market in Oslo compared to the stock market, for our respective sample periods. However, we only find that the housing market offers lower volatility, but not significant results supporting higher mean returns compared to OSEFX. Larsen and Weum concludes that housing investments in Oslo from 1991 to 2002 yields higher returns at lower risk, compared to the stock market.

6.3.2 Housing returns with total costs (TC)

Let us now examine the short-run behavior of real estate returns versus OSEFX, in order to see whether private households should choose to buy and sell a dwelling each quarter. The computation of quarterly real estate returns given this strategy is presented in Eq. 26 while for the OSEFX returns the method is presented in Eq. 47. Fig. 6 (a) displays the quarterly asset returns as a weighted average of properties in Oslo (blue line) and OSEFX (red line). This strategy has yielded negative quarterly real estate returns in 36 out of 44 quarters between 2010 and 2020. The lowest point is represented at Q3 of 2017 with a quarterly return of -6.04%. However, there is one period where you would experience positive quarterly returns, that is in the boom-market of 2016. The quarterly real estate appreciation in this period was larger than the huge transaction costs associated with buying and selling real estate. Because of taxation each quarter, the returns to OSEFX display lower variance compared to the no cost case, as you will face tax expenses and deductions when facing profits and losses, respectively.

Fig. 6 *Quarterly (a) and cumulative (b) ROA (TC). Oslo properties and OSEFX*



By looking at the cumulative returns when facing total costs each quarter, in Fig. 6 (b), one can easily observe that a short-run strategy is not profitable for real estate investments. This is mainly because the huge cumulative costs offset the asset appreciation and gains. On average, the drop in value when buying and selling each quarter is -100% over the sample period. You will suffer a full loss in asset value within Q1 of 2020. There is no need to display graphically the returns to homeownership for each stratum or district, due to the nature of the average returns presented above. The patterns for the different dwellings and districts will all look somewhat similar to this, with some areas and dwelling types facing a total loss of value faster than others. Delfim and Hoesli (2019) shares the same conclusion on the short-run strategy, and argues that an investor should allocate 0% of their money to direct real estate investments given a horizon less than 2.5 years, due to the large transaction costs. For a short-run investor, we observe that by buying and selling the OSEFX each quarter, you will face accumulated gains of 56.34%.

Table 13 *Return characteristics for ROA (TC), for all stratums*

Stratum	Returns	Volatility	Excess return	Sharpe ratio	Skewness	Kurtosis
Apartments	-0.0153	0.0208	-0.0191	-0.9158	-0.2260	3.1074
Houses	-0.0246	0.0248	-0.0284	-1.1461	0.1902	2.0966
Small houses	-0.0201	0.0180	-0.0239	-1.3300	-0.2764	2.1545
Inner East	-0.0129	0.0237	-0.0167	-0.7029	-0.1869	2.7550
Inner West	-0.0207	0.0216	-0.0245	-1.1339	-0.0371	2.5563
Outer East	-0.0128	0.0234	-0.0166	-0.7123	0.0433	3.0872
Outer West	-0.0195	0.0214	-0.0233	-1.0870	-0.3730	3.4773
Outer South	-0.0122	0.0206	-0.0160	-0.7761	-0.5525	2.9551
OSEFX	0.0126	0.0701	0.0089	0.1274	-0.9027	3.8670

Based on this strategy, the OSEFX outperform the real estate market, independent off dwelling type or area of investment, both based on the return and risk-adjusted return, as seen in Table 13. All stratums display negative Sharpe ratios and negative excess returns. From Table 14, we observe that for every stratum we can conclude that the ROA (TC) offered by the real estate market, for all stratums, is statistically significantly lower than that of OSEFX (based on the alternative hypothesis presented in Table 14). Furthermore, the F- test concludes that the real estate returns for each stratum offer statistically significantly lower variances.

***Table 14** Summary test statistics, ROA (TC), for all stratums.*

	Welch test of difference in mean quarterly returns $H_0: \mu_{R_1} - \mu_{R_2} = 0$ $H_A: \mu_{R_1} - \mu_{R_2} < 0$			F-test of equal variances $H_0: \sigma^2_{R_1} = \sigma^2_{R_2}$ $H_A: \sigma^2_{R_1} < \sigma^2_{R_2}$		
Stratum	$tStat$	$pValue$	$Reject\ H_0?$	$FStat$	$pValue$	$Reject\ H_0?$
Apartments	-2.5276	0.0074	Yes	0.0875	0	Yes
Houses	-3.3105	0.0008	Yes	0.1249	0	Yes
Small houses	-2.9961	0.0022	Yes	0.0568	0	Yes
Inner East	-2.2860	0.0132	Yes	0.1138	0	Yes
Inner West	-3.0035	0.0021	Yes	0.0945	0	Yes
Outer East	-2.2872	0.0132	Yes	0.1107	0	Yes
Outer West	-2.8975	0.0028	Yes	0.0929	0	Yes
Outer South	-2.2545	0.0143	Yes	0.0860	0	Yes

By testing the estimated Sharpe ratios, $\hat{\mathfrak{R}}$, using the Z-test as elaborated in Eq. 9 and using the alternative hypothesis that the Sharpe ratio of real estate investments is lower than that of OSEFX (left-tailed test), we can conclude that real estate investments offers statistically significantly lower Sharpe ratios than that of OSEFX, for all stratums. The test results are presented in Table 15.

***Table 15** Test statistics, Sharpe ratios and Probabilistic Sharpe ratios, ROA (TC), for all stratums*

Hypoteses	$H_0: \hat{SR} = SR^{OSEFX}$			$H_A: \hat{SR} < SR^{OSEFX}$		
Stratum	$\hat{\mathfrak{R}}$	σ_{SR}	Z_{stat}	$PSR(SR^{OSEFX})$	$pValue$	$Reject\ H_0?$
Apartments	-0.9158	0.1625	-6.5018	1.0000	0.0000	Yes
Houses	1.1461	0.1927	-6.6754	1.0000	0.0000	Yes
Small houses	-1.3300	0.1601	-9.1853	1.0000	0.0000	Yes
Inner East	-0.7029	0.1547	-5.4498	1.0000	0.0000	Yes
Inner West	-1.1339	0.1819	-7.0059	1.0000	0.0000	Yes
Outer East	-0.7123	0.1700	-5.0152	1.0000	0.0000	Yes
Outer West	-1.0870	0.1711	-7.1738	1.0000	0.0000	Yes
Outer South	-0.7761	0.1357	-6.7563	1.0000	0.0000	Yes

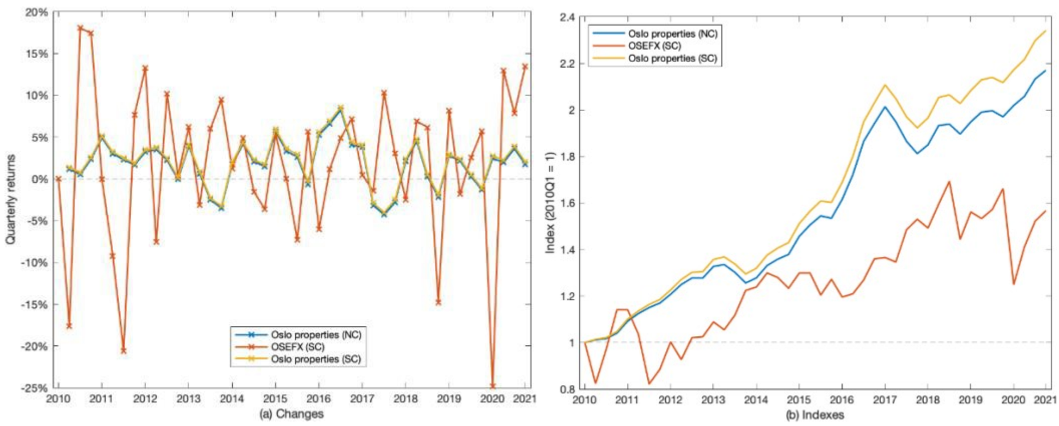
6.3.3 Housing returns with smoothed costs (SC)

ROA (SC)

Finally, the analysis will be centered around our last approach where we look at returns to a buy-and-hold strategy with smoothed costs, for a holding period of 11 years. Fig. 7 below show both quarterly mean returns (a) and cumulative return (b) for Oslo properties aggregated against the OSEFX (SC). The same trend as seen in Fig. 2 appear here as we include the relevant costs. In fact, the quarterly ROA (SC) are remarkably similar compared to those without costs, ROA (NC), as a consequence of the costs and the implicit rent component being almost counterbalanced throughout the whole period. In some quarters the implicit rent exceeds the cumulative costs, and the total returns (SC) are even higher than the sole price development (NC) for properties in Oslo. In addition, Fig. 7 (b) shows how surprisingly little differences in returns, as seen in Fig. 7 (a), can have a substantial effect on total returns over time.

When including smoothed costs, the Oslo real estate market appreciated 134.08% over the sample period. Furthermore, by realizing your mutual fund investments at year end 2020, you will face a tax rate of 22% on the capital gains, as seen in Table 6. The after-tax cumulative returns on the OSEFX then amount to 56.64% over the sample period, compared to a pre-tax accumulation of 72.62% as presented in Fig. 2.

Fig. 7 Quarterly (a) and cumulative (b) ROA (SC). Oslo properties and OSEFX



Again, we want to investigate whether the ROA (SC) differ across dwelling types. From Fig. 8 we observe that over the 11-year period, apartments outperform the two other dwelling types, which indeed perform much the same. Apartments appreciated by 138.73% over the 11-year period, whereas houses and smaller houses doubled their asset values throughout the period. The dispersion in the returns might be because the implicit rent offsets the costs to a large extent when it comes to apartments as the average implicit rent is over 1% higher for apartments than houses, as presented in Table 9. These results differ from Hill and Melser (2019, pp. 133-134), who find that houses outperform apartments in Sydney on the ROA (SC) metric as well. OSEFX fall far behind the real estate alternatives the same period. Furthermore, we observe that the volatility of housing returns seemingly are higher than those of apartments and smaller houses, and that apartment owners suffered the biggest loss in value during the setback in 2017.

