THE UNIVERSITY OF SHEFFIELD

Department of Urban Studies and Planning

The Determinants of European Office Rents

Thesis submitted to the University of Sheffield in fulfilment of the requirements for the degree of Doctor of Philosophy

Chan Woo Kim

August 2024

Table of Contents

Acknowledgements

I am profoundly grateful to Prof Craig Watkins and Dr Catherine Jackson for their advice, encouragement and patience throughout my conduct of this dissertation. I also thank Prof Michael White and Dr Berna Keskin for their invaluable comments and recommendations, as well as my colleagues and the staff members at the Department of Urban Studies and Planning for their support and guidance. Finally, I appreciate my family for all their unconditional support.

Abstract

Real estate is a complex economic commodity – it is durable, spatially immobile, and has limited divisibility. These characteristics mean that the structure and operation of the market is more complex than that of many other assets. For instance, while the inherent business needs of occupiers are met by real estate space, the durability of the commodity means that it also exhibits many of the characteristics of an investable asset. In this context, even at the simplest level, real estate economists tend to conceptualise the market as consisting of occupier and investor markets. More advanced analysis extends and develops this to recognise the distinctive nature of the supply side of the market and/or to consider the importance of spatial differentiation or to segment the market along quality lines. This makes real estate markets analytically complex and difficult to model. The desire to find effective models that can predict or forecast outcomes reliably and inform the decisions of users, developers and investors has given rise to the development of a large number of models over the past forty years.

Econometric models of the UK and European office markets form a large part of this empirical literature, and these models tend to be dominated by demand-side considerations. This approach is an appropriate method to understand the occupant submarket at least in the short term, as the rental determination process is clearly described in the single equation model and supply responsiveness is very limited. The rigid short-term supply side, however, is not generally considered explicitly, and any explanation of dynamics, temporary disequilibrium and convergence to the new equilibrium is missing.

The modelling literature divides into two broad groups: the first group consists largely of single equation models of rent that combine demand-side variables with limited consideration of the supply side; the second group consists of multi-equation models that seek to take more explicit account of the complex structure and dynamics of the market. For instance, some of the more complex modelling projects start with the textbook treatment of the office real estate market, generally referred to as the DiPasquale-Wheaton (DW) model. In the DW framework, the dynamics of the market is described as an anti-clockwise operation process that goes through 'submarkets' or quadrants. It begins with a short-term rental adjustment process of demand and supply, continues to price valuation of property, stimulating construction starts, and then moves to the level of total space stock adjusted by new supply, depreciation and demolition. In this framework, rent is highlighted as an occupation indicator in the short term, and a transmission factor which brings user sector change to other submarkets. In this context, the four-quadrant model and relevant discussions on the interactions of submarkets justify the adoption of a multi-equation approach in the analytic perspective of real estate economics. Since multi-equation models include subsectors as component equations and estimates simultaneously, the methodology enables comprehensive analysis in reflection of the theoretical interdependency.

Relevant model-building studies have tended to be more common in the U.S. than in the European market. Even though there are a few European analyses, they have tended to address one specific variable, single metropolitan or country market, or a subsector (e.g., the user market) rather than comprise comprehensive, systematic market analysis. Against this backdrop, this study aims to focus on the interaction process of submarkets and their convergence.

Based on the above, this study seeks to explore the determinants and dynamics of commercial real estate, particularly office rents, and apply these to the European office market from a neoclassical economic perspective. The interaction process of subsectors within the market system and their spatial integration impacts that go beyond individual cities or countries will be further examined. To achieve this aim, three objectives are established: (1) to understand

the determinants of office rents in selected European markets, (2) to explore differences across space and over time in the selected markets (space dynamics), and (3) to examine the interactions among the subsectors of the office markets.

In this study, the sample consists of six office centres, namely, London, Paris, Frankfurt, Amsterdam, Madrid and Milan, for the period 2007 to 2018 on the quarterly basis. The modelling approach starts with a simple operational framework and then seeks to add complexity, reflecting the DW theoretical model and the interaction it depicts. In the theoretically richer variants, each of the user, investment, flow and stock supply sectors (quadrants) are considered. Simultaneous estimation of the four equations enables the application of theoretical interaction of subsectors in the regression process.

The modelling work assesses different model structures and employs a range of methods of estimation. This allows for a systematic evaluation of the performance of the models in terms of their theoretical consistency, model properties and explanatory power. The role of endogenous variables needs to be highlighted, since a variable is not only relevant as a component of one equation but delivers change to the adjacent subsector equation as well. For instance, endogenous variables in the investment and development sectors indirectly impact on rent through the error term, while predictors in the occupier sector (rental equation) directly impact on the dependent variable (rent). The process demonstrates the structural interaction between equations, and implies that simultaneous estimation performs better than a single equation since additional information is reflected in the system.

There are significant technical challenges associated with the empirical analysis. Despite the theoretical advantage of more complex model structures, simultaneity is a significant econometric issue in the estimation. Simultaneity accompanies endogeneity of certain predictors, and the resultant heterogeneity causes the Gauss-Markov assumption to be unsatisfied. Since ordinary least squares (OLS) is no longer the best linear estimation unbiased estimator (BLUE), alternative methods, such as robust general least squares (GLS), panel, and three-stage least squares (3SLS), and generalised method of moments (GMM), are estimated. Each method improves OLS, as follows: 1) Robust GLS justifies the BLUE violation; 2) panel analysis enables regression of cross-section combined with time-series; 3) 3SLS reflects intersectoral endogeneity with the simultaneous estimation structure; and 4) GMM compares the maximum likelihood estimation (MLE) performance to that of OLS.

