Location, Location, Location!*

-A quality-adjusted rent index for the Oslo office market

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1 Introduction

During financial crises, commercial real estate (CRE) loans have often caused larger losses for banks than loans to households. Although many people would associate the global financial crisis with troubles in the household sector, corporate loans accounted for the bulk of losses in most countries (Solheim and Kragh-Sørensen, 2014).

In the aftermath of the global financial crisis, G20 Finance Ministers and Central Bank Governors endorsed 20 recommendations to address important data gaps - named the Data Gaps Initiative (DGI). One of the recommendations was to improve statistics on CRE (FSB-IMF, 2009). Consequentially, international organizations and national authorities have intensified their work to collect data on the CRE market. For instance, the European Statistical System and European System of Central Banks have started three work streams focusing on important indicators for CRE.[1] In addition, national initiatives have been taken by some European countries. However, DGI's third report emphasized that key challenges still remain in developing price indices for the CRE market (FSB-IMF, 2018).

Constructing indices for the CRE market is statistically challenging due to heterogeneity in the type, location, quality and size of the properties, the attractiveness of tenant and length of contract. Transaction data are considered to be the preferred data source, but are often scarce and incomplete, which in turn makes it difficult to estimate reliable indices (BIS, 2019).[2] Due to the lack of transaction data, many turn towards indices based on valuations. Such indices may be misleading, especially around turning-points. This is because they typically lag behind and often smooth the developments, see Geltner et al. (2003), Horrigan et al. (2009) and Cannon and Cole (2011). Furthermore, valuations may be biased (Gallimore and Wolverton, 1997; Kinnard et al., 1997; Crosby et al., 2010; Geltner et al., 2014).

In this paper, we fill part of the data gap for Norway by exploiting a rich transaction-based data set consisting of 14,171 signed rental contracts within the office segment in Oslo. The data set is unique, as it combines a large sample dating back to 2004 with information on important attributes, including an identifier for the building where the office is being rented out. The office market in Oslo is particularly interesting because banks have considerable exposures to this segment. Norges Bank uses sales prices for the prime office segment as an important indicator of developments in financial imbalances in Norway(Norges Bank, 2019a and Norges Bank, 2019b). Data limitations have, however, made it difficult to assess whether price developments in the prime segment are representative for the Oslo office market as a whole.

A first contribution of this paper is to present a detailed descriptive overview of the office market in Oslo. This overview is useful for the purpose of assessing both structural and cyclical risks in the CRE market. The main contribution of the paper is that we construct quality-adjusted rent indices for the Oslo office market, as well as different geographical sub-segments. For the purpose of constructing rent indices, we rely on

[1] The three work streams focus on supply and demand indicators, physical market indicators (sales prices, rents and yields) and financial variables related to the real estate market.

[2] In Europe, valuation data from the private company Morgan Stanley Capital International is often used (see for example ESRB (2018)).

the hedonic approach.[3] We control for important attributes, such as location, quality and contract specifics. Our results reveal that it is of major importance to control for micro-location, and in particular building fixed effects, as the explanatory power increases substantially the more granular location controls we apply. Similar results are found in Koster et al. (2013), where hedonic models are estimated based on data for Amsterdam, Rotterdam and Utrecht. Furthermore, we show that indices excluding location-specific information, or include less granular location controls than at the building level, portray quite a different time development for rents. Our results also suggest that distance to the closest metro station has a financially important effect on rents. In particular, an increase in the distance to a metro station of one mile lowers the per square foot price by about thirteen percent. Although we use data for Oslo, we believe that our results are relevant in a broader context, as they clearly display the importance of gathering data for micro-location when constructing rent indices.

An alternative to the hedonic approach is to calculate rent indices based on average rents. A major drawback with that approach is that mean rents are affected by compositional biases, e.g., if a relatively large number of leases have been signed in attractive locations or for high-quality office space. This is particularly problematic in periods where there are large new office developments in certain locations. An advantage with our quality-adjusted index is that it controls for such compositional changes. Another alternative for index constriction is to collect information on expert opinions. These will, however, be subjective and are only based on a subset of all transactions. Relative to that approach, our approach has the advantage that it is based on nearly all signed rental contracts in the Oslo office market. We show that our hedonic index yields a sharper fall in rents after the global financial crisis and more muted developments in the period between 2013 and 2015 than the average rent index. When constructing hedonic indices for the secondary housing market in Warsaw, Widlak and Tomczyk (2010) show similar results. In particular, they find that there is less variability in hedonic indices relative to mean and median indices, which they attribute to hedonic models being better at controlling for compositional changes.

As a third contribution, we investigate how developments in rent indices are affected by using the contract signature date instead of the start date of the lease. In the literature, the contract start date is most commonly used due to a lack of data on the signature date (see e.g., Wheaton and Torto (1994), Webb and Fisher (1996), Englund et al. (2008) and Kempf (2015)).[4] We find that a more timely detection of turning-points can be achieved by using information on the signature date. This is an important finding. The financial system is heavily exposed towards CRE, and timely detection of turning-points is critical for policymakers.[5] With reference to the DGI, this suggests that initiatives

[3] The hedonic model is often used when estimating house price indices (see Hill (2011) for a survey). The hedonic approach is employed to estimate price indices and to determine how different amenities affect rents. In this paper, we use quality-adjusted index and hedonic index interchangeably. While we opt for a hedonic approach, Cajias (2018) suggest that the generalized additive model for location, scale and shape, which allows for additional non-linearity, may improve explanatory power further. In particular, they argue that this approach can lead to substantial improvements in out-of-sample forecasting accuracy.

[4] Clark and Pennington-Cross (2015) is an exception, as they have information on the year the contract was signed.

[5] In the housing market, sales prices are estimated by using the date of the acceptance of the bid, which is comparable to the signature date, and not the date at which the house is officially acquired.

aimed at systematically collecting information on the signature date may be of particular relevance for detecting turning-points in the CRE market.

Finally, we use our quality-adjusted rent index as a dependent variable in an error-correction model. We find that employment and stock of offices are important explanatory variables. Our results show that rents have followed their estimated equilibrium closely and have re-adjusted quickly in periods of deviation. From a financial stability perspective, the risk of a sharp fall in rents is reduced because rents often are in line with their fundamentals. However, fundamentals may change fast and the high degree of equilibrium correction indicates that this may lead to an abrupt and severe correction in rents.