Fig. 8 *Quarterly (a) and cumulative (b) ROA (SC). Dwelling types and OSEFX*

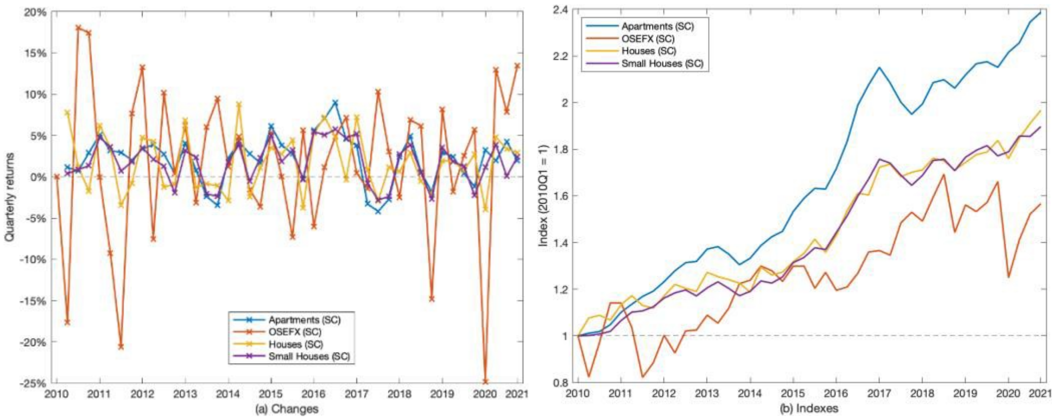
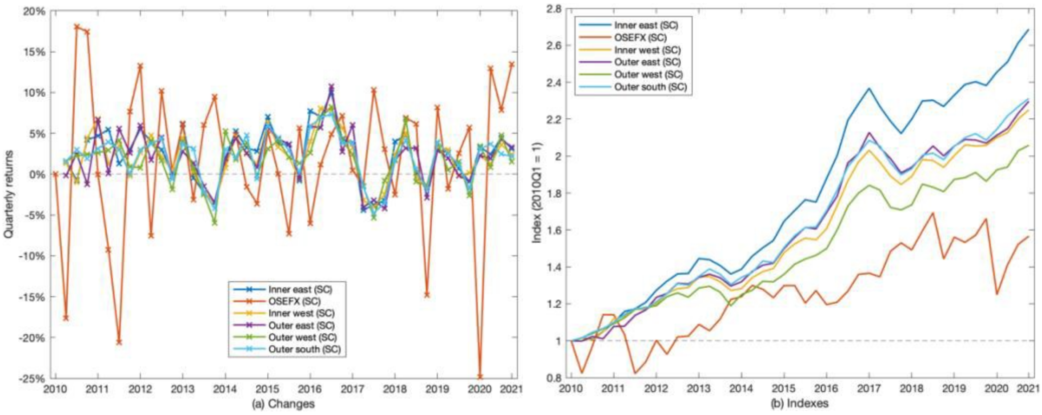


Fig. 9 (a) shows that the quarterly returns offered by all the districts are highly correlated. As observed in Table 16 below, the Inner East region experience the highest average volatility in the returns compared to the other districts, and Outer East experienced the maximum quarterly return out of all districts, with 10.73% in Q3 of 2016. Outer West district offered the lowest quarterly returns during the period, with -5.96% in Q4 of 2013.

***Fig. 9** Quarterly (a) and cumulative (b) ROA (SC), for apartments. Districts and OSEFX*



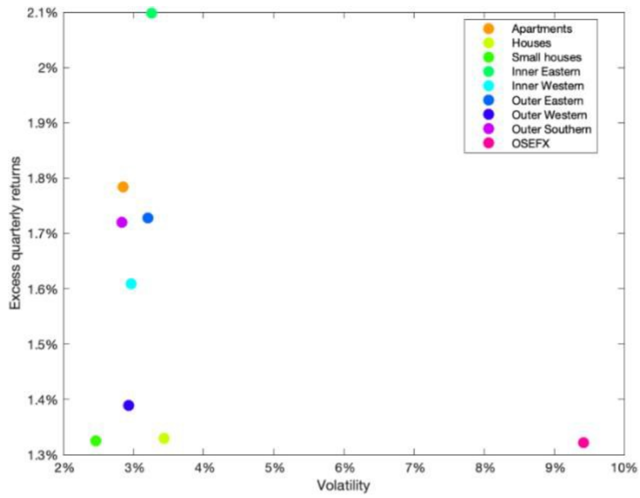
Again, it is the Inner East region, i.e., Gamle Oslo, Grünerløkka and Sagene, that offers the highest appreciation, with an immense 168.68% return over the 11 year period. The ROA (NC) appreciation during this period was 146.70% (see Fig. 4) implying that the additional 21.98% stems from the implicit rent. As we observe, the Outer South, Inner West and Outer East region all appreciated around 120%, and the Outer West experienced the lowest appreciation throughout the sample period, accumulating a 105.6% return.

***Table 16** Return characteristics for ROA (SC), for all stratums*

Stratum	Returns	Volatility	Excess return	Sharpe ratio	Skewness	Kurtosis
Apartments	0.0216	0.0285	0.0178	0.6258	-0.3088	3.0880
Houses	0.0171	0.0344	0.0133	0.3865	0.2018	2.0851
Small houses	0.0171	0.0246	0.0133	0.5380	-0.2753	2.1204
Inner East	0.0248	0.0326	0.0210	0.6435	-0.2466	2.7123
Inner West	0.0199	0.0297	0.0161	0.5420	-0.0494	2.5358
Outer East	0.0211	0.0321	0.0173	0.5388	-0.0058	3.0401
Outer West	0.0177	0.0294	0.0139	0.4732	-0.4288	3.5225
Outer South	0.0210	0.0283	0.0172	0.6071	-0.6327	2.9747
OSEFX	0.0169	0.0942	0.0132	0.1404	-0.8522	3.7315

From Table 16 we observe that the returns to homeownership, for all stratums, are represented by lower volatility and higher excess quarterly returns, thus offering superior risk-return relationship, compared to that of OSEFX. A private investor could then reduce their exposure to volatility remarkably without having to sacrifice on the returns at all, by shifting from mutual fund investments to real estate, as observed in Fig. 10. The dispersion in the quarterly excess returns for different stratums is also very high, ranging from 2.1% for the Inner East district, to 1.33% for Smaller Houses in Oslo.

Fig. 10 *Risk-return relationship for ROA (SC), for all stratums*



Based on the different figures and tables above, one would expect to be able to conclude that the returns offered by homeownership prove to be statistically significantly higher than that of OSEFX. As observed in Fig. 7, 8 and 9, the quarterly returns from OSEFX varies greatly, offering superior returns compared to real estate in some quarters, while far lower (and negative) returns in other quarters. By looking at the results from the Welch tests in Table 17 we are not able to conclude that the mean returns offered by real estate for different dwellings and areas are superior to those of OSEFX. The F-test proves that the mean real estate returns, independent of stratums offers significantly lower volatility than that of OSEFX.

Table 17 *Summary test statistics, ROA (SC), for all stratums.*

	Welch test of difference in mean quarterly returns $H_0: \mu_{R_1} - \mu_{R_2} = 0$ $H_A: \mu_{R_1} - \mu_{R_2} > 0$			F-test of equal variances $H_0: \sigma^2_{R_1} = \sigma^2_{R_2}$ $H_A: \sigma^2_{R_1} < \sigma^2_{R_2}$		
Stratum	$tStat$	$pValue$	$Reject\ H_0$?	$FStat$	$pValue$	$Reject\ H_0$?
Apartments	0.2870	0.3877	No	0.0916	0	Yes
Houses	-0.0154	0.5061	No	0.1334	0	Yes
Small houses	-0.0184	0.5073	No	0.0684	0	Yes
Inner East	0.4903	0.3130	No	0.1198	0	Yes
Inner West	0.1703	0.4327	No	0.0994	0	Yes
Outer East	0.2468	0.4030	No	0.1159	0	Yes
Outer West	0.0239	0.4905	No	0.0971	0	Yes
Outer South	0.2446	0.4039	No	0.0905	0	Yes

We are confident that the risk-return relationship for real estate investments is consistently superior to that of OSEFX, especially considering the findings represented in Table 16 and Fig. 10. The results from testing the modified Sharpe ratios conclude that the risk-adjusted returns offered by real estate investments, independent of dwelling types and districts (apartments), all outperform the benchmark Sharpe ratio of OSEFX.

Table 18 *Test statistics, Sharpe ratios and Probabilistic Sharpe ratios, ROA (SC), for all stratums*

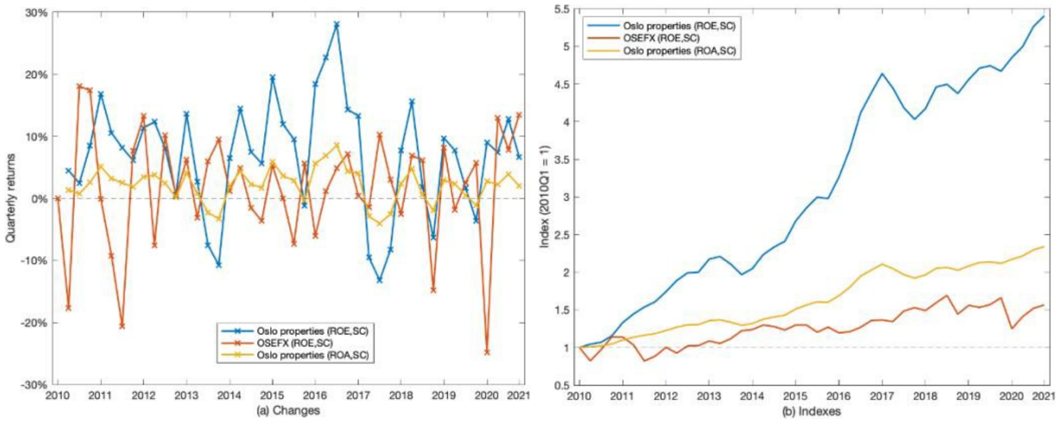
	$H_0: \hat{SR} = SR^{OSEFX}$			$H_A: \hat{SR} > SR^{OSEFX}$		
Stratum	$\hat{SR}$	σ_{SR}	Z_{stat}	$PSR(SR^{OSEFX})$	$pValue$	$Reject\ H_0?$
Apartments	0.6258	0.1812	2.6789	0.9963	0.0037	Yes
Houses	0.3865	0.1496	1.6447	0.9500	0.0500	Yes
Small houses	0.5380	0.1698	2.3421	0.9904	0.0096	Yes
Inner East	0.6435	0.1768	2.8453	0.9978	0.0022	Yes
Inner West	0.5420	0.1633	2.4593	0.9930	0.0070	Yes
Outer East	0.5388	0.1643	2.4242	0.9923	0.0077	Yes
Outer West	0.4732	0.1772	1.8778	0.9698	0.0302	Yes
Outer South	0.6071	0.1917	2.4344	0.9925	0.0075	Yes

Our findings coincide to some extent with findings of Hill and Melser (2019). They find that the average return to housing is significantly higher compared to shares, while we are not able to prove this statistically. However, we both coincide on the fact that real estate investments offer superior risk-return relationship. Delfim and Hoseli (2019) also supports this last statement.