This research study sheds light on the workings of European office studies by 1) narrowing the gap between demand-supply equilibrium theory and the empirical approach, and 2) improving the quality of econometric estimation by expanding the scope of analysis. First, the four-quadrant mechanism worked well in 3SLS estimation through its component equations. The equations are simultaneously estimated, and endogenous variables delivered the impact of one subsector to the others. The actual coefficients are generally matched with expected signs. Although some of the supply-side variables are statistically insignificant, the interaction processes properly operate in the comprehensive demand-supply system. Second, panel and 3SLS present improved estimation methods in terms of the analytic dimension. In the regression process, multiple office centres and submarkets are combined with time-series in the panel analysis and 3SLS, respectively. Comparison of both results to OLS supports the hypothesis that the quality of estimation is enhanced by structurally combined information.

List of Figures

List of Tables

1 Introduction

1.1 Context and Motivation

Conventional neoclassical economics views demand in the real and monetary markets as determined by the IS–LM model. In this vein, total demand and total supply are determined by the AS–AD model to achieve Walrasian equilibrium. However, the rigidity in the aforementioned supply sector poses difficulties in applying the neoclassical economic perspective of equilibrium, fluctuations, and convergence to new equilibriums directly to real estate and office markets.

Unlike the general framework in which fluctuations and transmission to and from the IS–LM and AS–AD models occur swiftly and efficiently, the demand and supply sectors in the real estate market differ on account of the finite good of space. Additionally, due to short-term inefficiencies, it requires a considerable amount of time, beyond a certain period, for adjustments to take place among subsectors to converge to a new equilibrium.

Real estate constitutes a significant part of the macroeconomy, with offices commonly classified as a major subset alongside housing and retail in the real estate sector. Despite this importance, real estate possesses characteristics such as rigidity and immobility that distinguish it from traditional assets such as stocks and bonds. From a neoclassical economic perspective, these characteristics imply that while spatial demand remains more consistently present, the supply of new space is (at least) not readily available in the short term.

Furthermore, the supply in the real estate market is heavily influenced by how government authorities make decisions regarding planning. Unlike the neoclassical economic perspective that assumes rational actors, the supply of new space by developers and construction companies in the actual real estate market often fails to adequately reflect spatial demand and is myopically implemented.

Real estate is a type of commodity comprising land and buildings and plays a role in the national economy from a macroeconomic viewpoint. Real estate is generally divided into residential, office, retail and industrial real estate, and office and retail are typically bundled together as commercial real estate. Office real estate provides workspace for businesses, especially service-oriented companies, such as those in the finance, insurance and real estate (FIRE) sectors. For these companies, exchanges of human resources and information circulation form the basis of their business, and offices provide the spatial medium in which the businesses can accumulate their core competencies. The office market is usually located in the centre of the metropolitan area, enabling economies of scale of countries and companies in the background of integrated space and human resources. The dominance of central office areas remains solid, even though alternative forms of urbanisation have been realised, such as office parks and edge cities, due to the advent of the information society and the change in work culture in line with telecommuting.

Considering the above overview of the office market, rental properties have been attracting considerable attention, with yield and vacancy as key variables in this field of research. This increased interest is relevant to the tangible features of real estate property, which can be divided into two submarkets: space and asset (capital). The real estate market essentially operates through the mechanism of a strong link between the two submarkets, and rents function as a mediator between these two markets. In the space market, rent is the price of a lease, adjusted by the supply of the owner and the demand of the tenant. In the asset market, the yield and capital value (CV) are determined through a valuation based on rent. Developers also decide whether to participate in a new development project by considering the market price of the asset, which is reflective of the rent. Thus, research on this variable is essential because rent is a starting point for an integrated understanding of the space and asset markets.

In quantitative economic methods, there exists a difference in empirical approaches depending on whether each sector is analysed individually or comprehensively. When considering these approaches, current quantitative empirical research can be broadly categorised into three models: traditional single equation models, multi-equation models, and error correction models (ECMs).

The analysis of the existing European office market has relied primarily on a single equation model focusing mainly on the demand side (see, for example, Thompson and Tsolacos, 2000, as one example of several). Due to the characteristics of the office market, which takes several years to renew supply, a demand-side analysis may be sufficient for the short term. This is because of uncertainty on the supply side, including a long construction period, land-use regulations and the duration to acquire development permits, and the unlikely change in the amount of supply. As a consequence, office rent is probably determined by demand factors in the short term. However, in the long term, using a single equation is essentially bounded, since changes in both demand and supply affect rent. In this sense, the adoption of a multi-equation is justified to reflect the influence of the supply sector, dynamic movement between key determinants of the market (such as an increase in the supply volume and vacancy rate) and the resulting rent decline. Therefore, using the multi-step equation structure for major cities in Europe will elucidate the dynamic mechanism of the variables. The establishment of this model is also expected to enable rational judgment of market participants to predict changes in rent more precisely.

While the equation structure is relevant to the topic of how to capture the comprehensive operation of the real estate market statically, the analytic method in conceptual real estate analysis includes a more extensive consideration of the dynamics in the real estate market than the models. According to DiPasquale and Wheaton (1992), the implication of the dynamics described in the four-quadrant model is that there will be convergence to the market equilibrium through short- and long-term adjustments. In the space market, an equilibrium rent is formed based on the supply and demand, and in the asset market, yield capitalises the equilibrium rent into the CV in the asset market. The amount of new supply is then determined in consideration of the CV and the amount of total stock is adjusted in the long term. As a result of technical advancements the field of real estate study has experienced, there is a wide range of analytical choices to track such temporal market movement. Among these, this study will seek to find an analytical method (operational empirical model) that provides appropriate linkages between such theoretical background and applied models.

Efforts have been made by researchers to develop theoretical frameworks to explain the workings of the real estate market and apply these frameworks to empirical analysis. Following Keogh (1992) and DiPasquale and Wheaton (1992)—who segmented the subsectors of the real estate market into user, investor, flow, and stock development sectors—there have been a series of attempts to quantitatively apply these frameworks in an empirical analysis. In the early 1980s, quantitative analyses often relied on traditional neoclassical economic frameworks of demand and supply sectors, but the application of the theoretical framework to empirical analysis has gradually stalled since the 1990s.