The literature on hedonic rent indices for CRE is still rather limited, despite the increased interest in the aftermath of the global financial crisis. This likely reflects the lack of complete and consistent data. Some recent studies exploit data sets with a wide range of attributes, but they only cover a brief time period. Evangelista et al. (2019) estimate hedonic rent indices for different types of CRE in Portugal using a data set that is rich in observations and information on attributes. A drawback is that the data only go back to 2015. In a another recent paper by Olszewski et al. (2019), hedonic rent indices for the Polish CRE market are constructed. These indices date back to 2013. Relative to these papers, our paper has the advantage that we consider a relatively long time period, which allow us to explore how different compositional biases can affect the time-series evolution of rents.

Another branch of the literature covers a more extensive time period, but lacks information on important attributes. Wheaton and Torto (1994) construct hedonic rent indices for offices in several metropolitan areas in the US from 1979 to 1991 based on a large sample with many attributes. They include controls for location, but at a less granular level than at the building level. Similarly, Slade (2000) and Kempf (2015) do not control for micro-location in their study of the German and Phoenix CRE markets.[6] We add to this literature by including a relatively rich set of controls in our specifications. In particular, we show that controlling for location at the building level increases explanatory power considerably. Furthermore, we show that indices based on models that do not control for location at the building level give quite a different picture of the developments in rents over time.

Webb and Fisher (1996) and Englund et al. (2008) estimate rent indices for offices within the central business district (CBD) of Chicago and Stockholm. In both studies, important attributes, such as location at the building level and quality are controlled for. However, the CBD segment will not necessary give a representative picture of developments for offices located in other parts of the city. Our results reveal that there are substantial within-city differences and that rents in the CBD segment of Oslo have been more volatile and risen more sharply than for the city as a whole.

The rest of the paper is structured as follows. Section 2 presents and summarizes the data. In Section 3, hedonic rent indices based on contract start date for Oslo and different sub-segments are developed. Developments in the indices are compared with the average and median rent. In the same section, hedonic indices based on contract signature date

[6]Kempf (2015) uses a large sample to estimate hedonic rental indices from 1997 to 2006 for different cities in Germany. Slade (2000) applies the hedonic method to estimate whether the importance of different explanatory variables varies with rental cycle, based on survey data for Phoenix.

are estimated and contrasted with indices based on start date. The section also presents and discusses the results from the estimated error correction model. Section 4 concludes.

2 Data and summary statistics

2.1 Data

The data have been acquired from Arealstatistikk AS – a private firm that specializes in collecting commercial real estate data and that writes regular reports on developments in the CRE market. The data set includes 16,326 signed rental contracts dating back to 1967. However, at the beginning of the sample, coverage is scarce, and there are only a handful of contracts each year prior to 2004. Our analysis is therefore confined to a sample starting in 2004, for which we have 14,171 contracts. Over this period, the number of contracts per year is relatively stable at around 900.[7]

The data set covers the majority of contracts within the office segment in Oslo. Compared with other parts of the CRE market, a high fraction of total office space is located in larger cities. Estimates from private analysts indicate that Oslo is the main hub, with approximately 90 million square feet of office space – about 50 percent more than the Bergen, Trondheim and Stavanger markets combined (Hagen, 2016).[8] Ongoing contracts in the data set as of 2018 Q3 account for around 55 million square feet, indicating that the data set covers about 60 percent of the Oslo office market.

In addition to data on the annual rent, each rental contract contains information on the exact address and GPS coordinates of the building. This allows us to control for building fixed effects in our hedonic regressions. Moreover, the data set includes information on number of square feet of each office rented out, whether the tenant is a public or private company, and whether the contract is a real renegotiation of an existing contract.[9] We calculate rent per square feet by dividing the annual rent by the size of the office being rented out. The data also include start and end dates of the lease, and – starting in 2007 – the date at which the contract was signed. By subtracting the start date of the lease from the end date of the lease, we calculate the length of the contract. We will mainly use contract start date in our calculations and estimations, since it covers a longer time period and more observations per year. However, we also estimate a hedonic index based on signature date to compare it to the index constructed based on contract start date.

2.2 Summary statistics

Mean and median annual rents are both close to USD 20 per square footage over the full sample, see Table 1a. Rents seem to be fairly symmetrically distributed around the mean. It is also evident that average office space is around 8,400 square feet, whereas the

[7]See Figure A.1 in the supplementary Appendix, which can be found here: http://www.andre-anundsen.com/JERER_Online_Appendix.pdf.

[8]These are the second, third, and fourth largest cities in Norway.

[9]A real renegotiation implies that an existing tenant renews a contract with new terms, e.g., an increase or a decrease in the number of square feet rented, or a change in the rent.

median is 3,330 square feet. The large difference between mean and median size reflects a fat-tailed distribution. A fairly large fraction of the contracts are very large premises, e.g., the 95^{th} and 99^{th} percentiles are respectively 29,000 and 97,000 square feet. The average contract length is 4.5 years, and – measured at the median – it takes about 90 days from a contract is signed until the lease starts.[10] A clear majority of the offices (94 percent) are rented out to private companies. Comparing the middle to the lower part of Table 1a, it is evident that private tenants pay lower rents and rent smaller premises.

A high share of signed rental contracts are for premises located in the City Centre, see Table 1b. Other important office locations are Vika-Aker Brygge, Skøyen, Lysaker, Nydalen and Helsfyr-Bryn.[11] In total, almost 60 percent of the contracts are signed at one of these locations. Public tenants are to a greater extent than private renters located in the City Centre excluding Vika-Aker Brygge, Helsfyr-Bryn and Nydalen. We also see that a larger fraction of public renters renegotiate existing contracts.

There is a marked difference in the distribution of contract lengths between low- and high-priced offices.[12] Offices with higher rent per square footage are in general rented out for longer periods. In particular, approximately one-sixth of the contracts with a high rent has an initial contract length of 10 years or longer, while the same number is only five percent for offices with a low rent. Five-year contracts are most common for medium- and high-priced offices, whereas three- and five-year contracts are equally common for offices with a relatively low price.

The size of the offices rented out and the contract length have been fairly stable over time within different percentiles. In contrast, rents have shown a clear time trend all over the distribution. Growth in rents was particularly high prior to the start of the global financial crisis and fairly low in the succeeding years. Further, in recent years, rents in the 25^{th} percentile have been flat, while rents in the 50^{th} and 75^{th} percentile have increased substantially.[13]

[10] See Figure A.2 in the supplementary Appendix for a plot of the distribution. There are some variations in the number of months between the signature date and contract start date for the contracts in the sample. The gap is often fairly small when contracts are renegotiated, while the gap can be substantial for new buildings or when buildings are completely renovated.

[11] An overview of the different city districts in Oslo is provided in Figure A.3 in the supplementary Appendix.

