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What drives office rents?*

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Abstract

Banks have substantial exposures to commercial real estate (CRE). Rental prices are important for CRE companies' debt-service capacity, which in turn affects the risk of future bank losses. In this paper, we estimate error correction models (ECMs) to determine the main drivers of office rents in Oslo and to detect deviations in rents from their estimated long-run equilibrium. We find that employment and stock of offices are important explanatory variables. Moreover, our results show that rents have followed their estimated equilibrium closely and have re-adjusted quickly in periods of deviation.

Keywords: Rental prices, commercial real estate, financial stability

JEL Classification: C20, E30, R30

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1 Introduction

Banks have substantial exposures to commercial real estate (CRE) and have experienced severe losses on this sector during crises (ESRB (2015) and Solheim and Kragh-Sørensen (2014)). In general, losses occur when a company is not able to service its debt and outstanding debt exceeds the value of its collateral. Rental prices are the main component of CRE companies' income and are therefore essential for their debt service capacity, but also for sales prices, as sales prices depend on the income generated from the property.

When assessing the risk of future bank losses on CRE, it is important to consider whether the development in rental prices is supported by fundamentals. If prices cannot be explained by underlying economic fundamentals, this may indicate a pronounced risk of a sharp fall in rental prices.

In this paper, we determine the main drivers behind rental prices in Oslo and estimate to what extent rents are backed by fundamentals. The Oslo office market is of specific interest as it is important for financial stability in Norway due to banks likely being highly exposed to this segment (see Hagen et al. (2018)). We employ a single equation error correction model (ECM) to estimate a long-run equilibrium as well as short-run dynamics. Moreover, the ECM provides estimates of how fast prices re-adjust towards their equilibrium after changes in the explanatory variables.

There exists a wide range of studies that apply ECMs to explain the developments in office rents. Most find that there exists a mechanism ensuring that rents move towards their estimated equilibrium and that rents re-adjust fairly quickly. McCartney (2012) provides a review of the literature and finds, based on ten studies, that when rents move away from their equilibrium in one period, on average half of the error is corrected the next period. Moreover, a one percent increase in supply or demand leads to on average -2 or 2 percent change in rents in the long-run, respectively.

A common feature among studies within CRE is the lack of high quality data for rental prices. There exists a branch of studies using prime rents from private companies, e.g. Hendershott, MacGregor, and Tse (2002), Mouzakis and Richards (2007), Hendershott et al. (2009) and Adams and Füss (2012). This statistic is partly based on expert opinions in situations with few transactions. In contrast to the mentioned literature, Englund et al.

(2008) construct a quality-adjusted rental price series by applying a hedonic approach on transaction data for the prime segment in Stockholm. A quality-adjusted index will result in a more representative rental price index than indices based on expert opinions or average rents. Internationally, there are few such indices (see Anundsen and Hagen (2020) for a review of the literature).

One important drawback of focusing on the prime segment is that this is a specific segment which will not necessarily give a representative picture of the overall development in a city. Studies that focus on broader geographical areas are McCartney (2012) for Dublin and Hendershott, MacGregor, and White (2002) for different regional UK markets. None of these apply a quality-adjusted rental index based on transaction data.

Our contribution to the literature is that we are the first to estimate equilibrium rents for the Oslo office market as a whole. We make use of a quality-adjusted rental price index for office rents in Oslo (see Anundsen and Hagen (2020)). We find that rents have followed their estimated equilibrium closely and that rents adjust fairly quickly, also compared to the literature. Furthermore, our estimate of the long-run elasticity of supply is in line with the literature, while we find a relatively strong long-run response on rents from increased demand. From a financial stability perspective, the risk of a sharp fall in rents is reduced because rents 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 remainder of the paper is structured in the following way. Section 2 describes the data. In Section 3, the model is presented, while Section 4 presents and discusses the empirical results. Section 5 concludes.

2 Data

We use different sources in order to gather relevant data for the office market in Oslo. In the paragraphs below, we group relevant explanatory variables for determining rental prices into supply and demand indicators. A complete overview of the data follows in Table A.1 in the Appendix.

As a dependent variable, we use the rental price index for the Oslo office market as a whole constructed in Anundsen and Hagen (2020). This is a quality-adjusted rental price index estimated using a hedonic method. The index is constructed based on transaction data for each signed contract and includes attributes such as location, quality and contract specifics. Anundsen and Hagen (2020) construct two rental price series: one is based on lease inception date and the other is based on lease signing date, starting in 2004 Q1 and 2007 Q1, respectively. We prefer lease signing date as it detects turning points more timely. In addition, it gives a more correct picture of the development in rental prices during contractions. In order to extend the series, we connect it with the growth in rents based on lease inception date.[1] The connected series is displayed in Figure 1.