In today's global economy, where nations influence each other and are closely interconnected, these influences extend to the real estate and office markets. Therefore, understanding the impact of globalisation on the real estate market is essential for enhancing the understanding of the office market. Thus, this study not only investigates the dynamics of major office markets within Europe, focusing on rents, but also conducts this analysis under the assumption that major European cities are closely interconnected due to the effects of globalisation.

In Europe, representative financial centres, such as London, Frankfurt, Paris and Amsterdam, are closely related as a consequence of market integration (Giussani et al., 1993). Consequently, macroeconomic indicators such as interest rates, employment, inflation and stock prices tend to impact spontaneously on European countries and cities. These indicators are exogenous variables which have a significant impact on the real estate market, suggesting that when a quantitative study is conducted focusing on the rent of major European office centres, a statistically significant result is likely to be the outcome.

However, to date, much applied econometric real estate research has focused on the United States (US) and the United Kingdom (UK; London and the City of London in particular), because of the data collection problem. Although some studies have examined European real estate as an integrated market, relatively few systematic studies have been conducted relative to single market analyses. This is similar in Asia, where research has recently been extended to financial hubs such as Hong Kong and Singapore, but this research is not as extensive or rich as the research conducted in the UK and the US. Therefore, this study seeks to: (1) obtain annual data on rent in the office market and independent variables in major cities in Europe over 10 years, and (2) conduct a statistical analysis to overcome the spatial limits of office rent research. The results of this study will contribute to this field by improving the predictability of the market in the region.

This introductory chapter presents a brief research outline of the features of real estate and the office market and justifies the need for research on the topic of European office rent and the determinants of rent in the office market. This chapter also describes the research aim as the final destination and the research objectives as the intermediate goals and presents the research questions of this study. Finally, the overall structure of the research study is described and clarified.

1.2 Objectives of Study

This study seeks to model and analyse the commercial real estate market, with a specific focus on the European office market. The real estate market is different from other asset markets due to the complexity of real estate as an asset, the complex regulatory and institutional framework that shapes its operation and its connectedness to uncertainty and dynamic capitalist economies. This research study explores the components and dynamics of the office market and reflects on the extent to which models can be consistent with or reflective of existing theories. The empirical results are expected to provide insight into the prospects of European markets and the methods employed will have the potential to contribute to future practice in the forecasting of real estate markets in general, as well as with regard to a panel of European metropolitan office markets specifically.

As mentioned in the above outline, the aim of this study is to explore the dynamics and determinants of commercial real estate, particularly office rents, and apply these to the European office market from a neoclassical economics perspective. Furthermore, the interaction process among subsectors in the market system and their spatial integration impacts beyond those on individual cities or countries are also examined.

In consideration of the context and the aim of the research, the following objectives are established:

- To understand the determinants of office rents in selected European markets
- To explore differences across space and over time in the selected markets (space dynamics)
- To examine the interactions between the subsectors of the office markets

To accomplish the presented objectives, the study addresses the following research questions:

- What are the determinants of office rents in the selected European markets?
- To what extent do office rents vary across space and time (spatial and temporal variation)?
- What are the interactions (or dynamics) among the submarkets?

In short, the study will seek to develop a range of applied models of a panel of European office markets. These models will capture the theoretical complexity to varying degrees and will be parameterised using a number of different methods of estimation. The results will allow for reflection on the trade-offs between theoretical complexity, the use of alternative methods of estimation and the utility of model outcomes.

1.3 Structure of Study

The rest of this thesis is structured into five further chapters. Chapters 2 and 3 set out the working of the real estate market, drawing on relevant economic theory. This will provide a key basis for consideration of the complex dynamics that drive market outcomes and should be considered in econometric model development. The chapters draw heavily on the four-quadrant model presented by DiPasquale and Wheaton. These chapters also look at previous empirical studies and consider the extent to which these do and do not seek to capture some of the complexity of the operations of the market. Taken together, this review of the literature provides the basis for the development of a series of applied models, ranging from simple single equation models with limited theoretical complexity to more complex multi-equation models designed to capture key dynamics and interactions. Chapter 4 sets out the research methods and design. The chapter presents details of the data collection and research methodology, transforming the initial model into an empirical model. It also describes the methods of estimation and the diagnostic tests used to establish the rigour and robustness of the research approach. Chapter 5 describes the regression analysis using various estimation techniques and diagnostic tests, including both all-sample estimations and individual city estimations. Chapter 6 provides the motivation and findings of the thesis, and discusses the implications for future research and practice. It highlights the strengths and weaknesses of this study, the similarities and differences with previous studies, and its academic contributions.

2 Workings of the Office Market (Literature review)

2.1 Introduction

This chapter explores the details of the real estate market's operation processes, focusing on its two submarkets: the space and asset (capital) markets. These two markets are driven by general macroeconomic factors as well as local economic and market factors that shape the demand for and supply of real estate. Supply and demand are impacted by a number of actors who participate in the market in accordance with their business needs. Therefore, to understand the overall structure and system of the market, the first step is to analyse the features and working processes of each submarket and to determine the key players' motivation to participate in the market. To achieve this goal, existing models, theories and publications will be reviewed, beginning with the well-known four-quadrant model of DiPasquale and Wheaton

(1992). This chapter thus seeks to establish a general conceptual framework for the study and establish an understanding of the market and its dynamic interactions.

A theoretical understanding of the individual sectors is a starting point for understanding the principles and structure of the real estate market. However, it should be understood that the individual sectors are linked with each other. The real estate market is subject to adjustments over time, thus deviating from the existing equilibrium in accordance with the interaction. However, the inelastic nature of the market causes time lags in the short- and long-term equilibrium convergence among the sectors and their variables. This complexity in the adjustment and convergence processes provides legitimacy to extend the realm of understanding into the "dynamics" between space and asset markets, including knowledge of how one sector depends on and reacts to another's changes, and which impacts affect the overall market. Therefore, this chapter reviews and discusses the interactions and dynamics between the space and asset markets.