ROE (SC)

Let us now take a deeper look at a highly relevant and interesting aspect of returns to real estate investments in Oslo, namely the ROE. This aspect is represented in Fig. 11 (a), showing that the quarterly ROE (SC) from owning a property in Oslo (blue line) displays far greater variance in the returns compared to OSEFX (red line), and the unlevered ROA (SC) (yellow line). This is because you claim 100% of the capital gains from real estate investments, but you only invest about 30% of the asset value from your own pocket, while the remaining 70% (on average) is borrowed funds. This leads to amplified profits and losses, hence, the risk also rises.

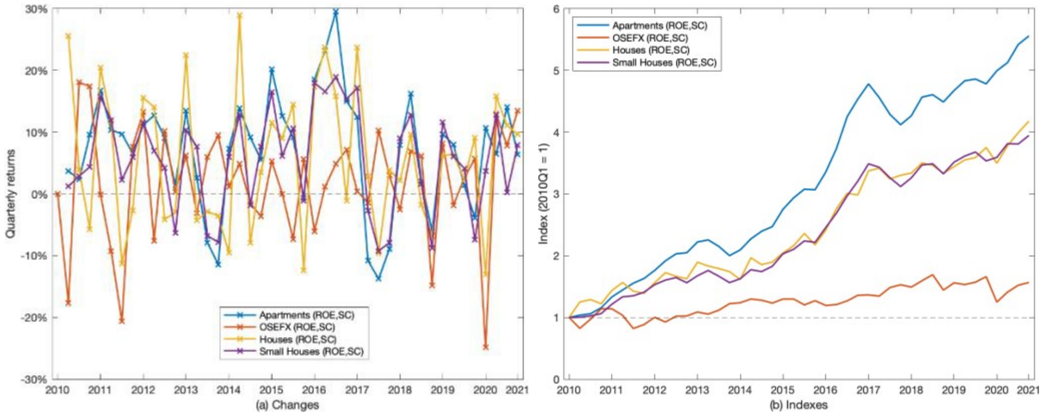
Fig. 11 Quarterly (a) and cumulative (b) ROE (SC). Oslo properties and OSEFX



The quarterly ROE (SC) ranges from 28.08% return in the boom market of 2016, to -13.20% in the third quarter of 2017. The maximum and minimum ROA (SC, yellow line) to Oslo properties was 8.54% in Q3 of 2016 and -4.02% in Q3 of 2017, thus we observe the amplifying effect, which is also observed in the cumulative plots in Fig. 11 (b). It is still worth noticing that even though the variance of the ROE (SC) seemingly is in the ballpark of the variance to the OSEFX, the minimum quarterly return to OSEFX during the sample period is far lower than that of the Oslo properties, with the largest drawdown at -24.83% in Q1 of 2020. ROE (SC, blue line) to residential real estate in Oslo has been massive over the 11-year period, with cumulative returns of approximately 441%, as seen in Fig. 11 (b). In comparison the ROA (SC, yellow line) show 134.08% accumulated returns over the 11-year period. Due to the fact that the ltv-ratios for OSEFX investments is considered to be zero, the ROE related to OSEFX is simply the 56.64% post-tax returns over the sample period.

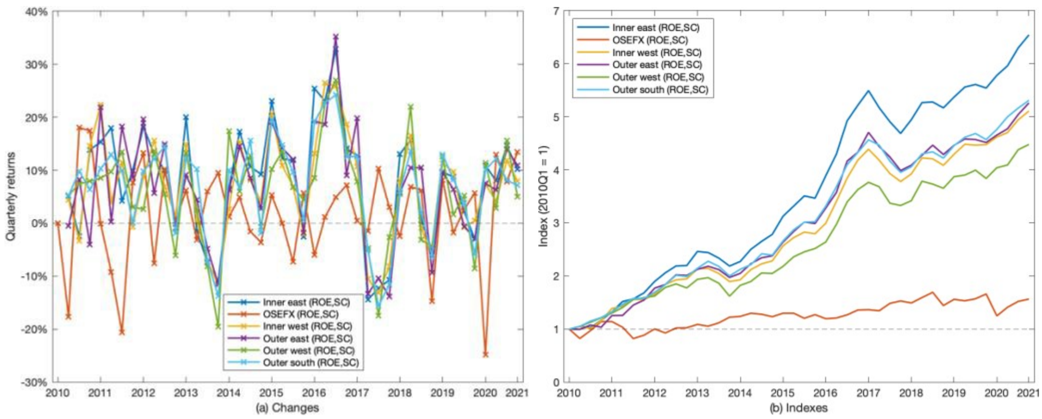
It is interesting to see if there are any specific dwelling types that offer higher ROE (SC) than others. The highest ROE (SC) came from investing in apartments, in Q3 of 2016, at 29.55%. Fig. 12 (b) displays that by buying an apartment in Oslo you will face the highest accumulated ROE (SC), of 455.90%. The same figures are 340.29% and 331.17% for houses and small houses, respectively.

Fig. 12 *Quarterly (a) and cumulative (b) ROE (SC). Dwelling type and OSEFX*



Is there a way for households to further maximize their ROE (SC)? Based on our results from section 6.3.1, there is no surprise that the Inner East district experienced the greatest ROE (SC) during our sample period, as presented in Fig. 13 (b), offering returns 6.54 times your equity investment in Q1 of 2010. Furthermore, the cumulative ROE (SC) when investing in apartments in Oslo is 4.18, 3.26, 3.36, 2.86 and 3.39 times that of OSEFX, for the Inner East, Inner West, Outer East, Outer East, and Outer South district, respectively. The Outer East region offered the highest quarterly ROE, with an immense 35.26% quarterly return in Q3 of 2016, as presented in Fig. 13 (a).

Fig. 13 *Quarterly (a) and cumulative (b) ROE (SC) for apartments. Districts and OSEFX*



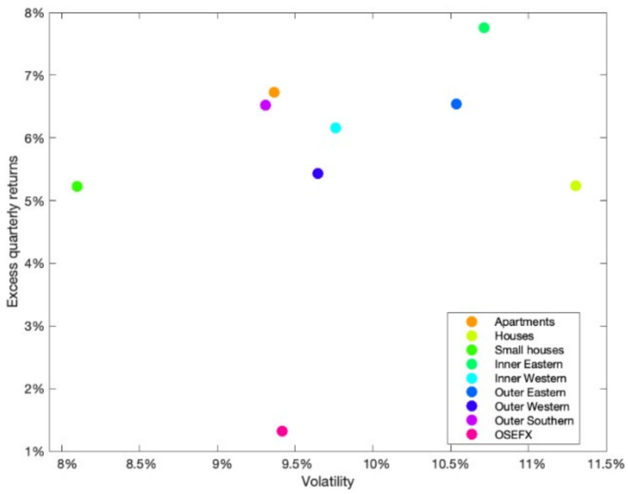
Based on the plots above it is fair to believe that the real estate market offers way better ROE (SC) than that of OSEFX, but at what cost? We get indications that you may have to persevere higher or similar volatility as OSEFX, by leveraging your real estate investments. Table 19 shows that the average quarterly ROE (SC) over the sample period is higher for real estate investments, independent of dwelling type and area of investment, compared to OSEFX.

Table 19 *Return characteristics for ROE (SC), for all stratums*

Stratum	Returns	Volatility	Excess return	Sharpe ratio	Skewness	Kurtosis
Apartments	0.0711	0.0937	0.0673	0.7185	-0.3088	3.0880
Houses	0.0562	0.1130	0.0524	0.4632	0.2018	2.0851
Small houses	0.0560	0.0810	0.0522	0.6451	-0.2753	2.1204
Inner East	0.0814	0.1072	0.0776	0.7244	-0.2466	2.7123
Inner West	0.0654	0.0976	0.0616	0.6309	-0.0494	2.5358
Outer East	0.0692	0.1054	0.0654	0.6211	-0.0058	3.0401
Outer West	0.0581	0.0965	0.0543	0.5631	-0.4288	3.5225
Outer South	0.0690	0.0931	0.0652	0.7003	-0.6327	2.9747
OSEFX	0.0169	0.0942	0.0132	0.1404	-0.8522	3.7315

We observe that by investing in smaller houses in Oslo, you will face higher excess returns, at lower risk compared to that of OSEFX. Furthermore, Outer South, Outer West, Inner West, and apartments in general offers remarkably higher excess quarterly returns, at approximately the same risk levels as OSEFX. Fig. 14 below displays these results perfectly. By compromising a bit on your risk tolerance, you will face higher excess quarterly returns by investing in apartments in the Inner East district. Based on the results in Fig. 14 (a), households would prefer investing in smaller houses, compared to apartments in the Outer West district and houses, as all three of these types offer more or less the same returns, but smaller houses face way lower risk.

Fig. 14 *Risk-return relationship, ROE (SC), for all stratums*



We conclude by stating that the ROE (SC) for real estate investments offer statistically significantly higher mean quarterly returns, independent of dwelling type and district. Furthermore, in line with our findings above, we cannot conclude that the volatility of the ROE (SC) for real estate is lower than that of OSEFX. These results are based on the test results represented in Table 20.