Further, as our supply indicator, we use total stock of offices in Oslo. There exist no official data on this. Private analysts make infrequent projections and Statistics Norway reports granular construction data quarterly. We use estimated stock of offices from Akershus Eiendom as of 2014 Q3 and construct historical time series by adjusting for completed office space each quarter.[2] In the literature, stock of offices is often created by combining infrequent stock data with frequent construction data, see e.g. Hendershott, MacGregor, and White (2002), Mouzakis and Richards (2007) and Englund et al. (2008). Ideally, we would have adjusted for offices demolished or converted, but we are not able to do so due to data limitations.[3] Four-quarter change in rents and stock of offices display a negative correlation, see Figure 2 a).

[1]Rental prices based on lease signing date lead rents estimated based on lease inception date with one quarter at the median. We therefore connect it with the change one period ahead.

[2]Hence, data from before 2014 Q3 are created by subtracting completed office space while data after 2014 Q3 are estimated by adding completed office space each quarter.

[3]Several private analysts have communicated that the ratio of conversion from offices to residential real estate increased around 2013-2014 (see e.g. Akershus Eiendom (2016)). As far as we are aware, there do not exist publicly available data for conversion of office space (measured in square meters). However, private analysts have pointed out that the premises converted are often old and inefficient and in practice have a small impact on rental prices.

We include data for employment in Oslo and GDP for Mainland Norway as demand indicators.[4] Employment in Oslo is reported at an annual frequency, and quarterly data are therefore constructed by cubic interpolation. This interpolation may affect the ability of the variable to explain short-run variations in rents. Figure 2 b) and c) show that four-quarter change in rents have shown a clear positive correlation with employment and GDP.

In addition, we include the office vacancy rate as an explanatory variable. Historically, rental prices have been high when office vacancy has been low - and vice versa, see Figure 2 d).

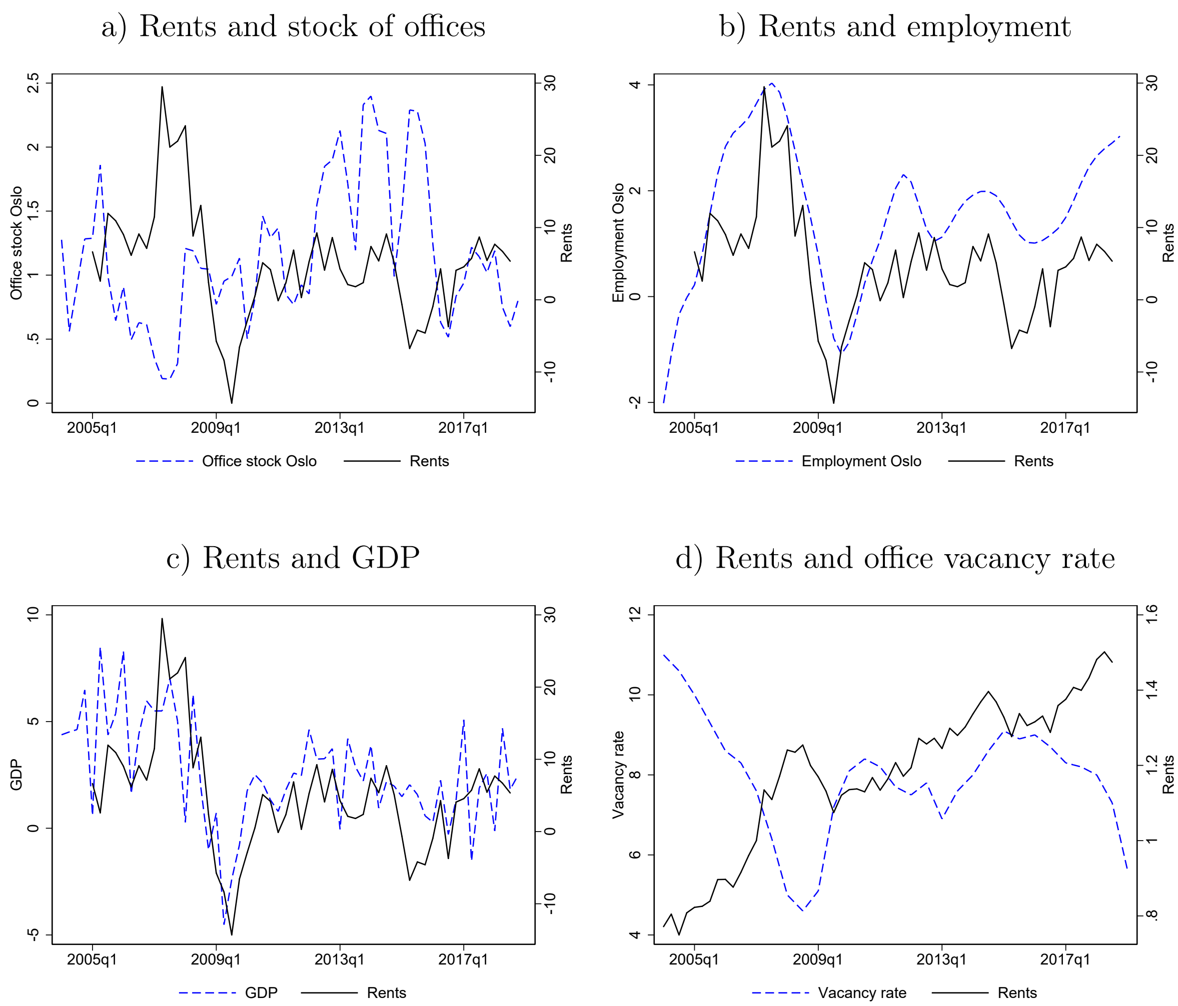
Figure 1: Rents for the Oslo office market as a whole