2.2 Overview of Real Estate and Office Market

Real estate is a complex economic commodity – it is durable, spatially immobile and has limited divisibility. These characteristics mean that the structure and operation of the market is more complex than that of many other assets. For instance, while the inherent business needs of occupiers are met by real estate space, the durability of the commodity means that it also exhibits many of the characteristics of an investable asset. In this context, even at the simplest level, real estate economists tend to conceptualise the market as consisting of occupier and investor markets. More advanced analysis extends and develops this to recognise the distinctive nature of the supply side of the market, and/or to consider the importance of spatial differentiation or to segment the market along quality lines. This makes real estate markets analytically complex and difficult to model. DiPasquale and Wheaton (1992) and Keogh (1994) have offered widely cited attempts to develop a conceptual framework that captures the unique and complex features of the real estate market and explains the interaction between different actors and different elements of the market. These models seek to consider the processes that shape critical outcomes such as rent, yields, CVs, quantity demanded and supplied, and stock.

2.2.1 Feature of the Real Estate Market

This section reviews previous conceptualisations of the real estate market by DiPasquale and Wheaton (1992) and Keogh (1994) and reconstructs their models for the purpose of this study.

The four-quadrant model illustrated in Figure 1 (DiPasquale and Wheaton, 1992) is a well-known and efficient tool used for understanding the overall operational principles of the real estate market. The right-hand side represents the user market while the left-hand side represents the investment or asset market (ownership). The four key variables considered in the figure are rent, price, construction and stock. This diagram assumes a long-term equilibrium between the variables, and unless the ending stock equals the starting stock, the diagram is not considered to reach a new equilibrium.

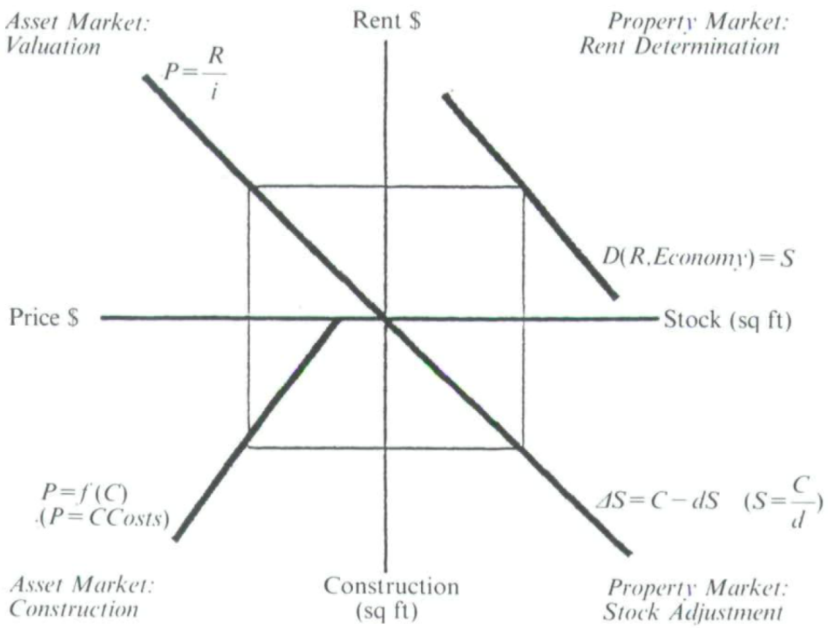

Figure 1. Four quadrant model for user and investment market (source: DiPasquale and Wheaton, 1992)

Keogh (1994) presented his conceptualisation of the real estate market in a more intuitive way, as illustrated in Figure 2. Here, the real estate market is subdivided into three sectors: the user market, the investment market and the development market. Although there are some differences in classification, the user market corresponds to the first quadrant of the DiPasquale and Wheaton (DW) model, the investment market corresponds to the second quadrant, and the development market corresponds to the third and fourth quadrants.

The rents determined in the user market signal the decision-making for investment and development activities by investors and developers. In the investment market, yields and CVs are determined by taking into account the required returns as exogenous variables, and the CV affects the developer's decision on a new project. In contrast to being a recipient in the flow of value information, in the adjustment process, the development market influences the other two markets with new supply after the completion of a launch (in the long term). The user and investment markets impact each other in the adjustment process in the short term. While the strength of this model lies in its detailed description of value information and adjustment process flows, the DW model is more advantageous in its description of the market using simplified mathematical terms, equations and graphs.