Table 20 *Summary test statistics, ROE (SC), for all stratums*

	Welch test of difference in mean returns $H_0: \mu_{R_1} - \mu_{R_2} = 0$ $H_A: \mu_{R_1} - \mu_{R_2} > 0$			F-test of equal variances $H_0: \sigma^2_{R_1} = \sigma^2_{R_2}$ $H_A: \sigma^2_{R_1} < \sigma^2_{R_2}$		
Stratum	$tStat$	$pValue$	$Reject\ H_0?$	$FStat$	$pValue$	$Reject\ H_0?$
Apartments	2.6542	0.0048	Yes	0.9888	0.4855	No
Houses	1.7307	0.0436	Yes	1.4406	0.8796	No
Small houses	2.0437	0.0221	Yes	0.7391	0.1655	No
Inner East	2.9462	0.0021	Yes	1.2943	0.7966	No
Inner West	2.3327	0.0113	Yes	1.0735	0.5904	No
Outer East	2.4089	0.0091	Yes	1.2516	0.7649	No
Outer West	1.9840	0.0253	Yes	1.0490	0.5612	No
Outer South	2.5582	0.0062	Yes	0.9770	0.4701	No

From Fig. 14 we observe that all stratums display higher excess quarterly returns compared to the OSEFX, but not necessarily lower volatility. However, the quarterly Sharpe ratios are way higher for real estate investments. Based on the test results presented in Table 21, we observe that the excess quarterly returns for all stratums are sufficiently large to conclude that the Sharpe ratios for all stratums are statistically significantly higher than the benchmark of OSEFX.

Table 21 *Test statistics, Sharpe ratios and Probabilistic Sharpe ratios, ROE (SC), for all stratums*

	$H_0: \hat{SR} = SR^{OSEFX}$			$H_A: \hat{SR} > SR^{OSEFX}$		
Stratum	$\hat{SR}$	σ_{SR}	Z_{stat}	$PSR(SR_{OSEFX})$	$pValue$	$Reject\ H_0?$
Apartments	0.7185	0.1872	3.0872	0.9990	0.0010	Yes
Houses	0.4632	0.1498	2.1550	0.9844	0.0156	Yes
Small houses	0.6451	0.1743	2.8961	0.9981	0.0019	Yes
Inner East	0.7244	0.1813	3.2221	0.9994	0.0006	Yes
Inner West	0.6309	0.1665	2.9457	0.9984	0.0016	Yes
Outer East	0.6211	0.1679	2.8632	0.9979	0.0021	Yes
Outer West	0.5631	0.1836	2.3028	0.9894	0.0106	Yes
Outer South	0.7003	0.1989	2.8144	0.9976	0.0024	Yes

7 Conclusion

The objective of this thesis is to examine whether direct residential real estate investments in Oslo, made by individuals and households, outperform the OSEFX based on quarterly-, cumulative- and risk-adjusted returns, for different dwelling types and areas.

When considering the sole price development of Oslo properties, we find that investing in apartments offer the highest cumulative returns, with 120.06% in the period from 2010 to 2020, while OSEFX accumulated a 72.06% return. Houses and smaller houses accumulated 105.41% and 90.22%, respectively. The dispersion in the cumulative apartment returns varies from 146.70% for the Inner East district, to 96.61% for the Outer West district, thus showing the value of taking into account the geographical area of investment, as pointed out by Benedictow et al. (2020). Contrary to these findings, we cannot conclude from our tests that real estate investments, when not considering any costs, have offered superior mean asset returns over the sample period, compared to OSEFX. They do, however, offer significantly lower volatility. These findings are mutual for all dwelling types and districts. Furthermore, all stratums but apartments in the Outer West district offers superior risk-return relationships, compared to that of OSEFX.

We show that private investors will struggle to profit from a short-term buy-and-sell strategy in the housing market. This is in line with findings of Delfim and Hoesli (2019). Transaction costs, living expenses and taxes all create frictions to such investments, and requires unsustainable run-ups in prices to be profitable, as observed in the boom market of 2016. Quarterly costs associated with buying and selling an apartment, house and smaller houses amount to 5.06%, 5.69% and 5.30%[7] of the estimated property, respectively. These extreme cost estimates explain why you will suffer a 100% loss in value of your investment prior to year-end 2020 by following this strategy. Hence, our interpretation indicates that investors should desist from investing in residential real estate with shorter investment horizon. From our results we argue that the investor should instead invest in OSEFX short-term, offering 56.35% cumulative returns over the sample

[7] Calculated as sum of average cost buyer, cost seller, and (liv. exp ÷ 4) from Table 9.

period. This result should be cautiously considered, as one should optimally have longer periods of history for OSEFX and other equity instruments. We conclude that given this strategy, the post-tax OSEFX returns offer significantly higher mean return and Sharpe ratio, compared to that of any dwelling type or district.

When considering a long-term horizon, we find that the implicit rent factor offsets the smoothed costs to a large extent, indicating superior returns for many dwelling types and districts compared to the no-cost-case. In terms of comparing with the OSEFX, we find that apartments appreciated 138.73% over the sample period, compared to 56.64% for the smoothed cost OSEFX returns. Again, the apartments in the Inner East region outperformed the other districts and dwelling types, offering superior mean returns and Sharpe ratios compared to other dwellings and areas. We find that all dwelling types and areas offer superior Sharpe ratios and lower variances in the returns, but not statistically significant better mean returns, when considering a smoothed cost structure, compared to that of OSEFX.

A unique aspect to real estate investments is the debt-to-equity ratio. A private household is first of all interested in their equity returns, or net wealth. Due to favourable tax implications, high ltv-ratios, and a pre-cost real estate appreciation of Oslo properties of 116.98% over the sample period, households experience immense ROE related to their real estate investments. We find that the ROE to homeowners is characterized by far greater variance compared to the general ROA. However, the mean quarterly ROE and Sharpe ratios are significantly higher compared to the ROE offered by investing in OSEFX.

We find that Oslo properties yields 441% cumulative ROE over the sample period. Apartments is the dwelling type offering the highest returns with an impressive 455.90% cumulative ROE, and 6.73% mean quarterly ROE over the sample period. Not surprisingly, we find that the Inner East district offer the highest quarterly Sharpe ratio and mean excess ROE, of 0.7244 and 7.76%, respectively. This district offers a cumulative ROE of 4.18 times that of OSEFX, over the sample period, which is truly remarkable. We conclude that, on the metric most relevant for private households, real estate investments in Oslo outperform the OSEFX on an average-, cumulative-, and risk-adjusted return metric, by a huge margin. Given these results, we conclude that the favourable ROE to housing investments in Oslo is another good reason, in addition to "the Norwegian housing model", as of why a large fraction of Norwegian citizens are homeowners.

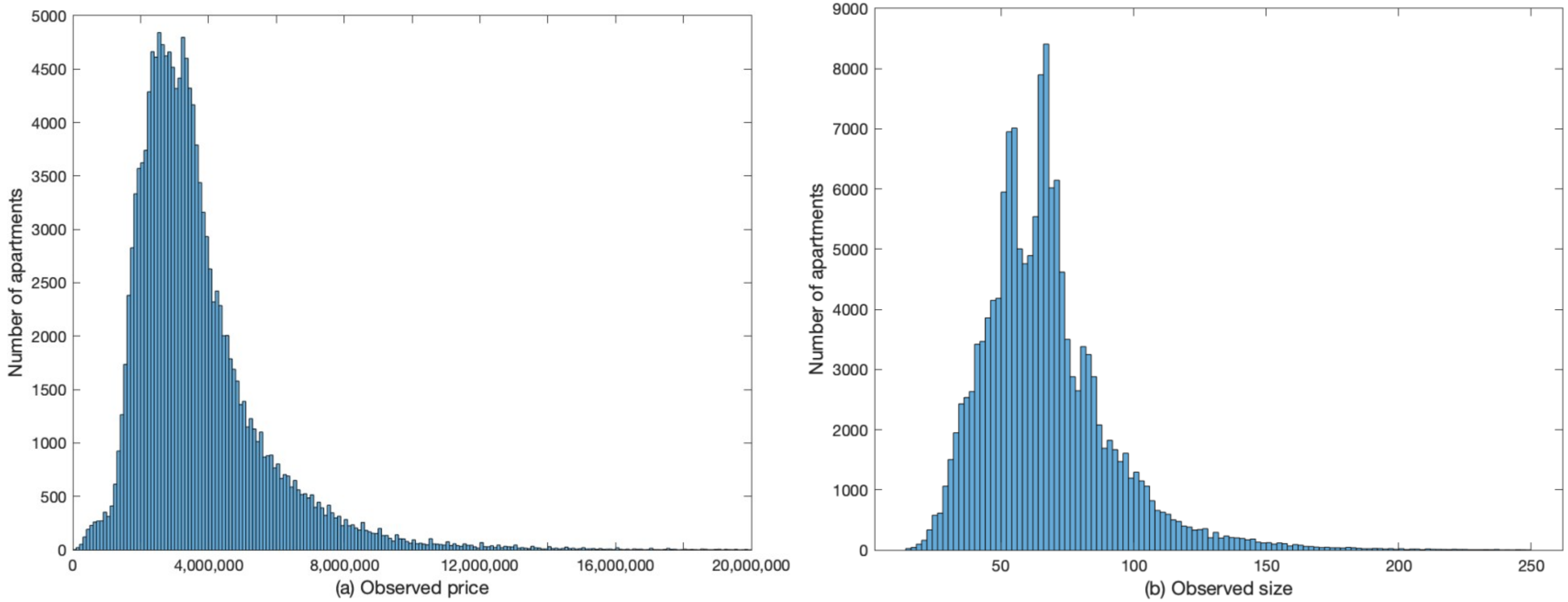
Due to limitations to our data set in terms of number of transactions related to each of the 17 districts of Oslo, we were not able to distinguish the return series down to district level for all dwelling types. It would have been interesting to see whether some districts perform significantly better or worse compared to each other and the OSEFX. Further research could also be conducted on secondary housing, thus studying if buying a dwelling for rental purposes will offer significantly higher returns and risk-adjusted returns compared to OSEFX, as well as other regions in Norway than just Oslo. To do so, one could have built on our model by adjusting tax rates and implications, loan-to-value ratios and living expenses, among other adjustments. It could also be interesting to see whether it is beneficial for private households to buy their own dwelling or rent, for different horizons. In addition, one could study longer and previous sample periods for the housing market in Oslo.