[12] Figure A.4 in the supplementary Appendix shows the distribution for different segments.

[13] Figure A.5 in the supplementary Appendix displays the time series developments of rents, size and contract length.

Table 1: Summary statistics for the full sample, private and public tenants

(a) Rent, size and contract length. Percentiles

Variable	10^{th}	25^{th}	Mean	Median	75^{th}	90^{th}
Full sample						
Rent per sq.ft. (USD)	11.6	15.9	22.5	21.3	27.3	34.9
Size (sq.ft.)	743	1,593	8,372	3,337	7,255	16,124
Contract length (years)	1	3	4.5	4	5	9
Public tenants						
Rent per sq.ft. (USD)	12.9	17.4	24	23.4	29.3	36.3
Size (sq.ft.)	2,164	5,016	24,496	10,576	25,145	63,648
Contract length (years)	1	3	6.3	5	10	12
Private tenants						
Rent per sq.ft. (USD)	11.5	15.8	22.4	21.1	27.2	34.9
Size (sq.ft.)	721	1,530	7,312	3,156	6,684	13,993
Contract length (years)	1	3	4.4	4	5	9

(b) Renegotiated contracts and geographical location. Fraction

Variable	All contracts	Public	Private
Private contracts (%)	93.8	-	-
Renegotiated contracts (%)	16	22.3	15.6
Vika-Aker Brygge (%)	8.9	3.9	9.2
City Centre excl. Vika-Aker Brygge (%)	20.4	27.7	19.9
Helsfyr-Bryn (%)	6.2	8.2	6.1
Skøyen (%)	8.1	2.3	8.5
Lysaker (%)	9.7	2.5	10.2
Nydalen (%)	5.1	7.3	5.0
Other locations (%)	41.5	48.1	41.1
Number of contracts	14,171	874	13,297

Notes: The tables show summary statistics for the variables covered by our data set. The sample covers the office segment of the CRE market in Oslo and spans the period 2004 Q1 – 2018 Q3. NOK values are converted to USD using the average exchange rate between USD and NOK in period 2004-2018, where the average USD/NOK = 0.150.

Location is often considered to be one of the most important attributes for determining real estate prices, see for example Zabel and Kiel (2008). We therefore utilize maps of Oslo divided into different districts to visualize within-city differences with regards to rents.[14]

There are differences in the median size of rented office space across different districts

[14] The city districts applied in the maps are created by merging four-digit ZIP codes, while the geographical division in Table 1b focused on office hubs pre-defined in the data set. These office hubs may consist of only parts of some ZIP codes. This makes it difficult to create maps based on the geographical division in Table 1 since four-digit ZIP codes is the highest granularity we have.

in Oslo.[15] The median size varies between 1,300 and 5,600 square feet. This indicates that many tenants are fairly small firms.[16] The largest rented premises are located in Gamle Oslo and Nordre Aker, while the smallest are located in the eastern parts of Oslo.

Moreover, offices in Oslo are clustered in the centre and south-western parts of the city.[17] There are no complete public statistics on the location of office space in Oslo, but projections from the private real estate agent *Akershus Eiendom* are broadly in line with our estimates (see Akershus Eiendom (2018)). A high fraction of the office space is located in the city districts Frogner, Ullern and the City Centre, which includes office hubs, such as Aker Brygge, Skøyen and parts of Bjørvika and Lysaker. Other important office districts are Gamle Oslo, Nordre Aker and St.Hanshaugen.

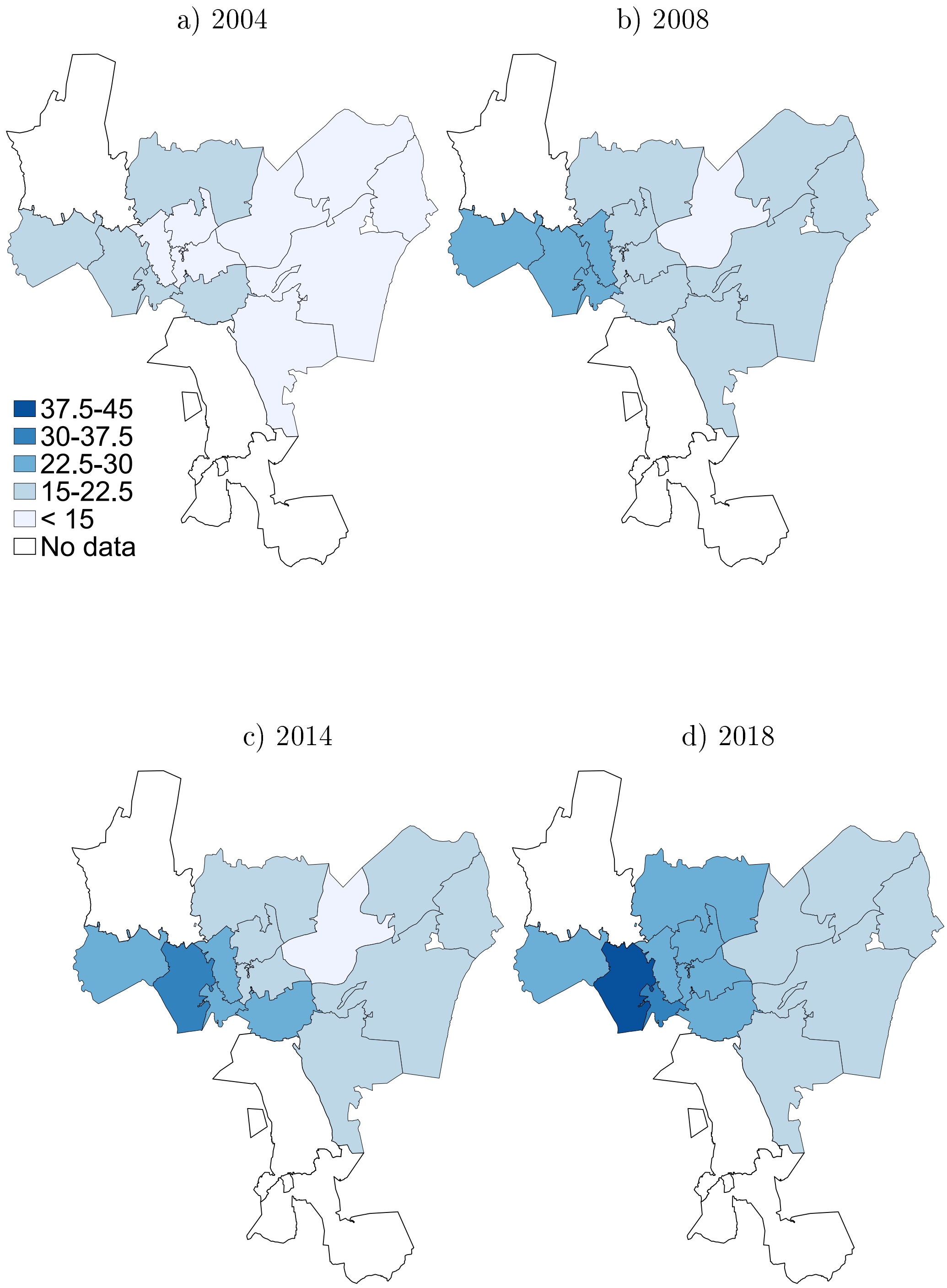
Figure 1 displays substantial differences in median rents between the different districts in Oslo. Moreover, the gap has widened the last 15 years. In 2004, median rents varied between USD 10.5 and USD 21 per square footage, with lowest rents in the eastern parts of the city. The median rents were at a higher level in all parts of the city in 2008; the change was especially strong in the city centre and western parts, see Figure 1a and b. From 2008 to 2018 the change in median rents has been more modest, with a larger change in the centre and flatter developments in the fringe zones, see Figure 1c and d. In 2018, the highest median rents were in Frogner with USD 39 per square footage, followed by the City Centre, while the lowest were recorded in Søndre Nordstrand where rents were roughly half the level of Frogner.