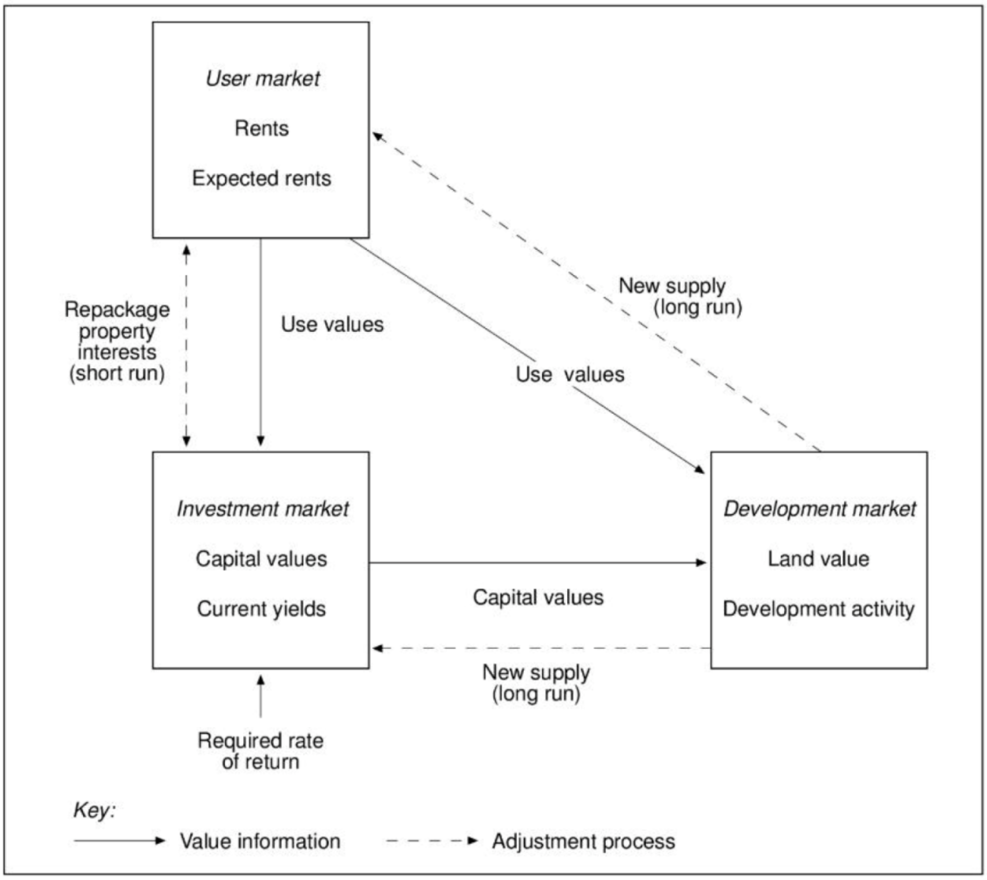

Figure 2. Simple model of the property market (source: Keogh, 1994)

2.3 Segmentation of the Office Subsectors

2.3.1 User Subsector

According to DiPasquale and Wheaton (1992), rent is determined in the space market, not in the asset (capital) market. The supply of space is given from the asset market, and the task for the property (asset) market is to find the equilibrium rent level for the demand and supply of space. Demand for space is based on rent and other exogenous economic factors (e.g., the level of firm production, income or number of households). Assuming other conditions are equal, expanding the production of firms or increasing the number of households creates an increase in demand for space.

The northeast (NE) quadrant is where rent is determined by space seekers. This quadrant thus presents the demand side of the space market, where the number of tenants and their willingness to make annual payments for space is reflected in the form of rent. The NE quadrant represents the space demand, which is composed of a horizontal axis representing the space inventory amount and a vertical axis representing the rent. Since the demand for space in the equilibrium should be equal to the amount of space in the space market, the DW model assumes that the inventory of space is fixed and that rent is determined at this equilibrium point. If there are either more (fewer) tenants or fewer (more) spaces, the rent will rise (fall). In addition, since they see the space demand as being affected by rent and macroeconomic conditions, the above process can be expressed as follows:

$$D\ (R, E) = S \tag{1}$$

where D = space demand, R = rent, E = economic condition, and S = space stock.

Under the traditional economic assumption of a market operating efficiently, and after competition among various users, the lands are allocated after a bid-ask price adjustment and their use reaches its highest and best use. Since rent is determined by a bid-ask adjustment between building owners and tenants, this operation should also be worked into the rent determination process. However, according to Lizieri (2009), rents are sticky because of lease contracts, which hamper rental and space adjustments. A shift in the market rent does not necessarily affect the occupants' rent. Additionally, a financial firm cannot immediately move its office to a larger or smaller location, even if there is a change in the market rent. It takes some time for firms to understand employment fluctuations and subsequently determine whether they need additional space or not. Despite these limitations and uncertainties, the rent model indicates that a shift in demand is still a key driver of rental change. Particularly in the short term, demand is a leading driver making an impact on rents.

The theory was later supplemented by Colwell (2002), who pointed out that it is the cap rate, not the interest rate, that affects the price valuation in the northwest (NW) quadrant. Since the cap rate is endogenous and the interest rate is exogenous, the difference makes an additional movement anticlockwise. For example, if the cap rate increases, the slope of the ray in the NE quadrant will become more volatile, and if the volatility of inflation decreases, the risk premium of the cap rate will decrease; however, if the risk premium increases due to the default rate increase, the cap rate will increase. Nevertheless, as there are many different scenarios, it is difficult to consider all possible cases.

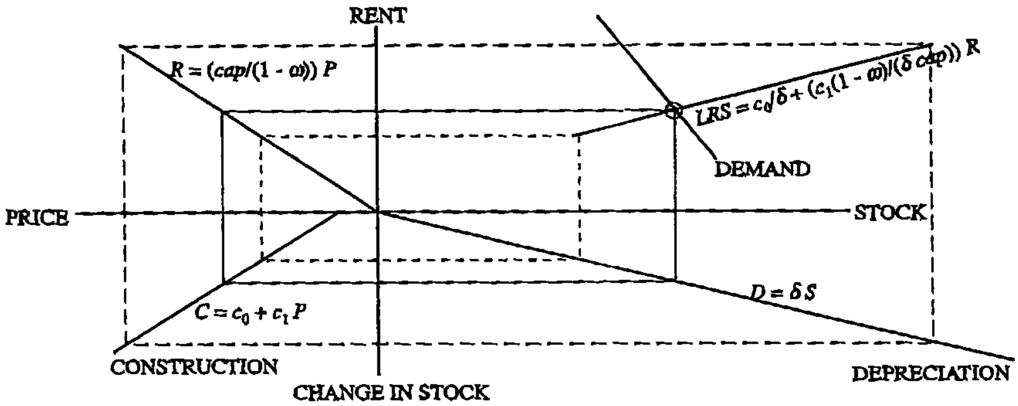

Figure 3. Amended four-quadrant model (source: Colwell, 2002)

$$\text{NE (user-demand): } LRS = \frac{c_0}{\delta} + \left(\frac{c_1(1-w)}{\delta cap}\right) R \quad (2)$$

The reciprocal of gross income multiplier = cap rate / (1-w), where w is the operating expense ratio.