Our findings may be of interest for different stakeholders. First, it might help private households in the choice of if, where and what to buy when it comes to real estate investments in Oslo, given an individual investment horizon, risk preference and comparable investment benchmark (OSEFX). Second, these results may be of interest for banks when distributing mortgages, as they can structure their loan agreements according to where and what their customers wish to invest in, due to differences in credit risk. Third, it may help real estate developers taking better decisions as of where and what to invest in. Finally, it is worth mentioning that historical returns not necessarily forecast future returns. Relatively low rental yield, and surprisingly strong returns over a decade to housing investments, could indicate bubble tendencies, as well as structural disadvantages to those standing outside of the housing market. We will leave it here, but those are definitely interesting topics that could be studied in relation to our results.

8 Appendix

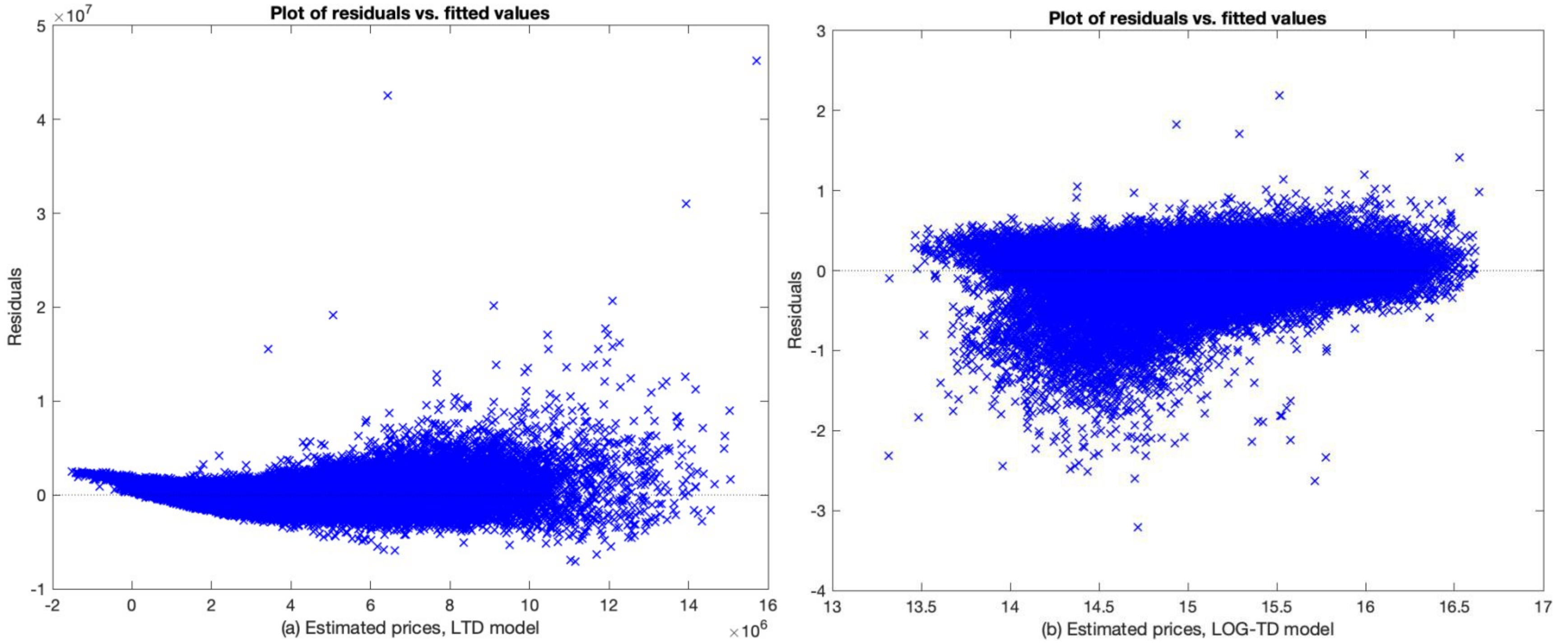
Appendix 1

Appendix 1 *Distribution of observed apartment prices (a) and -sizes (b)*



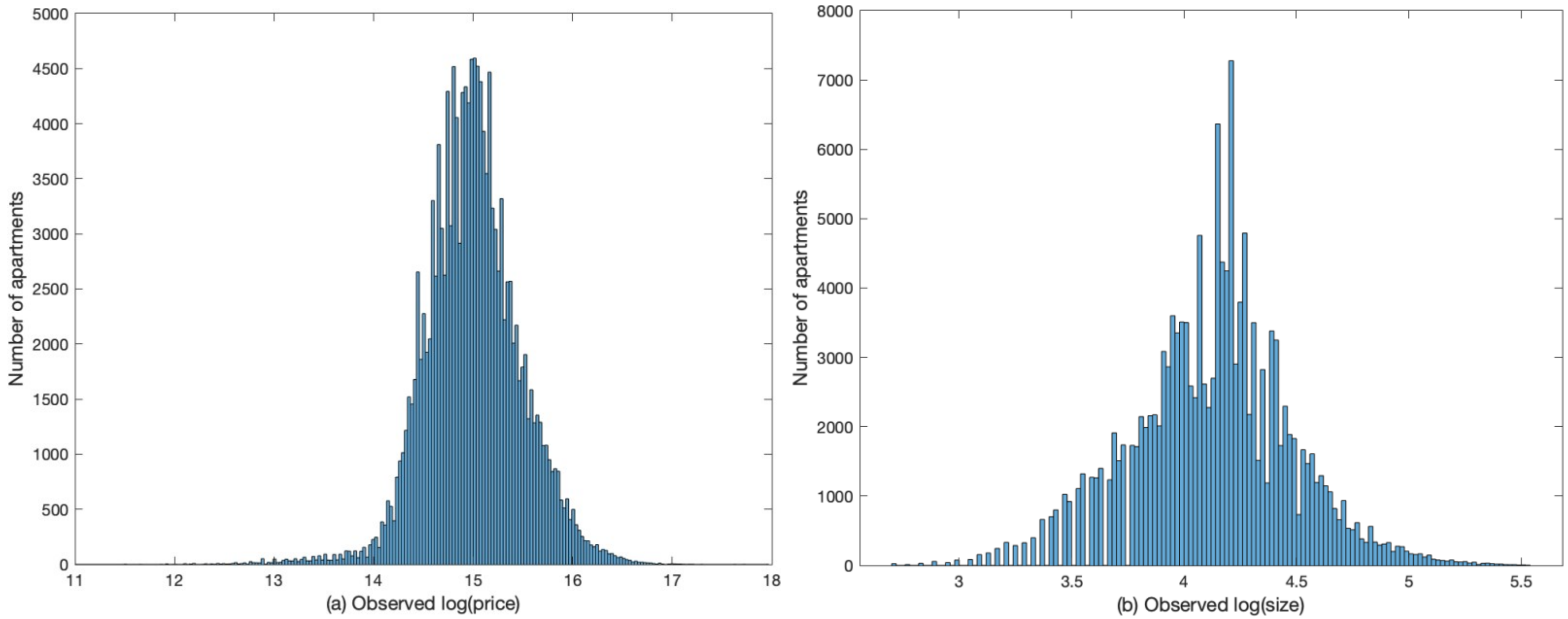
<u>Appendix 2</u>

Appendix 2 *Plot of residuals versus estimated prices for LTD model (a) and LOG-TD model (b)*



Appendix 3

Appendix 3 *Distribution of the logarithm of observed apartment prices (a), and the logarithm of sizes (b)*



Appendix 4

Appendix 4 Transaction costs when buying a dwelling

Dwelling	Apartments		Houses		Small houses	
Ownership type	SOUs	Co-ops	SOUs	Co-ops	SOUs	Co-ops
Stamp duty	2.5%[8]	0%[9]	2.5%[8]	0%[9]	2.5%[8]	0%[9]
Fees[10] (NOK)	1,152	1,052	1,152	1,052	1,152	1,052
Insurance[11] (NOK)	7,400	4,100	11,500	4,100	9,450	4,100

Appendix 5

Appendix 5 Yearly court fees, in relation to change in ownership of co-ops, The Norwegian Tax Administration (n.d.-c).

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
One court fee	860	860	860	860	860	860	1,025	1,049	1,130	1,150	1,172

Appendix 6

Appendix 6.1 Transaction costs when selling a dwelling

Dwelling	Apartments		Houses		Small houses	
Ownership	SOUs	Co-ops	SOUs	Co-ops	SOUs	Co-ops
Documentation[12] (NOK)	8,430	14,319	4,930	10,819	8,430	14,319
Commission[13]	2%	2%	2%	2%	2%	2%
Minimum commission[11] (NOK)	40,000	40,000	40,000	40,000	40,000	40,000
Fees (NOK)*	0	4,858	0	4,858	0	4,858
Home seller insurance**	**	**	**	**	**	**

*These fees are computed as explained in section 5.2.2, with the yearly one court fees computed as in Eq. 49
** These rates are presented in Appendix 6.2 below

8 (Kartverket, 2021b)
9 (Kartverket, 2021a)
10 (Kartverket, 2021c)
11 (HELP, n.d.)
12 (Krogsveen, n.d.-a)
13 (Stamsø, 2011, p. 17)

$$Fees\ (NOK) = 4 * (\frac{1}{11}\sum_{t=2010}^{2020} One\ court\ fee_t) * (1 + VAT) = \mathbf{4{,}858} \quad (49)$$

where, $Fees\ (NOK)$ is the total fee related to change in ownership of co-ops, $One\ court\ fee_t$ is the one court fee at time t, VAT is the Value Added Tax rate in Norway, of 25%.