a) Lease signing and inception date
b) Lease inception date and connected series

Notes: Figure 1 a) compares hedonic rental price indices for the Oslo office market as a whole based on lease inception and lease signing date. Figure 1 b) connects the series based on lease signing date with the series based on inception date. All indices are normalized to one in 2007 Q1.

[4]Ideally, we would only have used data for employment within the office segment, but are not able to do so due to data limitations.

Figure 2: Rents, stock of offices, employment, GDP and office vacancy



Notes: Rents, stock of offices, office vacancy and employment are data for Oslo, while GDP is for Mainland Norway. Figure 2 a), b) and c) display four-quarter change. In Figure 2 d) the rental price index is normalized to one in 2007 Q1 and the vacancy rate is measured in percent.

3 Model

Following existing literature, we use a long-run equilibrium model to estimate equilibrium rents in the office market (see e.g. Hendershott, MacGregor, and Tse (2002), Englund et al. (2008) and Hendershott et al. (2009)).[5] A commonly used long-run demand function for office space is a log-linear function of rents and demand components:

$$log(D(R, E)) = \alpha_0 + \alpha_r log(R) + \alpha_e log(E) \tag{1}$$

where R is office rents and E represents demand indicators. Furthermore, we expect the price elasticity to be negative and the elasticity of the demand components to be positive, i.e. $\alpha_r < 0$ and $\alpha_e > 0$. We denote the total supply by S.[6] In the long-run equilibrium, demand equals supply less the natural vacancy, where the natural vacancy rate, v^*, clears the market:

$$D(R^*, E) = (1 - v^*)S \tag{2}$$

where R^* is the rental equilibrium rate. By taking the logarithm of (2), substituting from (1), where R is replaced by R^* and solving with respect to $log(R^*)$, we get

$$log(R^*) = \gamma_s[log(1 - v^*) - \alpha_0] + \gamma_e log(E) + \gamma_s log(S) \tag{3}$$

where the parameters from the demand equation are given by $\alpha_r = 1/\gamma_s$ and $\alpha_e = -\gamma_e * \alpha_r = -\gamma_e/\gamma_s$. From $\alpha_r < 0$ and $\alpha_e > 0$ it follows that $\gamma_e > 0$ and $\gamma_s < 0$, i.e. higher demand leads to an increase in rents, while increased supply pushes rents down. Furthermore, we assume that the natural vacancy rate is constant and thus will be included in the intercept. This is a common assumption in the literature, see e.g. Hendershott, MacGregor, and White (2002), Hendershott et al. (2009) and McCartney (2012).

If these level variables are non-stationary, it is well known that standard inference

[5]In this paper, all variables are in nominal terms, while in the literature the variables are often converted to real values.

[6]We assume that S is exogenous when we derive rental prices in the long-run equilibrium.

ceases to be valid (see Granger and Newbold (1974)). In our case, we find empirical evidence of a unit root in all the level variables.[7] However, if the level series cointegrate, we can estimate a long-run relationship and conduct valid inference.[8] This implies that rents move towards their long-run equilibrium, i.e. rents error correct.