[15]Figure A.6a in the supplementary Appendix illustrates differences in median office size in a map of Oslo.

[16]Estimates by the private CRE broker *Akershus Eiendom* indicate that the average number of square feet per employee was roughly 270 in 2017 (EstateNyheter (2017)). This estimate is based on 170 rental contracts. The median size varied between 1,300-5,600 square feet across the different city districts. Assuming 270 square feet per employee, this corresponds to tenants with between 5 and 20 employees.

[17]We estimate each district's share of total office space in Oslo by taking the sum of all office space rented out in the district and dividing it by the total office space rented out in Oslo. This is only an estimate, as there may be differences in the data coverage we have for the districts, and the length of contracts varies somewhat across the districts. A map illustrating the within-city differences is shown in Figure A.6b in the supplementary Appendix.

Figure 1: Local differences in median rents per square footage over time (in USD)



Notes: The figure shows median rents per square footage in different parts of Oslo in selected years. The median rents are calculated based on the start of the lease. For 1) Alna, Grorud and Stovner and 2) Grünerløkka and Sagene median rents are estimated based on the observations for the combined area. Median rents are not shown for the districts Vestre Aker, Søndre Nordstrand and Nordstrand due too few observations. See Figure A.3 in the supplementary Appendix for a map that includes the name of each city district.

2.3 Data preparations

For the purpose of index construction, we truncate the data at the 1^{st} and 99^{th} percentiles of rents and square footage.[18] After the truncation, 13,621 observations remain. Furthermore, we include dummy variables for each building to control for building fixed effects. As some observations are needed to estimate a coefficient for each building dummy, we confine our data to rental contracts in buildings where at least five offices have been rented out (5^{th} percentile).[19] This leaves us with 12,121 observations. For the part of the analysis (Section 3.3) where we only include observations with signature date, we have 5,991 observations.[20]

3 Results

3.1 Hedonic models for CRE rents

The idea behind the hedonic model is to measure implicit prices for different attributes, as if they were traded separately. As shown in Rosen (1974), the price that clears the market for differentiated products is given by the sum of implicit prices for attributes. Offices possess numerous attributes, and the rent represents the sum of the implicit prices for these attributes. We let this be represented by the hedonic pricing function:[21]

$$R_{i,t} = f(X_{i,t}) \tag{1}$$

in which $X_{i,t}$ is a vector of attributes for office i at time t. The function $f()$ is the hedonic pricing function that maps the attributes of unit i at time t into a rent, $R_{i,t}$. A common econometric operationalization when constructing quality-adjusted price indices is the log-log specification (Diewert, 2003; Malpezzi, 2008), which we also employ in this paper.[22] We estimate several variants of a specification of the following form:

[18] This is done quarter-by-quarter to avoid removing a disproportionately large number of observations at the start and at the end of the sample, as rents display a clear time trend.

[19] There are two reasons why we for most of the buildings have multiple rental contracts. First, a tenant typically only rents a part of the building, i.e., at each point in time, there are usually many tenants with different rental contracts within the same building. Second, contracts expire and are re-negotiated or office space is rented out to a new tenant.

[20] Compared with contract start date, we lose 4,182 observations as these data start in 2007 and we lack also information on signature date, for some contracts in the period thereafter. Some observations are also lost, as we require the number of days from signature date to start date to be at least 30 days. Finally, observations are also lost when requiring that only contracts for offices in buildings with at least five contracts should be kept.

[21] An alternative to the hedonic approach would be to estimate repeat-sales indices. However, while we have unique identifiers at the building level, we do not have identifiers at the office level. Contrasting repeat-sales indices with hedonic indices is therefore not possible in our case.

[22] Another commonly used specification is the lin-log specification (see e.g., Rosen (1974); Cropper et al. (1988); Pope (2008); Anundsen and Røed Larsen (2018)). Sieg et al. (2002) has shown that index estimates are robust across different functional forms. However, they opt for the log-log specification for index construction. A similar approach is followed by Anundsen and Røed Larsen (2018).

$$log(R_{i,j,k,t}) = \alpha_j + \delta_k + \gamma_t + \boldsymbol{\beta}'\boldsymbol{X}_i + \varepsilon_{i,j,k,t} \quad (2)$$

in which subscript i refers to a particular office, j is location (ZIP code), k is building, and t is time. The vector α_j is location fixed effects, δ_k is building fixed effects, γ_t is year-by-quarter fixed effects. The vector $\boldsymbol{X}$ contains attributes pertaining to office i, such as size, contract length, a dummy for private versus public renter, etc. Building fixed effects are included in order to capture time-invariant attributes such as a building's micro location and average quality.[23]

The formulation in Equation (2) is convenient for the purpose of constructing an index that measures developments in rents, having controlled for differences in attributes and location.[24] This is because the index at time s is simply given by exponentiating the difference between the coefficient on the dummy for time s and the coefficient on the dummy for the base period. Since the base period is excluded from the estimation to avoid perfect multi-collinearity, the index at time s is simply the exponentiation of the coefficient on the dummy at time s.

In Table 3, we summarize results from estimating Equation (2) on different subsets of attributes. Column (I) only includes year-by-quarter fixed effects. This specification is very similar to constructing an index based on quarterly averages of rents.[25] The explanatory power when only including time dummies is relatively low, suggesting that important information is being left out.