Appendix 6.2 *Home seller insurances, for different dwelling- and ownership types, based on figures from Pedersen (2021)*

Ownership	Co-ops			SOUs		
Dwellings	Min., NOK	Max., NOK	Rate*	Min., NOK	Max., NOK	Rate*
Apartments	2,500	24,000	0.20%	4,000	24,000	0.33%
Houses	2,500	24,000	0.20%	10,250**	48,750**	0.5%**
Small houses	2,500	24,000	0.20%	10,250**	48,750**	0.5%**

*The rates are expressed as a percentage of the total price of the dwelling

**As we do not know whether the seller will include a report in the selling process or not, we use the average cost estimates of selling with and without a so-called "Boligsalgsrapport".

Appendix 7

***Appendix** 7 Regression output based on LOG-TD model for dwelling types*

Variable	D	Apartments				Houses				Small houses			
		Estimate	SE	tStat	pValue	Estimate	SE	tStat	pValue	Estimate	SE	tStat	pValue
Intercept	-	11.55805	0.01014	1139.48	0	12.23524	0.04844	252.59	0	12.26512	0.03674	333.88	0
Region_Alna	1	-0.32181	0.00262	-122.87	0	-0.41133	0.02439	-16.86	0	-0.46035	0.01615	-28.50	0
Region_Bjerke	2	-0.19274	0.00303	-63.55	0	-0.15352	0.02444	-6.28	0	-0.21960	0.01650	-13.31	0
Region_Frogner	3	0.20027	0.00228	87.72	0	0.33974	0.02696	12.60	0	0.31706	0.02030	15.62	0
Region_Gamle Oslo	4	-0.10706	0.00217	-49.32	0	-0.06467	0.03018	-2.14	0.03216	-0.07562	0.01905	-3.97	0
Region_Grorud	5	-0.40275	0.00345	-116.58	0	-0.43894	0.02415	-18.18	0	-0.43300	0.01711	-25.30	0
Region_Nordre Aker	6	0.08791	0.00306	28.74	0	0.13009	0.02283	5.70	0	0.11661	0.01583	7.37	0
Region_Nordstrand	7	-0.09128	0.00288	-31.73	0	-0.02677	0.02220	-1.21	0.22798	-0.09098	0.01576	-5.77	0
Region_Sagene	8	0.06567	0.00214	30.65	0	0.17823	0.05563	3.20	0.00136	0.20168	0.03466	5.82	0
Region_Sentrum	9	0.06545	0.01216	5.38	0	-	-	-	-	-	-	-	-
Region_St. Hanshaugen	10	0.10503	0.00243	43.25	0	0.12455	0.03635	3.43	0.00061	0.15473	0.03385	4.57	0
Region_Stovner	11	-0.46118	0.00390	-118.24	0	-0.45962	0.02319	-19.82	0	-0.53994	0.01610	-33.53	0
Region_Søndre Nordstrand	12	-0.47457	0.00391	-121.30	0	-0.55112	0.02255	-24.44	0	-0.58029	0.01588	-36.54	0
Region_Ullern	13	0.12446	0.00326	38.21	0	0.08953	0.02319	3.86	0.00011	-0.00161	0.01610	-0.10	0.92044
Region_Vestre Aker	14	0.03736	0.00329	11.36	0	0.09377	0.02233	4.20	0	0.01661	0.01588	1.05	0.29567
Region_Østensjø	15	-0.18577	0.00260	-71.57	0	-0.17461	0.02301	-7.59	0	-0.18702	0.01575	-11.87	0
Region_Marka	16	-	-	-	-	-0.19424	0.03372	-5.76	0	-0.29297	0.09095	-3.22	0.00128
Ownership_Co-ops	1	-0.13987	0.00130	-107.88	0	-	-	-	-	-0.06719	0.00391	-17.18	0
Floor_2	1	0.02778	0.00167	16.67	0	-	-	-	-	-	-	-	-
Floor_3	2	0.02966	0.00172	17.27	0	-	-	-	-	-	-	-	-
Floor_4	3	0.02900	0.00182	15.91	0	-	-	-	-	-	-	-	-
Floor_5	4	0.04745	0.00233	20.41	0	-	-	-	-	-	-	-	-

Variable	D	Apartments				Houses				Small houses			
		Estimate	**SE**	**tStat**	**pValue**	**Estimate**	**SE**	**tStat**	**pValue**	**Estimate**	**SE**	**tStat**	**pValue**
Floor_6	5	0.04272	0.00329	12.98	0	-	-	-	-	-	-	-	-
Floor_7	6	0.05893	0.00429	13.74	0	-	-	-	-	-	-	-	-
Floor_8	7	0.06753	0.00535	12.61	0	-	-	-	-	-	-	-	-
Floor_9	8	0.08515	0.00728	11.70	0	-	-	-	-	-	-	-	-
Floor_10	9	0.11791	0.00881	13.38	0	-	-	-	-	-	-	-	-
Floor_11	10	0.12455	0.00906	13.74	0	-	-	-	-	-	-	-	-
Floor_12	11	0.12388	0.01090	11.36	0	-	-	-	-	-	-	-	-
Floor_13	12	0.11606	0.01562	7.43	0	-	-	-	-	-	-	-	-
Floor_14	13	0.23115	0.02999	7.71	0	-	-	-	-	-	-	-	-
Floor_15	14	0.28436	0.04472	6.36	0	-	-	-	-	-	-	-	-
Floor_-1	15	-0.11890	0.01277	-9.31	0	-	-	-	-	-	-	-	-
Floor_-2	16	-0.14507	0.01861	-7.80	0	-	-	-	-	-	-	-	-
Floor_-3	17	-0.12736	0.03033	-4.20	0	-	-	-	-	-	-	-	-
Floor_-4	18	-0.15853	0.05245	-3.02	0.00251	-	-	-	-	-	-	-	-
Bedrooms	-	0.01314	0.00111	11.84	0	0.00689	0.00276	2.49	0.01272	0.02115	0.00252	8.40	0
2010Q2	1	0.00880	0.00524	1.68	0.09287	0.07620	0.02197	3.47	0.00053	0.00240	0.01488	0.16	0.87185
2010Q3	2	0.01338	0.00538	2.49	0.01292	0.08947	0.02308	3.88	0.00011	0.00986	0.01635	0.60	0.54657
2010Q4	3	0.03971	0.00553	7.18	0	0.07328	0.02415	3.03	0.00242	0.02183	0.01738	1.26	0.20911
2011Q1	4	0.08723	0.00540	16.14	0	0.13454	0.02383	5.65	0	0.06714	0.01603	4.19	0
2011Q2	5	0.11614	0.00516	22.52	0	0.17029	0.02143	7.95	0	0.10145	0.01502	6.76	0
2011Q3	6	0.14316	0.00542	26.44	0	0.13620	0.02261	6.02	0	0.10706	0.01597	6.70	0
2011Q4	7	0.16098	0.00560	28.73	0	0.12898	0.02372	5.44	0	0.12382	0.01629	7.60	0
2012Q1	8	0.19173	0.00538	35.64	0	0.17591	0.02342	7.51	0	0.15662	0.01581	9.90	0
2012Q2	9	0.22721	0.00514	44.22	0	0.21850	0.02196	9.95	0	0.17611	0.01501	11.73	0
2012Q3	10	0.25197	0.00548	45.99	0	0.20661	0.02290	9.02	0	0.18723	0.01633	11.46	0

Variable	D	Apartments				Houses				Small houses			
		Estimate	SE	tStat	pValue	Estimate	SE	tStat	pValue	Estimate	SE	tStat	pValue
2012Q4	11	0.25376	0.00564	45.02	0	0.19815	0.02412	8.22	0	0.16621	0.01620	10.26	0
2013Q1	12	0.29154	0.00544	53.58	0	0.26489	0.02281	11.61	0	0.19583	0.01600	12.24	0
2013Q2	13	0.29719	0.00516	57.63	0	0.25241	0.02162	11.68	0	0.21757	0.01461	14.89	0
2013Q3	14	0.27058	0.00540	50.11	0	0.24445	0.02292	10.66	0	0.19532	0.01607	12.16	0
2013Q4	15	0.23278	0.00567	41.04	0	0.23426	0.02401	9.76	0	0.16984	0.01626	10.44	0
2014Q1	16	0.25233	0.00544	46.41	0	0.20548	0.02406	8.54	0	0.18641	0.01617	11.53	0
2014Q2	17	0.29117	0.00517	56.31	0	0.29045	0.02194	13.24	0	0.22319	0.01487	15.01	0
2014Q3	18	0.31627	0.00530	59.63	0	0.26666	0.02313	11.53	0	0.21631	0.01591	13.60	0
2014Q4	19	0.33058	0.00559	59.11	0	0.27806	0.02513	11.07	0	0.23799	0.01645	14.47	0
2015Q1	20	0.38711	0.00521	74.26	0	0.31264	0.02283	13.70	0	0.28502	0.01578	18.06	0
2015Q2	21	0.42170	0.00507	83.23	0	0.33975	0.02130	15.95	0	0.30146	0.01473	20.47	0
2015Q3	22	0.44608	0.00534	83.54	0	0.38286	0.02287	16.74	0	0.33119	0.01633	20.28	0
2015Q4	23	0.44087	0.00554	79.57	0	0.34433	0.02338	14.73	0	0.32570	0.01645	19.80	0
2016Q1	24	0.49248	0.00544	90.49	0	0.39543	0.02432	16.26	0	0.37668	0.01665	22.63	0
2016Q2	25	0.55758	0.00504	110.66	0	0.46461	0.02158	21.53	0	0.42352	0.01480	28.62	0
2016Q3	26	0.64066	0.00544	117.69	0	0.51121	0.02286	22.36	0	0.47711	0.01632	29.23	0
2016Q4	27	0.68246	0.00569	119.88	0	0.50729	0.02369	21.41	0	0.52068	0.01688	30.85	0
2017Q1	28	0.71680	0.00541	132.57	0	0.57687	0.02386	24.18	0	0.56967	0.01634	34.86	0
2017Q2	29	0.68046	0.00522	130.39	0	0.58540	0.02186	26.78	0	0.55963	0.01503	37.24	0
2017Q3	30	0.63457	0.00542	117.12	0	0.55566	0.02316	24.00	0	0.52920	0.01617	32.72	0
2017Q4	31	0.60371	0.00554	109.01	0	0.56707	0.02461	23.04	0	0.50283	0.01639	30.68	0
2018Q1	32	0.62462	0.00539	115.98	0	0.57412	0.02460	23.33	0	0.52816	0.01636	32.29	0
2018Q2	33	0.66996	0.00510	131.45	0	0.60297	0.02160	27.91	0	0.56470	0.01480	38.16	0
2018Q3	34	0.67327	0.00535	125.95	0	0.59752	0.02270	26.33	0	0.56759	0.01572	36.11	0
2018Q4	35	0.65159	0.00546	119.25	0	0.57674	0.02384	24.19	0	0.53876	0.01610	33.47	0