In practice, Gardiner and Henneberry (1988) provided a primitive rent forecasting model which focused on habit-persistence theory. Henneberry et al. (2005) argued that profitability is a driver of development, which is derived from the value of development deducted by the cost of development. Put simply, they said that its main players are the planner and the developer (Henneberry et al., 2005).

This section indicates that new stock is adjusted by adding new construction stocks and subtracting depreciations from the current stock, and that the adjustment process has a certain time lag. In the equation of D (R, E) = S, when the supply is determined on the right-hand side, demand in the equilibrium is determined by the occupier's willingness to pay for the space, considering the rent level and economic condition. The main actor in the NE quadrant is the occupier (or tenant), in other words, the consumers of the space. In the commercial real estate market, demand for the office market is especially relevant within the service industry represented by FIRE. In this respect, the office market is distinguishable from other real estate markets (particularly the housing market) because the occupiers are usually institutions with a large number of employees.

When occupiers conclude a contract with the supplier for leased space, it is usually a long-term lease because of the firm's size. In other words, an occupier's inelasticity in the short term is likely to cause an additional amount of vacancy because of their inability to move in and out to other available properties. For instance, the following factors can change the occupier's space demand: a supply increase due to newly constructed space, a supply decrease due to the loss of existing stock, employee reductions due to restructuring, or employee recruitment due to company expansion. The occupiers' inability to move to another space until the lease expires makes a quick response to market changes harder. As a consequence, the inelasticity of the occupiers' space demand creates a time lag between supply and demand in the space market.

2.3.2 Investment Subsector

Investors, including institutions and individuals, recognise real estate as investment property. They choose investment targets in consideration of the yields (capitalisation rate), CV and investment risk. As Keogh (1994) highlighted, the current real estate market yield relative to other asset markets is closely related to the development market, since real estate yields are expected to fluctuate in line with those of other asset markets. For example, if returns of other markets are higher than the real estate market, then rental yields are expected to rise; this encourages development projects by inducing asset inflows into real estate.

The NW quadrant is where assets are valued and investors seek an investment opportunity based on the pricing of the market. The vertical axis in the NW quadrant describes the rent and the horizontal axis shows the price; the slope is a ratio of the two, which is defined as the capitalisation rate, describing the current yield for investors to invest in real estate assets. A steep slope indicates a high cap rate and a gentle slope means a low cap rate:

$$P = R / i \tag{3}$$

The view of DW on the cap rate can be summarised as two broad points: (1) DW refers to four considerations of the cap rate: the long-term interest rates, expected growth rate in rents, risks associated with income stream (cash flow) from rents, and government tax codes on real estate; and (2) the cap rate is an exogenous variable and is determined in consideration of interest rates and returns of other assets such as stocks, bonds and short-term deposits. However, Colwell (2002) has argued against the second view, stating that the cap rate is not an exogenous variable, such as the nominal interest rate affected by exogenous variables (Colwell, 2002). Instead, the cap rate includes a risk premium and corresponds to a number of endogenous variables:

$$\text{NW (investment-demand):} \quad R = \left(\frac{cap}{1-w}\right) P \tag{4}$$

where R = rent, P = market price, c = cap rate, and w = operating expenses.

Considering investment is a behaviour of risk-taking and profit-seeking at the expense of the risk, a real estate investment would attract investors when its expected return considering risk is higher than that of competitive markets. In addition, during a phase of economic uncertainty in the real estate market, investors are reluctant to participate unless they are compensated by enough return for the risk. In regard to this point, Jackson and Orr (2018) investigated how real estate investors react when there is economic policy uncertainty (EPU) in the market. Their empirical results indicate that investors seek greater certainty, such as higher tenant credit, a better location, a safer lease condition and less building risk when they face EPU.

As key actors in the NW quadrant, the market participation of investment firms is mainly motivated by the development profit they would achieve after the successful proceeds of new development projects. From the viewpoint of investment profit maximisation, the real estate market is a substitute market that competes with traditional markets, the stock market and the bond market. In the past, inelasticity of the real estate market (particularly in the short term) and comparatively limited information circulation contributed to the notion that the market has a high level of uncertainties, which for investors is synonymous with investment risk.

However, owing to the advent of the information society, restrictions on information flow are increasingly overcome, and this phenomenon is more evident in developed capital markets such as the European and North American markets and Asian financial hubs (i.e., Hong Kong and Singapore).

Moreover, modern portfolio theory (MPT) proposed by Markowitz (1952) contributed to shedding investors' non-preference for the real estate market. As the theory emphasises minimising unsystematic risk – a risk that is removable or reducible by investment diversification to multiple asset classes – investors have taken the viewpoint of efficient asset distribution and have thus focused on investing in alternative assets, including real estate, rather than relying solely on assets in the traditional markets. The heterogeneity of a real estate market is an advantageous feature for investors, once the benefits from the removal of aforementioned unsystematic risk outweigh the costs of the market's constraints. In other words, its differentiation from bond and stock gives legitimacy to real estate investment.

2.3.3 Development Subsector - Flow

The southwest (SW) quadrant is where new assets are constructed by an injection of capital into the investment market. In other words, the SW quadrant represents the supply side of the asset market, and the ray in the quadrant is shaped by construction costs and the amount of total supply. In equilibrium, the construction cost will be determined at the same level as the price in the NW quadrant (as discussed in section 2.1.2), since no additional margin or costs for construction will be incurred.

In the DW model, the above explanation is expressed as

$$P = f(C) \tag{5}$$

However, after a developer decides to supply a new space, it will take time to obtain permission from the city council or planning authority, thus creating a lag for new construction quantities determined in the SW quadrant to be supplied to the market.