In Column (II), we augment the time-dummy specification by including ZIP code fixed effects. It is evident that location matters, as the explanatory power increases substantially.[26]

In Column (III), we add observable attributes for the office being rented out. The explanatory power increases somewhat, and the coefficients on both size and contract length are statistically significant at conventional significance levels. The signs of the coefficients may seem counterintuitive, as they imply that a larger size and longer contracts result in higher rents per square footage. One challenge is that we cannot observe

[23]This dummy is time-invariant and will only capture a building's average quality. In reality, there would likely be some variations in quality over time as investments are made. Examples of other studies that have included building fixed effects in their hedonic model are Webb and Fisher (1996) and Englund et al. (2008).

[24]An implicit assumption is that coefficients for the different attributes do not change over time. We follow Anundsen and Røed Larsen (2018) and estimate the hedonic model year-by-year. The correlation between the fitted values from the two specifications is 0.92. Looking at R^2 across years, there is very little variation, and they are close to the R^2 based on the full-sample analysis. We take this as evidence that there is little to gain from using a time-varying parameter model in our case. Results are summarized in Table A.1 in the supplementary Appendix.

[25]There will, however, be some minor differences due to the log transformation in the estimation of the hedonic model.

[26]A ZIP code consists of four digits in Norway, where the first refers to a larger area within a municipality. The second, refers to an area within the larger area, etc. Therefore, the granularity increases as more digits are added. We have also estimated the specification in Column (II) using two- and three- digit ZIP codes, which cover broader areas than ZIP codes with four digits. The explanatory power increases as more digits are added, which shows that granularity matters, see Table A.2 in the supplementary Appendix.

Table 2: Alternative specifications of the hedonic model

	(I)	(II)	(III)	(IV)	(V)
log(Size (sq.ft.))			0.047***	0.046***	0.017***
			(0.00)	(0.00)	(0.00)
Private renter			-0.018	-0.018	-0.031***
			(0.01)	(0.01)	(0.01)
Contract length (years)			0.019***	0.020***	0.015***
			(0.00)	(0.00)	(0.00)
Renegotiation			-0.025***	-0.024***	-0.013**
			(0.01)	(0.01)	(0.01)
Dist. to closest metro (miles)				-0.126***	
				(0.01)	
Observations	12,121	12,121	12,121	12,121	12,121
R^2	0.226	0.541	0.582	0.586	0.705
Time fixed effects	✓	✓	✓	✓	✓
ZIP code fixed effects		✓	✓	✓	
Building fixed effects					✓

Notes: The table shows estimation results for alternative hedonic models for rents. The sample period covers 2004 Q1–2018 Q3. Standard errors are reported in parenthesis below the point estimates. The asterisks denote significance levels: * = 10%, ** = 5% and *** = 1%.

quality improvements that are made before the new tenant moves in. We suspect that such quality improvements are more likely for larger office space and for tenants that plan to stay for a longer period. The empirical results in the literature regarding the sign of these coefficients have been mixed (see Kempf (2015) for a review of the literature). Furthermore, we observe that private renters pay a discount and that renegotiated contracts carry a lower rent.[27]

In Column (IV), we add a measure of the distance to the closest metro station for each building.[28] While this has little bearing on the explanatory power, it has a financially important and statistically significant effect on rents; our results suggest that if the distance to a metro station increases by one mile, rent per square footage is almost 13 percent lower.

We add building fixed effects in Column (V). Building fixed effects will be perfectly collinear with ZIP code fixed effects and distance to metro station, since the location of a

[27]In Table A.3 in the supplementary Appendix, we report results when the specification in Column (V) is estimated separately for private and public tenants to explore potential coefficient-heterogeneity. We find that the coefficients are fairly similar in the different sub samples.

[28]We only include metro stations where at least three metro lines stops. Further, we also include Lysaker and Skøyen, which are two important public transportation hubs that do not have a metro station.

building is constant over time. Therefore, this specification excludes these two variables. Controlling for building fixed effects increases the explanatory power substantially, which shows the importance for rents of micro location and the quality of the building.

This is our preferred specification as important attributes are controlled for and as it yields the highest explanatory power. When constructing indices for local sub-markets of Oslo, this specification is estimated separately for the markets under consideration.

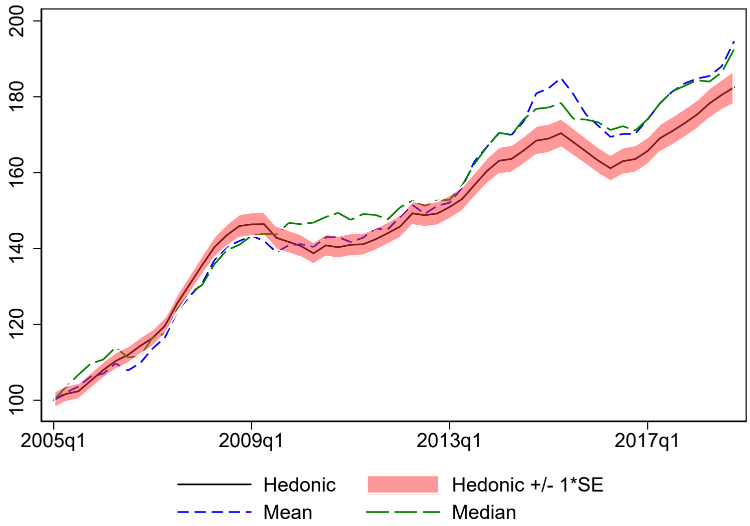
3.2 Comparing the quality-adjusted index to other indices

In Figure 2, we compare the evolution of median and mean rents to the quality-adjusted rent index backed out by our hedonic model. We also add a fan for $+/-$ one standard error around the hedonic index. While the three indices show similar developments over the first few years of the sample, there are some rnotable differences between the indices starting around 2009. The hedonic index suggests a larger drop in rents in 2009 than both the mean and median indices. Further, whereas mean and median rents portray a picture of rapid price growth between 2013 and 2015, the hedonic index suggests relatively muted developments over the same time period. In the period from 2016 and onwards, the three indices have shown similar developments, but the mean and the median indices display stronger price growth starting in 2018 than the hedonic index.