Variable	D	Apartments				Houses				Small houses			
		Estimate	SE	tStat	pValue	Estimate	SE	tStat	pValue	Estimate	SE	tStat	pValue
2019Q1	36	0.67871	0.00524	129.49	0	0.59644	0.02395	24.90	0	0.57252	0.01566	36.56	0
2019Q2	37	0.70043	0.00498	140.63	0	0.61630	0.02121	29.05	0	0.58980	0.01447	40.77	0
2019Q3	38	0.70234	0.00520	135.01	0	0.62402	0.02194	28.44	0	0.60126	0.01530	39.29	0
2019Q4	39	0.68813	0.00540	127.33	0	0.65184	0.02424	26.89	0	0.57735	0.01602	36.04	0
2020Q1	40	0.71697	0.00526	136.40	0	0.61125	0.02444	25.01	0	0.58655	0.01576	37.22	0
2020Q2	41	0.73342	0.00502	146.03	0	0.65806	0.02167	30.36	0	0.62283	0.01481	42.05	0
2020Q3	42	0.77231	0.00502	153.85	0	0.69116	0.02210	31.27	0	0.62136	0.01509	41.17	0
2020Q4	43	0.78871	0.00530	148.84	0	0.71983	0.02298	31.32	0	0.64301	0.01615	39.81	0
Age_2	1	-0.11462	0.00284	-40.31	0	-0.05785	0.01149	-5.03	0	-0.04641	0.00791	-5.87	0
Age_3	2	-0.08491	0.00312	-27.21	0	-0.11324	0.00893	-12.68	0	-0.09788	0.00715	-13.69	0
Age_4	3	-0.10658	0.00254	-41.90	0	-0.09203	0.00815	-11.29	0	-0.10776	0.00611	-17.63	0
ln_Size	-	0.76469	0.00250	305.88	0	0.67082	0.00893	75.15	0	0.65762	0.00736	89.40	0

Appendix 8

***Appendix 8** Regression output based on LOG-TD model for districts of apartments*

Variable	D	Inner East				Inner West				Outer East			
		Estimate	SE	tStat	pValue	Estimate	SE	tStat	pValue	Estimate	SE	tStat	pValue
Intercept	-	11.46409	0.01963	583.98	0	11.56682	0.01887	612.88	0	13.35638	0.02748	486.12	0
Ownership_Co-ops	1	-0.17148	0.00217	-78.98	0	-0.16910	0.00303	-55.75	0	-0.13440	0.00277	-48.60	0
Floor_2	1	0.04693	0.00337	13.91	0	0.06241	0.00372	16.76	0	0.00288	0.00330	0.87	0.38242
Floor_3	2	0.05296	0.00343	15.45	0	0.07249	0.00376	19.29	0	0.00170	0.00337	0.51	0.61338
Floor_4	3	0.05500	0.00357	15.42	0	0.07050	0.00387	18.20	0	0.00210	0.00359	0.59	0.55785
Floor_5	4	0.07528	0.00402	18.75	0	0.09358	0.00434	21.58	0	-0.03512	0.00645	-5.44	0
Floor_6	5	0.07774	0.00584	13.31	0	0.11729	0.00627	18.70	0	-0.05747	0.00692	-8.30	0
Floor_7	6	0.10385	0.00788	13.17	0	0.13080	0.00925	14.13	0	-0.05698	0.00784	-7.27	0
Floor_8	7	0.10420	0.01199	8.69	0	0.19120	0.01278	14.96	0	-0.03506	0.00826	-4.25	0
Floor_9	8	0.13146	0.01651	7.96	0	0.18543	0.02125	8.73	0	0.00326	0.01046	0.31	0.75555
Floor_10	9	0.18193	0.01996	9.11	0	0.26408	0.02870	9.20	0	0.01746	0.01113	1.57	0.11653
Floor_11	10	0.24293	0.02128	11.41	0	0.25380	0.03576	7.10	0	0.00776	0.01085	0.72	0.47437
Floor_12	11	0.21805	0.02646	8.24	0	0.39269	0.05874	6.68	0	0.00429	0.01223	0.35	0.72601
Floor_13	12	0.24718	0.03273	7.55	0	0.20690	0.06907	3.00	0.00274	0.00356	0.01614	0.22	0.82539
Floor_14	13	0.27014	0.04539	5.95	0	-	-	-	-	0.05521	0.03820	1.45	0.14839
Floor_15	14	0.29246	0.05657	5.17	0	-	-	-	-	-0.01953	0.08735	-0.22	0.82310
Floor_-1	15	-0.13111	0.04185	-3.13	0.00173	-0.12207	0.03501	-3.49	0.00049	-0.12992	0.02318	-5.61	0
Floor_-2	16	-	-	-	-	-	-	-	-	-0.16954	0.02347	-7.22	0
Floor_-3	17	0.02644	0.13841	0.19	0.84848	-	-	-	-	-0.22943	0.07145	-3.21	0.00132
Floor_-4	18	-	-	-	-	-	-	-	-	-	-	-	-
Bedrooms	-	0.03480	0.00216	16.09	0	0.00061	0.00224	0.27	0.78624	0.06725	0.00235	28.57	0
2010Q2	1	0.01226	0.00999	1.23	0.21976	0.01205	0.01054	1.14	0.25305	-0.00497	0.01050	-0.47	0.63624

Variable	D	Inner East				Inner West				Outer East			
		Estimate	SE	tStat	pValue	Estimate	SE	tStat	pValue	Estimate	SE	tStat	pValue
2010Q3	2	0.00167	0.01019	0.16	0.86944	0.00062	0.01089	0.06	0.95452	0.01633	0.01075	1.52	0.12855
2010Q4	3	0.03995	0.01071	3.73	0.00019	0.04302	0.01133	3.80	0.00015	0.00049	0.01077	0.05	0.96340
2011Q1	4	0.08280	0.01038	7.98	0	0.10775	0.01092	9.87	0	0.06193	0.01090	5.68	0
2011Q2	5	0.13350	0.00985	13.55	0	0.11862	0.01030	11.51	0	0.05972	0.01052	5.68	0
2011Q3	6	0.14360	0.01018	14.10	0	0.15211	0.01085	14.02	0	0.11073	0.01114	9.94	0
2011Q4	7	0.17075	0.01083	15.77	0	0.14894	0.01113	13.38	0	0.13380	0.01112	12.03	0
2012Q1	8	0.22149	0.01032	21.47	0	0.17370	0.01086	16.00	0	0.18817	0.01098	17.13	0
2012Q2	9	0.25755	0.00975	26.43	0	0.21879	0.01051	20.82	0	0.20189	0.01047	19.27	0
2012Q3	10	0.28441	0.01037	27.43	0	0.23816	0.01101	21.64	0	0.24286	0.01134	21.42	0
2012Q4	11	0.28310	0.01074	26.35	0	0.24123	0.01148	21.02	0	0.23673	0.01131	20.93	0
2013Q1	12	0.33959	0.01030	32.96	0	0.28429	0.01127	25.23	0	0.26090	0.01082	24.10	0
2013Q2	13	0.33230	0.00984	33.76	0	0.28460	0.01074	26.49	0	0.27119	0.01030	26.33	0
2013Q3	14	0.30656	0.01008	30.42	0	0.26157	0.01122	23.31	0	0.25326	0.01114	22.74	0
2013Q4	15	0.26935	0.01078	24.98	0	0.22390	0.01165	19.23	0	0.21437	0.01133	18.91	0
2014Q1	16	0.28605	0.01029	27.80	0	0.23042	0.01122	20.54	0	0.22968	0.01090	21.07	0
2014Q2	17	0.33444	0.00977	34.23	0	0.27462	0.01067	25.73	0	0.26940	0.01041	25.88	0
2014Q3	18	0.36364	0.00994	36.59	0	0.29784	0.01082	27.53	0	0.29163	0.01085	26.88	0
2014Q4	19	0.38862	0.01081	35.94	0	0.30915	0.01129	27.37	0	0.29671	0.01107	26.81	0
2015Q1	20	0.45308	0.00989	45.81	0	0.36846	0.01064	34.64	0	0.34927	0.01051	33.23	0
2015Q2	21	0.48630	0.00969	50.19	0	0.39907	0.01022	39.04	0	0.38737	0.01019	38.02	0
2015Q3	22	0.51827	0.00992	52.26	0	0.41803	0.01081	38.68	0	0.41920	0.01117	37.53	0
2015Q4	23	0.50687	0.01057	47.98	0	0.40966	0.01145	35.77	0	0.40939	0.01089	37.60	0
2016Q1	24	0.57815	0.01027	56.31	0	0.44695	0.01111	40.24	0	0.46218	0.01090	42.41	0
2016Q2	25	0.64259	0.00949	67.72	0	0.52237	0.01035	50.46	0	0.51322	0.01004	51.13	0
2016Q3	26	0.73474	0.01019	72.14	0	0.59623	0.01099	54.27	0	0.61113	0.01111	55.02	0