This perspective is specified by Colwell (2002), who stated that a new construction includes the replacement of a depreciated building with a new supply. In this sense, he viewed construction activity as a gross investment (rather than a net investment) and defined the construction lag as "gestation":

$$C_1 = c_0 + c_1 P_1 \tag{6}$$

Tsolacos et al. (1998) enhanced knowledge of this quadrant's working process in the DW model by adopting Keogh's (1994) adjustment dynamics in the user, investment and development markets. Based on this theoretical framework, Tsolacos et al. made an early attempt to analyse the UK office market using three structural equations which empirically modelled Keogh's classification of subsectors and used the dependent variables of rent, CV and office building development. Although it was not statistically possible to capture the short-term adjustment in the investment and development market, rent equation and development equation (excluding the short-term fluctuation effect), their analysis was statistically significant, as it provided proof of the operations of long-term dynamics in the UK.

As the key actors in this quadrant (SW), developers and builders carry out new development projects and attract investors' capital to the construction projects. To carry out the project, they need to obtain development permission from the relevant authorities, that is, central and regional governments or local planning authorities (LPAs), in consideration of urban planning policies. For this reason, a planning regime is an essential factor in this quadrant.

Developers analyse the feasibility and probability of a project internally and examine how to source financing for the project. Profitability is calculated by deducting costs from the total revenue generated by the development, where the costs consist primarily of land acquisition, construction costs, service fees for professionals (e.g., fees for lawyers, accountants and solicitors) and taxes. When it comes to financing, particularly in the case of office development, often a large project tends to be burdened with borrowing more than a certain percentage of the total project cost. As a result, the loan is typically raised from multiple investors rather than a single source.

For various types of loans, borrowers (i.e., builders and developers) may receive funding from direct investment; however, indirect investment is also available due to the development of the modern financial system. In the case of indirect investment, a loan is raised from securitising and purchased by individual investors as a similar concept to stock investment. Such diversification of raising loans enables investors to inject their capital into the real estate market taking appropriate options in consideration of their financial status and the project's prospects.

2.3.4 Development Subsector - Stock

The northeast (NE) and southeast (SE) quadrants of the DW model represent spatial aspects in the real estate market. Of these, the SE quadrant, which indicates the supply of space, is determined by the adjustment of new construction and depreciation, and includes the development sector. When new space is offered by a developer in the asset market, the additional space should be added to the previous space inventory. At the same time, other spaces will depreciate from the existing inventory. Therefore, the new inventory, considering the increase and decrease effect of the new supply and the loss of previous space from depreciation, becomes the current inventory of the amount of space. Setting t-1 as the previous space and t as the current space, the above situations can be expressed as shown in equation (1):

$$S(t) = S(t-1) + C - dS(t-1) \tag{7}$$

where s = stock, c = new construction, and d = depreciation rate.

According to Colwell (2002), one of the constraints of the SE quadrant in the DW model is that it neglects expectation and vacancies. The expectation here refers to that of a space provider. Once the expectation of rent increases (i.e., the rent is expected to rise), the vacancy rate will be temporarily increased beyond the natural vacancy rate because of the postponement of a lease contract. This expectation then causes the rent to decrease and affects the adjustment process in the SE quadrant:

$$\text{SE (user-supply): } D = \delta S \tag{8}$$

Lizieri (2009) claimed that if the market is completely efficient, there should be no overbuilding. (1) Rent is determined in a space market, where it is (2) capitalised using yield to investors, and (3) a real estate price is established based on the rent and yields. (4) The price combined with the construction cost determines how much new supply will be provided (higher price → more supply), and (5) a new space amount at time t is determined by the last period's space (t-1) + new construction – depreciation.

Rent amounts react to changes in demand in the space market, and asset prices react to changes in demand in the investment market. By contrast, new supply takes a long time because of the lags between the decision-making and the actual completion. Longer lags occur in the case of larger assets such as complex office buildings. Therefore, the role of a planning policy and the reactions of developers are important for achieving reasonable regulation and obtaining the developer's decision to provide a proper amount of property to enable a new equilibrium to be achieved in a short period. If either side is unsuccessful in this process, it will take the market a longer time to achieve the new equilibrium. The level of shocks (increase or decrease in space demand) is relevant to this issue, since temporary (transitory) shock is easy to resolve after only a small amount of space is supplied while permanent shock is not. Additionally, the developer's accuracy in forecasting is important because if it is myopic or extrapolating, the amount of supply will not match the amount required for the market. A combination of these two factors, that is, the demand shock for space is permanent and the developer's forecast is myopic, causes multiple cobweb processes, which serve only to increase the time the market takes to reach a new equilibrium.

Since space supply is strongly influenced by policy and the permission of the planning authority, its impact has been an object of consistent interest to researchers in the user market. Jones and Orr (1999) conducted an empirical study demonstrating that the inelastic supply of retail space in city centres causes an increase in rent in the long term. Henneberry and Mouzakis (2004) examined the impact of planning policy for the investment market, analysing the property market while considering economic measures. Jackson and Watkins (2005, 2007) researched planning policy for the UK market. Jackson and Watkins (2005) first explored a narrow range of planning restrictions and examined the impacts of various elements in policies by setting three equations of rent (i.e. the NE side), yield and CV. They stated that developers respond to the demand of investors and users and that supply is affected by planning decisions (i.e., approval for development) (Jackson and Watkins, 2005). Later, Jackson and Watkins (2007) explored how the policy environment, and the planning system in particular, affect the performance of commercial real estate, especially the retail market, and pointed out the weakness of the DW model because it places too much focus on perfunctory treatments. Ratcliffe (2009) provided a description of the general planning application process. According to his classification, there are various market participants: occupiers, regulators, activists, communities, NGOs, suppliers, lenders, employees, shareholders, investors and property developers. In the development process, developers are required to pay attention to the location, design and construction. For construction, each country has its own system to assess built properties, such as the Building Research Establishment Environmental Assessment Method (BREEAM) used in the UK.

In terms of market actors, developers and builders are key players in the SW quadrant. Central and local government, LPAs and the public sector are other key actors in that the planning policy significantly affects the supply of commercial real estate markets. Their activities start in the SW quadrant of the DW model and affect the SE quadrant. Subsection 2.4.1 provides a detailed description.