In order to investigate which factors have contributed to the differences between the mean rents and the hedonic index, we consider alternative hedonic indices, leaving out information on ZIP code and building fixed effects. Figure 3 displays the mean index and the baseline hedonic index, together with two alternative hedonic indices; one where we exclude the building fixed effects while including ZIP code fixed effects and one where we exclude both building fixed effects and ZIP code fixed effects. It is evident that excluding building fixed effects and ZIP code fixed effects makes the hedonic index closer to the mean index. This indicates that the main compositional biases associated with the mean index are due to time variations in transactions related to geographical locations and quality of the buildings and not other attributes such as contract length, size, renegotiation, etc.[29] With the quality-adjusted rent index, we control for this, giving a more representative picture of market developments. The finding that adding building fixed effects matters so much is important, since it suggests that systematic data collection on micro-location may give a better picture of developments in the CRE market.

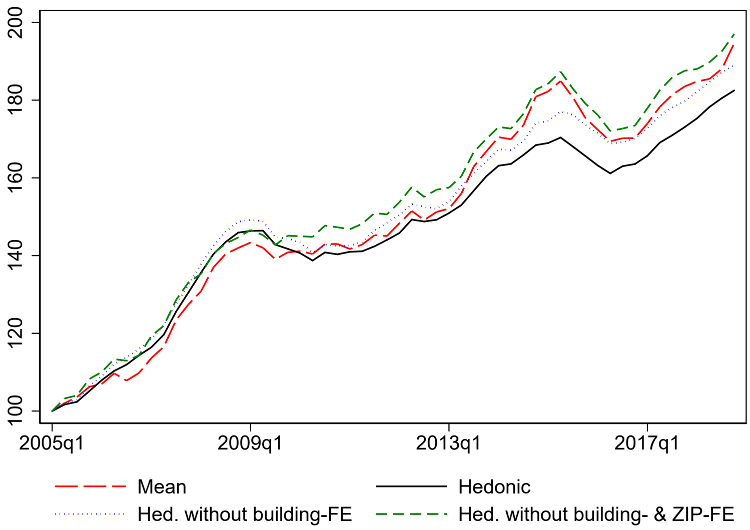
[29]E.g., the number of transactions within attractive/less attractive locations or among buildings with high/low quality has been relatively high in periods. As a result, a rental index calculated as a simple average and a quality-adjusted hedonic index will show different results.

Figure 2: Developments in mean rents, median rents and the quality-adjusted hedonic rent index



Notes: The figure compares developments in mean rents, median rents and the quality-adjusted hedonic index. All indices are estimated as a four-quarter moving average, e.g. the first observation in 2005 Q1 is estimated by taking the average from 2004 Q2 - 2005 Q1. Further, the series are normalized to 100 in 2005 Q1.

Figure 3: Mean rents compared with alternative hedonic indices



Notes: The figure compares developments in mean rents to alternative hedonic indices. All indices are estimated as a four-quarter moving average, e.g. the first observation in 2005 Q1 is estimated by taking the average from 2004 Q2 - 2005 Q1. Further, the indices are normalized to 100 in 2005 Q1.

3.3 Geographical differences within the Oslo market

In this section, we investigate whether developments in rents at Vika-Aker Brygge are representative for other locations in Oslo. This is of particular interest, as Norges Bank considers sales prices in Vika-Aker Brygge market to be a particularly important indicator of CRE market vulnerabilities, where sales prices are calculated using observed rents and estimated yields.[30] However, limited availability of data has made it difficult to assess whether sales price developments in Vika-Aker Brygge are representative for the overall Oslo market. One important step towards assessing the representativeness of this index is by comparing the developments in rents in Vika-Aker Brygge with those in the rest of Oslo.[31]

We estimate three separate hedonic models to investigate potential differences in the evolution of rents: one for Vika-Aker Brygge, one for offices traded close to Vika-Aker Brygge (City Centre and Frogner, excluding Vika-Aker Brygge), and one for the rest of Oslo.[32] The results are shown in Figure 4. It is evident that price developments for Vika-Aker Brygge and the City Centre and Frogner are similar, whereas developments for the rest of Oslo have been more muted. In particular, the rapid growth in rents before the global financial crisis and in the period 2013–2015 was pronounced in Vika-Aker Brygge and offices in nearby locations, whereas the increase was more moderate in the rest of Oslo. Similarly, we observe that the fall in rents following the financial crisis was greater in Vika-Aker Brygge and Frogner and the City Centre. In a recent paper, Pourcelot et al. (2020) construct a hedonic rent index for residential real estate in France over the period 1970-2013. Similar to our findings for the Norwegian commercial real estate market, they find that there are differences in rental growth between different geographical sub-markets.

From a financial stability perspective, the marked difference in rental growth between different geographical sub-markets in Oslo underlines the importance of not only following the overall Oslo market, or a specific segment, as CRE companies' exposure towards different areas in Oslo varies. CRE companies exposed towards Vika-Aker Brygge and the rest of the city centre have likely experienced substantial growth in their rental income thereby improving their debt-service capacity, while CRE companies mainly exposed towards eastern parts of Oslo have experienced a more muted growth in their rental income.

3.4 Hedonic indices based on signature dates

We have so far constructed all our indices based on the start date of the lease, since we only know the signature date from 2007.[33] Our summary statistics revealed a considerable lag between the start of the lease and the date at which the contract was signed (and

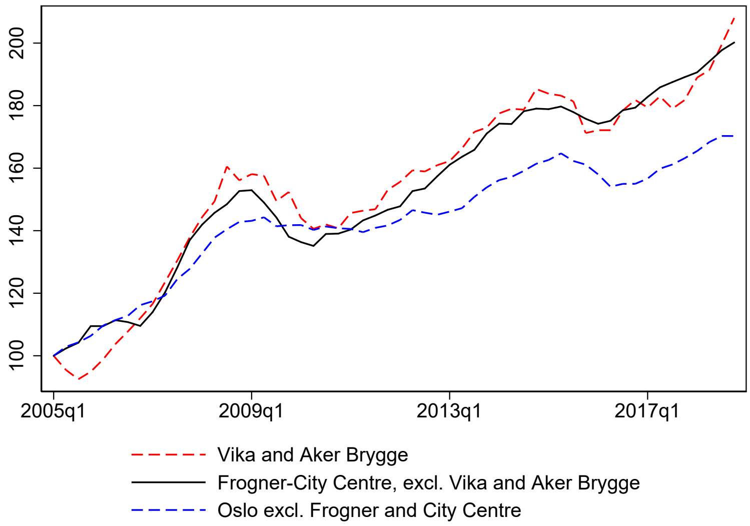
[30]Norges Bank focus on sales prices for prime offices located in Vika-Aker Brygge.

[31]We have also constructed separate hedonic rental indices for eastern and western Oslo – a common geographical division of Oslo. Index developments for eastern and western Oslo are shown in Figure A.7 in the supplementary Appendix.