A general error correction model for rental prices can be formulated based on Equation (3):

$$\Delta log(R_t) = \tau + \beta_e \Delta log(E_t) + \beta_s \Delta log(S_t) + \beta_v v_{t-1} \\ + \gamma_R(log(R_{t-1}) - \gamma_e log(E_{t-1}) - \gamma_s log(S_{t-1})) + \omega_t \tag{4}$$

where τ is the constant term which also includes the natural vacancy rate and ω_t is an $i.i.d$ error term, with $\omega_t \sim N(0, \sigma^2)$. Changes in rents are determined by shifts in demand and supply, as well as deviations in rents or in the vacancy rate from their estimated equilibrium levels. We expect that if rents or the vacancy rate are above their estimated equilibrium, rents will fall until they have re-adjusted. Thus, we expect that $\gamma_R, \beta_v < 0$. The pace of the adjustment process increases with the value of these coefficients. As rents and the vacancy rate are determined contemporaneously, we use the lagged vacancy rate as a proxy for vacancy rates in a given period to mitigate endogeneity problems.

Two simple methods are often applied when estimating error correction models. We refer to these methods as the one-step and the two-step method. The one-step method involves estimating Equation (4) by OLS. Assuming weak exogeneity, cointegration can be determined by whether the coefficient on the lagged rental prices, γ_R, is significantly smaller than zero.[9] The second method is a two-step estimation procedure. First, the residual from an OLS regression on Equation (3) is estimated, where the residual will be an estimate of how rents deviate from their equilibrium. The residuals are stationary

[7] See Tables A.2 and A.3 in the Appendix for relevant test results. The Augmented Dickey-Fuller test indicates that employment might be trend-stationary, while we are not able to reject the null of non-stationarity when we apply the Phillips-Perron test. Based on these results, we assume that the level series for GDP, rental prices, stock of offices and employment all have a unit root.

[8] If a linear combination of these variables with a unit root is stationary, the series are said to be cointegrated (Engle and Granger (1987)).

[9] 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.

if the variables cointegrate. In the second step, we replace the long-run relationship in Equation (4) with the estimated residual, and apply OLS to the resulting equation.

Both the one-step and two-step method have some limitations. When using the one-step method, weak exogeneity is necessary in order to estimate long-run coefficients without a loss of information, see Ericsson and MacKinnon (2002). A drawback of the two-step method is that the coefficients in the first stage suffer from finite sample bias, see Banerjee et al. (1993). Given that our sample size is not too large, this bias causes some concern. In addition, when testing for cointegration in the two-step method, we have to make the quite strict assumption of equal short-run and long-run elasticities. We therefore proceed with the one-step method. Results from the two-step method are given in the Appendix as a robustness test. Previous studies have typically used the two-step method when estimating ECMs for rental prices.

Since we have a single equation model, we implicitly assume that there only exists one long-run relationship in our model. We apply the Johansen test to investigate the plausibility of this assumption. When we only include employment or GDP as the demand component, we find empirical evidence of one long-run relationship.[10] If we include both demand components in the specification, the test results indicate that there exist several cointegrating vectors. Englund et al. (2008) estimate models with only one long-run relationship even though the empirical results have suggested the presence of several cointegrating vectors.

[10] See Appendix Tables A.4, A.5 and A.6 for relevant test results.

4 Results

The results from applying the one-step method with different demand indicators are presented in Table 1. We find empirical evidence of employment and stock of offices being weakly exogenous for the cointegrating vector while this assumption seems to be more questionable when it comes to GPD, see Table A.7 in the Appendix for test results.[11]

In all three specifications considered, the coefficient on the lagged rental prices index is significant, and we conclude that a long-run relationship exists. This implies that the error correction mechanism works as expected, i.e. rents move towards their estimated equilibrium. The equilibrium coefficients vary between -0.5 and -0.65, which implies that prices re-adjust quickly. This is somewhat higher than in the literature (see McCartney (2012) for a survey).

Moreover, the contemporaneous response to a change in employment is strong in Columns I and III: a one percent increase in employment leads to a 4.5 and 4.1 percent increase in rents, respectively. The long-run response is almost equal when only employment is included as a demand variable (Column I), but are substantially lower when we augment the regression with GDP (Column III), see also Table 2 where the long-run coefficients for the level variables are calculated from Table 1. This is likely due to the high correlation between the two variables. Similarly, the long-run effect of an increase in GDP is strongest when employment is not included as an additional demand indicator (Column II versus Column III), while the contemporaneous response is roughly the same.

Furthermore, the long-run elasticity of stock of offices is fairly stable at around -2.3 when employment is included in the specification (Column I and III), but falls if only GDP is used as a demand indicator (Column II). Moreover, the contemporaneous effect of an increase in stock of offices is not significant, and the sign of the coefficient also varies in the different specifications. Finally, the vacancy rate seems to have an almost negligible impact on changes in rents, which is somewhat surprising as rents are highly correlated with the vacancy rate, see Figure 2 d).[12] Furthermore, the specification in Column III yields the highest explanatory power. When applying the two-step procedure, the results

[11] Cointegration can be determined by whether the coefficient on lagged rental prices is significantly smaller than zero given weak exogeneity.