Variable	D	Inner East				Inner West				Outer East			
		Estimate	**SE**	**tStat**	**pValue**	**Estimate**	**SE**	**tStat**	**pValue**	**Estimate**	**SE**	**tStat**	**pValue**
2016Q4	27	0.77364	0.01087	71.20	0	0.64956	0.01161	55.93	0	0.63437	0.01120	56.66	0
2017Q1	28	0.80873	0.01042	77.60	0	0.67993	0.01110	61.24	0	0.68934	0.01061	64.99	0
2017Q2	29	0.76073	0.00984	77.32	0	0.64543	0.01086	59.42	0	0.64400	0.01038	62.03	0
2017Q3	30	0.71927	0.01014	70.91	0	0.60254	0.01120	53.82	0	0.60767	0.01084	56.07	0
2017Q4	31	0.68262	0.01044	65.40	0	0.57515	0.01163	49.46	0	0.56016	0.01083	51.73	0
2018Q1	32	0.71861	0.01017	70.66	0	0.59749	0.01130	52.87	0	0.57372	0.01054	54.44	0
2018Q2	33	0.76236	0.00954	79.92	0	0.64503	0.01066	60.51	0	0.60140	0.01025	58.68	0
2018Q3	34	0.76108	0.00997	76.31	0	0.64046	0.01103	58.07	0	0.62893	0.01065	59.03	0
2018Q4	35	0.74193	0.01031	71.94	0	0.61866	0.01154	53.59	0	0.59581	0.01058	56.32	0
2019Q1	36	0.76870	0.00988	77.80	0	0.65127	0.01095	59.46	0	0.62173	0.01032	60.25	0
2019Q2	37	0.79231	0.00932	85.05	0	0.67912	0.01041	65.24	0	0.63806	0.01000	63.84	0
2019Q3	38	0.79655	0.00963	82.69	0	0.67514	0.01076	62.76	0	0.63313	0.01056	59.95	0
2019Q4	39	0.78466	0.01016	77.19	0	0.67522	0.01132	59.64	0	0.62114	0.01079	57.56	0
2020Q1	40	0.81414	0.00985	82.67	0	0.69516	0.01101	63.14	0	0.63950	0.01044	61.23	0
2020Q2	41	0.83504	0.00935	89.34	0	0.70584	0.01060	66.61	0	0.65411	0.01011	64.69	0
2020Q3	42	0.87552	0.00936	93.51	0	0.73931	0.01034	71.49	0	0.69168	0.01011	68.41	0
2020Q4	43	0.90301	0.01005	89.85	0	0.76122	0.01104	68.94	0	0.72030	0.01045	68.95	0
Age_2	1	-0.11460	0.00408	-28.12	0	-0.22057	0.01032	-21.37	0	-0.15752	0.00866	-18.19	0
Age_3	2	-0.06090	0.00511	-11.91	0	-0.20974	0.01044	-20.08	0	-0.09902	0.01101	-9.00	0
Age_4	3	-0.00245	0.00362	-0.68	0.49912	-0.27847	0.00970	-28.72	0	-0.23594	0.00751	-31.43	0
ln_Size	-	0.74237	0.00494	150.14	0	0.84174	0.00392	214.67	0	0.27797	0.00689	40.32	0

__Appendix 8__ Regression output based on LOG-TD model for districts of apartments, continued

Variable	D	Outer West				Outer South			
		Estimate	**SE**	**tStat**	**pValue**	**Estimate**	**SE**	**tStat**	**pValue**
Intercept	-	11.29330	0.02818	400.69	0	11.44869	0.03629	315.51	0
Ownership_Co-ops	1	-0.06421	0.00350	-18.34	0	-0.18146	0.00365	-49.71	0
Floor_2	1	0.01851	0.00394	4.70	0	0.00667	0.00388	1.72	0.08594
Floor_3	2	0.02052	0.00437	4.69	0	-0.00526	0.00406	-1.30	0.19501
Floor_4	3	0.00600	0.00524	1.14	0.25278	-0.02099	0.00441	-4.76	0
Floor_5	4	0.01883	0.00820	2.30	0.02171	-0.00966	0.00940	-1.03	0.30412
Floor_6	5	0.02377	0.01004	2.37	0.01793	-0.04133	0.01233	-3.35	0.00080
Floor_7	6	0.02559	0.01129	2.27	0.02341	0.01179	0.01418	0.83	0.40549
Floor_8	7	0.05344	0.01199	4.46	0	-0.00877	0.01500	-0.58	0.55876
Floor_9	8	0.04394	0.01842	2.38	0.01710	-0.02766	0.01700	-1.63	0.10369
Floor_10	9	-0.03152	0.02475	-1.27	0.20274	0.00269	0.02536	0.11	0.91546
Floor_11	10	-0.04108	0.03435	-1.20	0.23174	0.05645	0.02239	2.52	0.01169
Floor_12	11	-	-	-	-	0.02423	0.02445	0.99	0.32181
Floor_13	12	-	-	-	-	-	-	-	-
Floor_14	13	-	-	-	-	-	-	-	-
Floor_15	14	-	-	-	-	-	-	-	-
Floor_-1	15	-0.12601	0.01811	-6.96	0	-0.04837	0.03501	-1.38	0.16710
Floor_-2	16	-0.12012	0.02450	-4.90	0	0.15642	0.07181	2.18	0.02939
Floor_-3	17	-0.16246	0.03335	-4.87	0	0.43289	0.09077	4.77	0
Floor_-4	18	-0.16487	0.05184	-3.18	0.00147	-0.07055	0.14342	-0.49	0.62282

Variable	D	Outer West				Outer South			
		Estimate	**SE**	**tStat**	**pValue**	**Estimate**	**SE**	**tStat**	**pValue**
Bedrooms	-	0.02888	0.00292	9.90	0	0.00268	0.00317	0.85	0.39749
2010Q2	1	0.01512	0.01427	1.06	0.28937	0.01260	0.01342	0.94	0.34796
2010Q3	2	0.03659	0.01478	2.48	0.01330	0.03918	0.01397	2.81	0.00503
2010Q4	3	0.05954	0.01511	3.94	0	0.05548	0.01381	4.02	0
2011Q1	4	0.08438	0.01493	5.65	0	0.08362	0.01335	6.26	0
2011Q2	5	0.11271	0.01396	8.08	0	0.11958	0.01319	9.06	0
2011Q3	6	0.15216	0.01484	10.25	0	0.14667	0.01412	10.39	0
2011Q4	7	0.16070	0.01516	10.60	0	0.14446	0.01449	9.97	0
2012Q1	8	0.16746	0.01429	11.72	0	0.17084	0.01363	12.53	0
2012Q2	9	0.20706	0.01380	15.00	0	0.20392	0.01302	15.67	0
2012Q3	10	0.22239	0.01490	14.93	0	0.24409	0.01397	17.47	0
2012Q4	11	0.20259	0.01528	13.26	0	0.23530	0.01430	16.45	0
2013Q1	12	0.24103	0.01502	16.04	0	0.26914	0.01365	19.72	0
2013Q2	13	0.24752	0.01380	17.94	0	0.29692	0.01289	23.03	0
2013Q3	14	0.22146	0.01473	15.03	0	0.27205	0.01361	19.98	0
2013Q4	15	0.15896	0.01562	10.18	0	0.22628	0.01418	15.95	0
2014Q1	16	0.20925	0.01504	13.91	0	0.25329	0.01357	18.67	0
2014Q2	17	0.22604	0.01394	16.21	0	0.27072	0.01319	20.52	0
2014Q3	18	0.26315	0.01436	18.33	0	0.31422	0.01382	22.74	0
2014Q4	19	0.25998	0.01534	16.95	0	0.30571	0.01397	21.89	0
2015Q1	20	0.28879	0.01409	20.49	0	0.36012	0.01331	27.07	0
2015Q2	21	0.32747	0.01378	23.76	0	0.40018	0.01286	31.11	0
2015Q3	22	0.34604	0.01458	23.73	0	0.42538	0.01405	30.29	0
2015Q4	23	0.35767	0.01514	23.62	0	0.42334	0.01400	30.24	0
2016Q1	24	0.38132	0.01518	25.13	0	0.47626	0.01385	34.38	0

Variable	D	Outer West				Outer South			
		Estimate	SE	tStat	pValue	Estimate	SE	tStat	pValue
2016Q2	25	0.44646	0.01388	32.17	0	0.53946	0.01298	41.56	0
2016Q3	26	0.52348	0.01515	34.56	0	0.60692	0.01418	42.82	0
2016Q4	27	0.56251	0.01581	35.58	0	0.64099	0.01440	44.52	0
2017Q1	28	0.58449	0.01474	39.65	0	0.67510	0.01350	50.02	0
2017Q2	29	0.56814	0.01432	39.67	0	0.65603	0.01321	49.64	0
2017Q3	30	0.51151	0.01513	33.82	0	0.60353	0.01385	43.58	0
2017Q4	31	0.50145	0.01597	31.40	0	0.56367	0.01372	41.09	0
2018Q1	32	0.51628	0.01537	33.59	0	0.57830	0.01336	43.29	0
2018Q2	33	0.57943	0.01420	40.80	0	0.61553	0.01281	48.07	0
2018Q3	34	0.56817	0.01486	38.25	0	0.61841	0.01397	44.27	0
2018Q4	35	0.55272	0.01519	36.39	0	0.59512	0.01387	42.90	0
2019Q1	36	0.58928	0.01456	40.48	0	0.63139	0.01326	47.61	0
2019Q2	37	0.59312	0.01358	43.66	0	0.65350	0.01280	51.04	0
2019Q3	38	0.60740	0.01460	41.62	0	0.66214	0.01351	48.99	0
2019Q4	39	0.57985	0.01474	39.35	0	0.64123	0.01368	46.89	0
2020Q1	40	0.61184	0.01454	42.07	0	0.66777	0.01338	49.93	0
2020Q2	41	0.61840	0.01380	44.80	0	0.70060	0.01283	54.59	0
2020Q3	42	0.66272	0.01389	47.72	0	0.72139	0.01309	55.13	0
2020Q4	43	0.67609	0.01454	46.51	0	0.73925	0.01335	55.37	0
Age_2	1	-0.06784	0.00911	-7.44	0	-0.16818	0.00975	-17.25	0
Age_3	2	-0.14899	0.00932	-15.99	0	-0.24342	0.00881	-27.61	0
Age_4	3	-0.24184	0.00878	-27.56	0	-0.01257	0.00843	-1.49	0.13612
ln_Size	-	0.87192	0.00661	131.93	0	0.75544	0.00902	83.74	0

Appendix 9

Please see the separate attachment for a full overview of the MATLAB code we used in relation to our data analysis and the completion of this thesis.

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