[32]Approximately one third of the total office space in Oslo is located in the City Centre and Frogner (see Figure A.6 in the supplementary Appendix).

[33]We also lack signature dates on some observations from 2007, see Section 2.3.

Figure 4: Hedonic rent indices for Vika-Aker Brygge, Frogner and City Centre and the rest of Oslo



Notes: The figure compares developments in rent indices across different pats of Oslo. The indices are estimated as a four-quarter moving average, e.g. the first observation in 2005 Q1 is estimated by taking the average from 2004 Q2 - 2005 Q1. Further, the indices are normalized to 100 in 2005 Q1.

rental price agreed upon). Since sales prices in CRE are seen as an important indicator of developments in financial imbalances in Norway, timely detection of turning-points are of particular importance. In this section, we compare rent indices based on start date to those based on signature date.

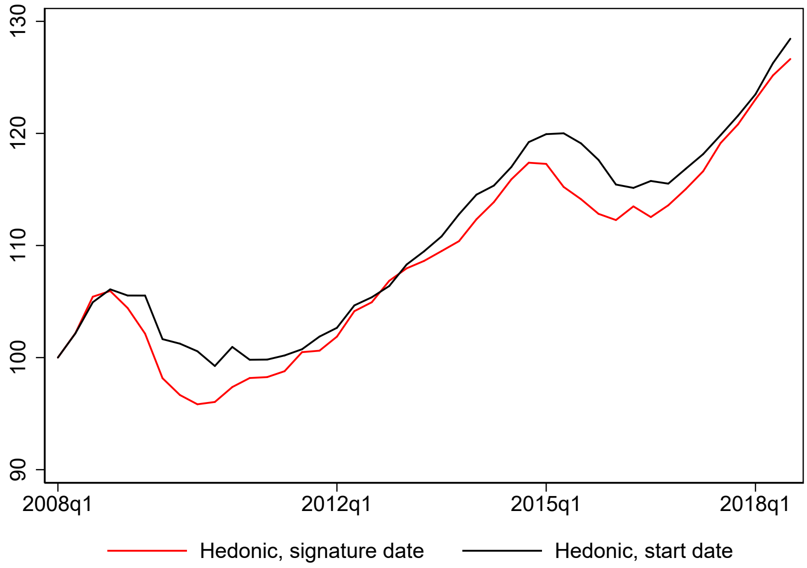
Figure 5 displays hedonic indices based on both contract signature date and start date of the lease. Developments are fairly similar, however; the hedonic index based on signature dates detects turning-points earlier and shows a sharper correction in rents both in the years after the global financial crisis and in 2015. Using signature dates is therefore likely to generate a more correct picture of rent developments since developments in the hedonic index based on start-date will also be based on contracts signed at relatively higher prices prior to the correction.[34]

3.5 Equilibrium rents

Developments in rents are vital for CRE companies' debt service capacity. In Norway, banks are likely highly exposed to the office market in Oslo (see Hagen et al. (2018)). From a financial stability point of view, it is therefore of interest to assess the risk of a sharp fall in rents in this segment. The risk will depend on whether rents are in line with what is implied by the evolution of the underlying fundamentals. If rents are

[34] Table A.4 in the supplementary Appendix reports results when estimating a hedonic model using contract signature date, whereas Figure A.8 in the supplementary Appendix displays developments in the hedonic indices based on signature date for Vika-Aker Brygge, the City Centre and Frogner (excluding Vika-Aker Brygge) and the rest of Oslo. The figure displays similar results as the hedonic indices based on start-date: rent growth has been higher in the City Centre and nearby areas than the rest of Oslo.

Figure 5: Hedonic rent indices based on signature date versus start of lease



Notes: The figure compares developments in hedonic indices based on contract signature date versus start date of the lease. The indices are estimated as a four-quarter moving average. Further, the indices are normalized to 100 in 2008 Q1.

substantially higher than their estimated equilibrium, the risk of a pronounced fall in rents will likely be high. To address this question, we use a long-run equilibrium model to estimate equilibrium rents.[35] Assuming a log-linear demand function, we formulate an error correction model for rents:

$$\Delta log(R_t) = \tau + \beta_e \Delta log(E_t) + \beta_s \Delta log(S_t) + \beta_v v_{t-1} + \gamma_R(log(R_{t-1}) - \gamma_e log(E_{t-1}) - \gamma_s log(S_{t-1})) + \omega_t \quad (3)$$

where τ is the intercept and ω_t is an $i.i.d$ error term, with $\omega_t \sim N(0, \sigma^2)$. The intercept also captures the natural vacancy rates, as it is assumed to be constant. This is common assumption in the literature, see e.g. Hendershott et al. (2002) and McCartney (2012). Further, R denotes rents, E demand indicators, S supply indicators and v the vacancy rate. Changes in rents are determined by shifts in demand and supply, as well as deviations in rents from their estimated equilibrium, given by $log(R_{t-1}) - \gamma_e log(E_{t-1}) - \gamma_s log(S_{t-1})$, and changes in the vacancy rate. We expect that $\gamma_R < 0$, i.e. that the level series cointegrate and that rents re-adjust back to their estimated equilibrium when there are deviations.[36] The closer γ_R is to -1, the faster rents

[35] There are several studies that apply error correction models to explain developments in office rents, e.g. Hendershott et al. (2002), Englund et al. (2008) Hendershott et al. (2009).

[36] Formally, cointegration can be determined by whether γ_R is significantly smaller than zero, assuming weak exogeneity. The distribution of γ_R under the null hypothesis of no cointegration is non-standard. Ericsson and MacKinnon (2002) provide critical values for this cointegration test.

move back to their estimated equilibrium. Furthermore, as rents and the vacancy rate are determined contemporaneously, we use lagged vacancy rate to mitigate endogeneity problems.

As a dependent variable in the regression, we use rents based on signature date. In order to extent the series back to 2004, we connect it with the growth in rents based on contract start date. We use employment as a demand indicator, an estimate of the total stock of offices as a supply indicator and we also include the lagged office vacancy.[37]

The long-run response from a change in both the demand and the supply indicator is fairly strong, see Table 3. The long-run elasticities are given by dividing each level variable's coefficient by the coefficient for lagged rents and multiply with minus one. Thus, our estimated model indicates that a one-percent increase in employment will increase rents with 4.2 percent, while rents will fall with 2.2 percent if the stock of offices increases with one-percent. Several studies apply error correction models to determine the drivers of office rents. McCartney (2012) provides a survey of the literature for Europe, and finds that the average long-run elasticities of supply and demand are -2 and 2, respectively. There are variations across studies, however, and supply elasticities range between -1 and -6 in the studies included in the survey by McCartney (2012), while demand elasticities are estimated to be between 1 and 4. Our results are within these ranges.