[12] In the literature, the coefficient on the supply indicator is often not significant in the short-run equation. Whether the coefficient of the vacancy rate is significant has varied between different studies.

are broadly the same, see Tables A.8 and A.10 in the Appendix.[13]

Our preferred model specification is given by Column I in Table 1. The specification in Column III has the highest explanatory power, but we found evidence of several cointegrating relationships with this specification. Furthermore, the empirical results indicate that GDP is not weakly exogenous with respect to the cointegrating vector in the specification in Columns II and III.

[13]Engle and Granger (1987) suggest testing for a unit root in the residuals from the first stage in the two-step method. This test builds on the strict assumption of equal short- and long-run coefficients. The residuals from the specifications in Column I, Column II and Column III in Table A.8 are all stationary, which indicates the existence of a long-run equilibrium, see Table A.9 in the Appendix for the results from the test.

Table 1: Regression results. One-step ECM. Dependent variable: D.Log(Rent)

	(I)	(II)	(III)
D.Ln(Employment Oslo)	4.50***		4.10***
	(1.32)		(1.24)
D.Ln(GDP)		0.35***	0.28**
		(0.12)	(0.12)
D.Ln(Stock Oslo (square metres))	0.17	-0.95	-0.20
	(1.46)	(1.48)	(1.37)
L.Vacancy rate	-0.00	-0.01*	-0.01
	(0.01)	(0.01)	(0.01)
L.Rents	-0.50**	-0.55**	-0.65***
	(0.13)	(0.13)	(0.13)
L.Ln(Employment Oslo)	2.09***		1.41**
	(0.68)		(0.68)
L.Ln(GDP)		0.51***	0.40***
		(0.14)	(0.14)
L.Ln(Stock Oslo (square metres))	-1.15*	-0.42	-1.43**
	(0.65)	(0.43)	(0.62)
Constant	-8.59*	0.30	-0.67
	(4.72)	(5.67)	(5.16)
Observations	58	58	58
Adjusted R2	0.284	0.239	0.377
Durbin Watson statistics	2.1	1.8	2.0

Notes: Standard errors are reported in parenthesis below the point estimates. 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).

Table 2: Long-run relationship from Table 1. Dependent variable: Log(Rent)

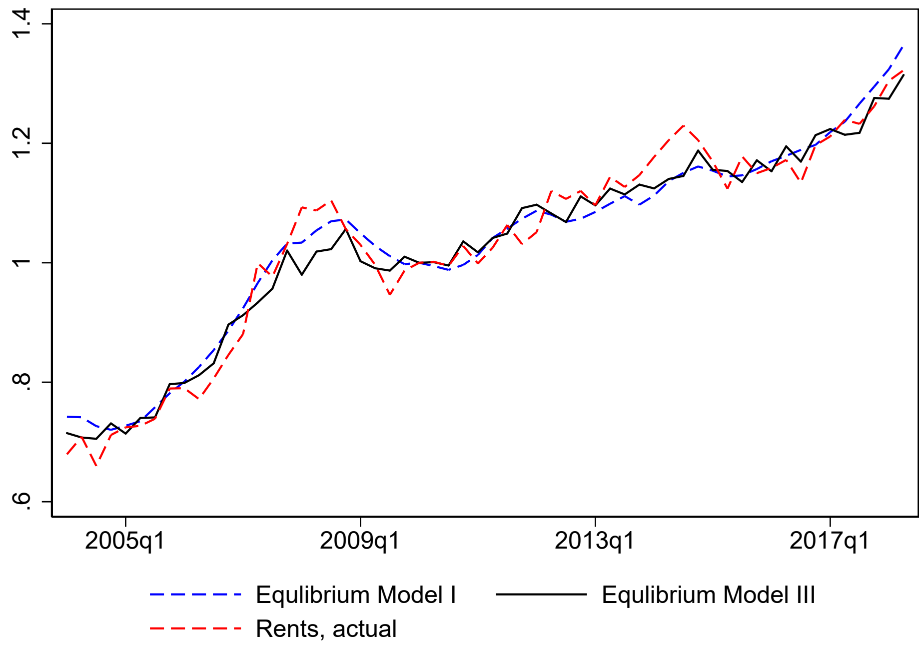
	(I)	(II)	(III)
Ln(Employment Oslo)	4.2***		2.2**
	(1.05)		(0.94)
Ln(GDP)		0.9***	0.6***
		(0.20)	(0.19)
Ln(Stock Oslo (square metres))	-2.3*	-0.8	-2.2**
	(1.30)	(0.82)	(0.92)

Notes: The estimates of the long-run elasticities are given by the coefficients of the level variable divided by the coefficient of lagged rents from Table 1. Standard errors are reported in parenthesis below the point estimates and are calculated using the delta method. The asterisks denote significance levels: * = 10%, ** = 5% and *** = 1%.

In Figure 3, we compare actual rents with their estimated long-run equilibrium from the specification in Columns I and III. As clearly illustrated in the figure, the series have followed each other closely in the sample period. However, there are some notable deviations. Before the financial crisis, rents were somewhat higher than their estimated fundamental values, while they were somewhat lower in 2009. In 2014, actual rents were also somewhat higher than what was indicated by their estimated long-run equilibrium.

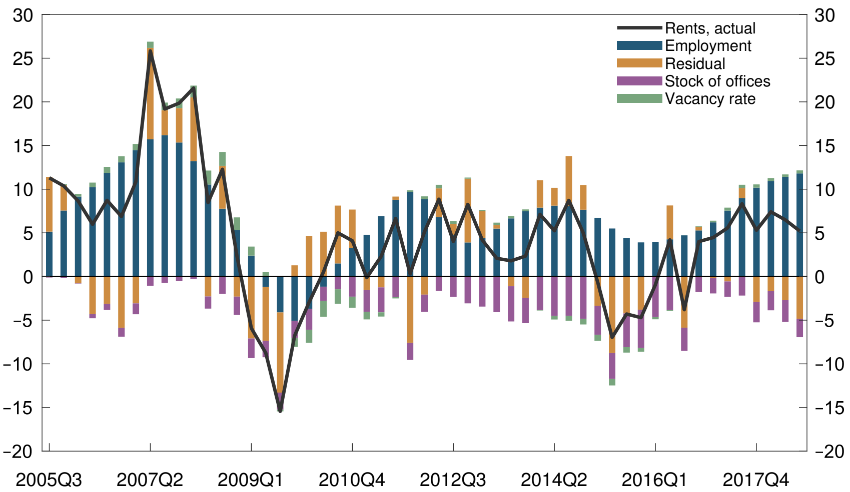
Furthermore, in Figure 4, we decompose the four-quarter change in rents by its explanatory variables. In the years preceding the financial crisis, high growth in employment in Oslo combined with low construction activity contributed to rapid rental growth. However, when rental growth peaked at above 20 percent in 2007, a substantial part could not be explained by its fundamentals. This unexplained part is captured by the residuals (yellow bars). Further, rents fell rapidly in 2008-2009, and a significant share was unexplained. Except for the correction in rental prices in 2015, four-quarter change in rents have fluctuated around five percent since 2010. The change in rents in this period can mainly be attributed to the fundamentals.

Figure 3: Actual rents and their estimated long-run equilibrium



Notes: Equilibrium estimated based on the specifications in Column I and Column III in Table 1. Normalized to one in 2010 Q1.

Figure 4: Decomposed change in rents



Notes: Based on the specification in Column I in Table 1. Decomposition of four-quarter change (log-approximation) in rents applying the Wold Representation Theorem. The residuals capture the change that is not explained by the explanatory variables.

Furthermore, we investigate the robustness and forecasting abilities of our preferred model by applying recursive estimation. We recursively expand the sample by one quarter starting from 2009 Q4.

The recursive estimation of the adjustment parameter, as well as the coefficients of the variables in the long-run relationship, are displayed in Figure 5 a). The coefficients are stable over the sample period. A high degree of stability indicates that our results are robust and that our model has good forecasting abilities. The estimated long-run effects of a one percent increase in employment and stock of offices are similar for all the different subsets at around 4 percent and -2 percent, respectively. The adjustment parameter also displays a high degree of stability, but has trended somewhat upwards the previous years by increasing from -0.75 to -0.5. However, this parameter is clearly negative for all subsets, which indicates that there is a mechanism ensuring that rents re-adjust quickly towards their estimated equilibrium, and it does not appear to be a bubble in rents in any of the samples.