Furthermore, the empirical results indicate that rents re-adjust quickly towards their estimated long-run equilibrium. The equilibrium coefficient equals -0.5, which implies that when rents move away from their equilibrium in one period, half of the error is corrected the next period.[38] This is on the high-side of the studies surveyed by McCartney (2012), in which the error correction term ranges between -0.1 and -0.9. Results are not directly comparable, however, since several of the studies surveyed use annual data, while we use quarterly data. The risk of a sharp fall in rents is reduced because rents are often in line with their fundamentals. However, fundamentals may change fast and the high degree of equilibrium correction indicates that this may lead to an abrupt and severe correction in rents.

In Figure 6 we plot 1-step ahead forecasts for growth in rents. The forecasts are conditional on the explanatory variables, as they accrued. For forecasting purposes, we estimate the model until the third quarter of 2016, then we compare 1-step ahead forecasts (dashed blue line) to actual rent growth (solid black line). The red fans show confidence intervals up to 95%. The model does a fairly good job in forecasting rent growth, except for the very last observation, which falls outside the 95% confidence interval.

[37] A complete overview of the data and their sources is shown in Table A.5 in the supplementary Appendix.

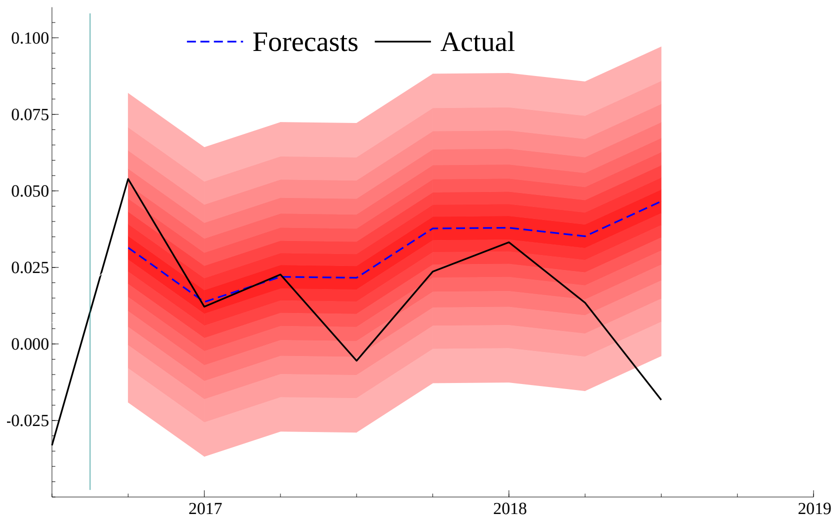
[38] Figure A.9 in the supplementary Appendix shows that rents have followed their estimated equilibrium path closely.

Table 3: Regression results. Dependent variable: Δ log(Rent$_t$)

Variable	Coefficient	SE
Intercept	-8.59*	4.72
Δ log(Employment$_t$)	4.50***	1.32
Δ log(Office stock$_t$)	0.17	1.46
Vacancy rate$_{t-1}$	-0.00	0.01
log(Rents$_{t-1}$)	-0.50**	0.13
log(Employment$_{t-1}$)	2.09***	0.68
log(Office stock$_{t-1}$)	-1.15*	0.65
Observations	58	
R^2	0.284	
Durbin Watson statistics	2.1	

Notes: The asterisks denote significance levels: * = 10%, ** = 5% and *** = 1%. The critical values for the t-statistic for the coefficient on lagged rents are given in Ericsson and MacKinnon (2002).

Figure 6: 1-step ahead forecasts for rent growth over the period 2016 Q4 – 2018 Q3



Notes: The figure shows 1-step ahead forecasts for growth in rents (dashed blue line) and actual rent growth (solid black line). The red fans show confidence intervals up to 95%. The forecasts are conditional on the explanatory variables, as they accrued. For forecasting purposes, we estimate the model until the third quarter of 2016.

4 Conclusion

In the aftermath of the global financial crisis, G20 Finance Ministers and Central Bank Governors endorsed 20 recommendations to address important data gaps - named the Data Gaps Initiative. One of the recommendations was to improve statistics on CRE. Data on CRE is in general scarce and incomplete. Furthermore, it is statistically challenging to construct indices for CRE due to heterogeneity in e.g., the type, location, quality and size of the property, attractiveness of the tenant, etc.

In this paper, we have utilized a unique data set on rental contracts for the Oslo office market to construct hedonic indices for the city as whole, as well as different sub-segments. Our results reveal that it is of major importance to control for micro-location, and in particular building fixed effects, as the explanatory power increases substantially the more granular location controls we apply. Furthermore, our results indicate that a more timely detection of turning-points can be achieved by using the signature date instead of the more typically used start date of the lease. The financial system is heavily exposed towards CRE, and timely detection of turning-points is critical for policymakers. Rental data for the CBD-segment is accessible for most big cities in Europe, while data for other segments often are scarce. Policy makers therefore tend to focus on the CBD-segment. We find that there have been large inter-city differences in rent developments in Oslo, suggesting that focusing only on the CBD-segment may not be representative for the city as a whole. Our results suggest that initiatives aimed at systematically collecting information on contract signature date may be of particular relevance for detecting turning-points in the CRE market. Furthermore, our results suggest that information on micro-location is important to gather in order to improve estimates of growth in rents, and that policymakers and market participant may be better informed if indices are estimated also for other segments than the CBD.

Finally, we estimate an error correction model to detect deviations in rents from their estimated equilibrium. We show that rents have followed their estimated equilibrium closely and re-adjusted quickly in periods of deviations. From a financial stability perspective, the risk of a sharp fall in rents in Oslo is reduced by rents often being in line with their fundamentals. However, fundamentals may change fast and the high degree of equilibrium correction indicates that this may lead to an abrupt and severe correction in rents.

Our study is confined to Norwegian data, and an avenue for future research would be to explore if similar results are obtained for other countries. A weakness with our paper is that we do not observe quality changes over time, such as renovation. Controlling for time-varying and unit-specific attributes in hedonic models for the CRE-market would be useful to purge indices further for compositional effects and unobserved heterogeneity. While we do control for building fixed effects, there are additional variations within a building (floor, view, sunlight, etc.) that we do not capture. Studies that could control for this would certainly be welcome, both in order to estimate the value of such amenities and to see how it affects estimated rent developments. Another promising avenue for future research is to link data on rental contracts in the CRE-market with firm-specific information in order to explore how e.g., firm profitability and liquidity may affect rental contracts.

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