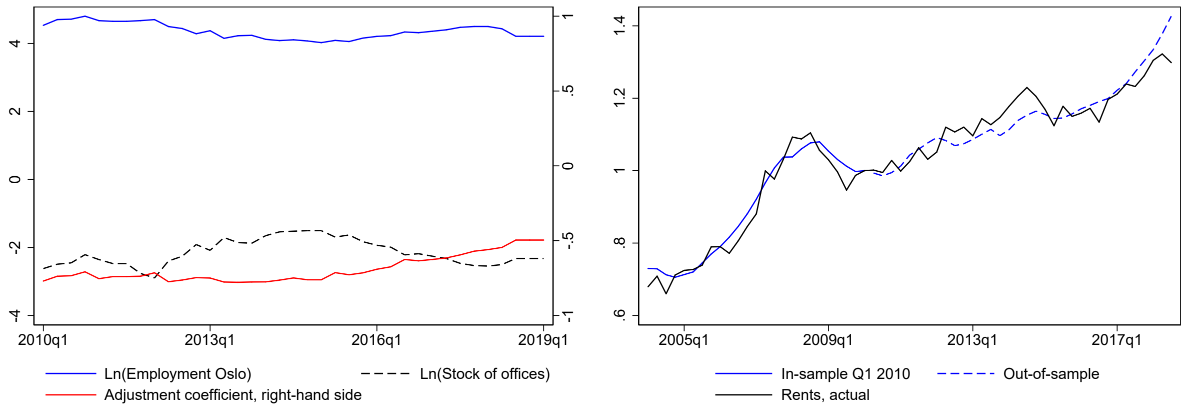
The high degree of stability in our coefficient estimates indicates that our model would perform well out-of-sample. This is shown in Figure 5 b), where the out-of-sample forecasts, based on the long-run relationship, are broadly in line with the overall development in actual rents.

Our results suggest that rental prices follow their fundamentals closely. In periods of deviation, they quickly move back to their estimated equilibrium. This reduces the risk of a sharp fall in rents in Oslo.

Figure 5: Recursive estimation and out-of-sample forecasts

a) Recursive coefficient estimates

b) Out-of-sample estimates of long-run equilibrium rents



Notes: In Figure 5a), we employ recursive estimation with end point from 2010 Q1 to 2018 Q4 on the specification presented in Column I in Table 1. The long-run coefficients for employment and stock of offices are given by their coefficient estimates divided by the coefficient of the adjustment parameter. In Figure 5b), we estimate the long-run coefficient based on a sample from 2004 Q1 - 2010 Q1 and then we make projections based only on the long-run relationship. These forecasts are compared with actual rents.

5 Conclusion

The Oslo office market is important for financial stability in Norway as banks are likely to have substantial exposures to this market. In this paper, we employ error correction models to detect deviations in rents from their estimated long-run equilibrium. If rental prices cannot be explained by underlying economic fundamentals, it may indicate a pronounced risk of a sharp fall in rental prices.

We find that rents have followed their estimated equilibrium closely and that rents re-adjust quickly in periods of deviation. Moreover, we find that employment and stock of offices are important explanatory variables. These results are robust for the sample end point. The high degree of stability in the coefficients suggest that our model has good forecasting abilities.

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.

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A Appendix

Table A.1: Data sources

Variable	About the series
Employment Oslo	The series is break-adjusted for the change in age-limit in 2005 and the use of a new data source in 2015. Quarterly numbers are constructed by cubic interpolation of the annual data. Source: Statistics Norway.
GDP	Gross domestic product Mainland Norway. Value. Quarterly data. Source: Statistics Norway
Office rents Oslo	Based on lease signing date. Connected from 2006 with office rents based on lease inception date. Sources: Arealstatistikk and Anundsen and Hagen (2020)
Stock of offices Oslo	Estimate of stock of offices in 2014. Time series constructed by adjusting for completed office space each quarter. Sources: Akershus Eiendom and Statistics Norway
Office vacancy rate Oslo	Semi-annual data. Quarterly data constructed by linear interpolation. Source: DNB Næringsmegling

Table A.2: Augmented Dickey-Fuller test. P-values

	Rents	Emp. Oslo	GDP	Stock of offices
No trend	0.34	0.99	0.32	0.98
Trend	0.21	0.05	0.20	0.71

Notes: The number of lags are chosen based on the Akaike Information Criterion. All variables are in logarithmic form.

Table A.3: Phillips-Perron test. P-values

	Rents	Emp. Oslo	GDP	Stock of offices
No trend	0.33	1.00	0.86	0.98
Trend	0.51	0.16	0.04	0.76

Notes: All variables are in logarithmic form.

Table A.4: Johanson cointegration test

Johansen tests for cointegration

Trend: constant — Number of obs = 56

Sample: 2004q4 - 2018q3 — Lags = 3

maximum rank	parms	LL	eigenvalue	trace statistic	5% critical value
0	21	693.02834	.	39.4689	29.68
1	26	708.02914	0.41477	9.4673*	15.41
2	29	712.75986	0.15545	0.0059	3.76
3	30	712.76279	0.00010		

Notes: Johanson cointegration test for rental prices, employment and stock of offices.

Table A.5: Johanson cointegration test

Johansen tests for cointegration

Trend: constant — Number of obs = 58

Sample: 2004q2 - 2018q3 — Lags = 1

maximum rank	parms	LL	eigenvalue	trace statistic	5% critical value
0	3	474.5798	.	32.1665	29.68
1	8	487.70488	0.36402	5.9164*	15.41
2	11	490.65004	0.09657	0.0261	3.76
3	12	490.66307	0.00045		

Notes: Johanson cointegration test for rental prices, GDP and stock of offices.

Table A.6: Johanson cointegration test

Johansen tests for cointegration

Trend: constant Number of obs = 55

Sample: 2005q1 - 2018q3 Lags = 4

maximum rank	parms	LL	eigenvalue	trace statistic	5% critical value
0	52	841.37464	.	83.5466	47.21
1	59	861.36121	0.51654	43.5735	29.68
2	64	872.69298	0.33772	20.9100	15.41
3	67	879.05385	0.20650	8.1882	3.76
4	68	883.14796	0.13832		

Notes: Johanson cointegration test for rental prices, employment, GDP and stock of offices.

Table A.7: Weak exogeneity test

Variable	Model I	Model II	Model III
Employment Oslo	WE		WE
GDP		Not WE	Not WE
Stock of offices	WE	WE	WE

Notes: WE is used as an abbreviation for weak exogeneity with respect to cointegrating vector. As suggested by Johansen (1992), we test for weak exogeneity by performing an F-test for $\alpha = 0$ in the equation

$$\Delta z_t = \alpha * \beta' x_{t-1} + \epsilon_t$$

where z_t is a vector of potentially weakly exogenous variables, ϵ_t is an $i.i.d$ error term, with $\epsilon_t \sim N(0, \sigma^2)$, and x_t includes z_t and rental prices.

Two-step method

First, we estimate a long-run equilibrium using OLS on a stochastic version of Equation (3):

$$log(R_t) = \tau_0 + \gamma_e log(E_t) + \gamma_s log(S_t) + \epsilon_t \tag{A.1}$$

ϵ_t is assumed to be a stationary error term. The estimated residual, denoted by $\hat{\epsilon_t}$, will be stationary if the variables cointegrate. In the second step, we replace the deviation from the long-run relationship in Equation (4) with $\hat{\epsilon_t}$, to get the equation

$$\Delta log(R_t) = \tau_1 + \beta_e \Delta log(E_t) + \beta_s \Delta log(S_t) + \beta_v v_{t-1} + \gamma_R * \hat{\epsilon}_{t-1} + \omega_t \tag{A.2}$$

where we expect that $\gamma_R, \beta_v < 0$. We assume that ω_t is an $i.i.d$ error term, with $\omega_t \sim N(0, \sigma^2)$. Finally, we apply OLS to Equation (A.2).

Table A.8: Regression results. Two-step ECM. Long-run relationship. Dependent variable: Log(Rent)

	(I)	(II)	(III)
Ln(Employment Oslo)	4.59		3.31
	(0.25)		(0.38)
Ln(GDP)		1.25	0.45
		(0.10)	(0.11)
Ln(Stock Oslo (square metres))	-2.63	-1.95	-2.86
	(0.31)	(0.40)	(0.28)
Constant	-17.39	14.82	-3.21
	(2.11)	(5.14)	(3.94)
Observations	59	59	59
Adjusted R2	0.961	0.928	0.969

Notes: Standard errors are reported in parenthesis below the point estimates.

Table A.9: Augmented Dickey-Fuller test of the residuals from Table A.8

	Test statistic	P-value
Model I	-3.93	0.00
Model II	-3.16	0.02
Model III	-5.13	0.00

Notes: Number of lags chosen based on the Akaike Information Criterion. Residuals from the estimated long-run relationships in Table A.8.

Table A.10: Regression results. Two-step ECM. Short-run dynamics. Dependent variable: D.Log(Rent)

	(I)	(II)	(III)
D.Ln(Employment Oslo)	4.47***		4.26***
	(1.30)		(1.21)
D.Ln(GDP)		0.39***	0.24**
		(0.12)	(0.10)
D.Ln(Stock Oslo (square metres))	-0.05	-1.68	-0.40
	(1.38)	(1.40)	(1.28)
L.Vacancy rate	0.00	-0.00	-0.00
	(0.00)	(0.00)	(0.00)
L.Error-term Model I	-0.49***		
	(0.12)		
L.Error-term Model II		-0.45***	
		(0.11)	
L.Error-term Model III			-0.62***
			(0.13)
Constant	-0.01	0.05*	-0.00
	(0.02)	(0.03)	(0.02)
Observations	58	58	58
Adjusted R2	0.296	0.233	0.386

Notes: Standard errors are reported in parenthesis below the point estimates. The asterisks denote significance levels: * = 10%, ** = 5% and *** = 1%.