2.3.5 External Factors

(1) Macroeconomic and Governmental Factors

Following the microeconomic factors, macroeconomic aspects should be analysed to determine their impact on the real estate market in the short and long term. Unlike the micro factors mentioned above, the macro factors have a relatively external (exogenous) influence, as they are generated outside of the real estate market system. The economic policy of the government is also considered a component of these factors.

Expectations for a country's macroeconomic variables, such as economic growth rates, interest rates and taxes, have huge impacts on developers' investment decisions, since investment is a much more volatile variable than production (three to four times more volatile, in general) (Ball et al., 1999). Development takes place when there is demand in the spatial and investment markets that is kicked off by capital injection as part of the country's economic activity. In addition, in the case of commercial real estate (unlike residential real estate), the capital input is likely to be led by private institutions rather than the state. In addition, while the supply in the general IS-LM curve has a certain level of elasticity, the inelasticity of the real estate market results in a short-term supply volume that cannot respond quickly to demand (Ball et al., 1999). These points indicate that changes in macroeconomic conditions reflect on investment and impact the new supply and ongoing development. In particular, owing to the characteristics of the macroeconomic environment repetitively moving between peaks and troughs within a certain time frame, the impact is considered cyclical, which causes further uncertainty and difficulty in forecasting the market. Under the condition that economic cycles exist and the cycles are known to be repetitive, rational developers will make investment decisions on their projects based on such uncertainty.

Globally, there was a real estate boom in the 1980s, followed by an overall recession hitting the real estate market in the 1990s. Dahesh and Pugh (2000) have suggested that the reasons for the 1980s boom were the deregulation of economic regulations, the collapse of the Bretton Woods system, the intensification of competition among nations and the globalisation of the financial system. They explained the factors which impacted the financial and investment side and led to the activation of the real estate market (Dahesh and Pugh, 2000).

The phenomenon was largely influenced by the liberalisation of the financial system in many countries, the greater influence of the open economic system and the freedom of movement between capitals. In an open economy, these effects are not limited to one country, and they occur simultaneously worldwide because the boom or recession in the investment market affects the credit of institutional investors at the time of bank lending. It can thus be concluded that macroeconomic variables became more important in real estate market analysis as the global economy evolved into a more open system and one that is linked across countries.

(2) Geographical Factors

Geographical factors have become a component of macroeconomic factors since the 2000s as a consequence of globalisation.

Since Castells (1994) declared the advent of the information age, working space has experienced significant changes. With the rapid progress in information and communication technology (ICT) and the convergence of the international economic system, researchers have started to analyse the influence of one city over another and examined the hierarchies among them (Friedmann and Wolff, 1982; Friedmann, 1986; Sassen, 1991, 2000). Friedmann and Wolff (1982) predicted that global integration would not only occur on a national level but also at regional and city levels, driven mainly by the growth of massive urban regions worldwide. Friedmann (1986) also discussed the essential role of metropolitan regions and defined cities that play a core role as 'world cities', that is, cities which have a higher spatial hierarchy than other cities. In a similar context, Sassen (1991, 2000) has stated that world cities function as strategic sites where the global economic system is concentrated, and thus corporations' employment and facilities are congregated in these regions. Jones (2013) commented on the trend that, in relation with the development of ICT, there have been huge structural changes in the office market in general, and in the European industry, especially among the FIRE industries.

Lizieri (2009) asserted that the global integration effect is concentrated on international financial centres (IFCs), and as their spatial availability is less than the demand, their rent and price increase due to excessive demand. International financial centres also function to liquidate real estate assets into "less heavy" financial products, such as mortgage-backed securities (MBS) and securities issued by real estate investment trusts (REITs). Such environmental changes in the global market induce the user, investment and development markets of each country to be more integrated and synchronised, which causes higher systematic (undiversifiable) risk and more volatile fluctuation in the event of external shocks. The downside of the linkages between international capital markets is also highlighted by the fact that they are referred to as 'contagious' (Dornbusch et al., 2000), following the 1994 Mexican economic crisis and the 1997 Asian financial crisis.

Jones (2013) discussed the growing connectivity between the world's office centres, highlighting that this phenomenon needs attention. With regard to the above issues, the labour market is showing greater flexibility and fluidity. This has been accomplished by structural changes in the management of companies, such as outsourcing core business segments, mitigating the organisational culture and alleviating rigidity in decision-making processes. In a similar vein, Jackson et al. (2008) noted that major world cities are economically dynamic based on the integration of economic systems. Two implications can be drawn from this discussion. First, investors and their capital now have liquidity, enabling their investment to move freely back and forth across borders. Second, due to the liquidity issue, the majority of international real estate markets at the same time form the financial centres. The close linkages with other centres suggest that investment across borders and continental boundaries may not be effective in terms of the diversification of risk.

Relevant empirical research has been conducted that provides some evidence for the above arguments. For example, Taylor et al. (2002) analysed the inter-city relationships and influences for 316 cities and 100 global companies and concluded that the hierarchy of cities is dependent on spatial influences. Lizieri and Kutsch (2006) estimated that 40% of major offices in the City of London are occupied by foreign firms, which testifies to global integration, and Lizieri (2009) also suggested that indices from Globalization and World Cities (GaWC) or Z/Yen, which provide details on the influence of global cities, can be used to grasp the competitiveness of world cities in terms of their financial centres. According to Lizieri's (2009) classification of global financial centres, using the global city index from Z/Yen and Mastercard, evidence of global integration includes risk diversification, economic imbalances, promoting growth, and policy and discipline. Focusing on the aspect of regional convergence, Eichholtz et al. (1998) empirically showed that continental factors lead to close correlation, which investors should consider. According to them, Europe and North America have continental factors while the Asia-Pacific region does not. The implication of this outcome is that a UK institution which invested in other European countries for the purpose of diversification, for example, would still be exposed to regional and geographical risks because of the continental co-movement impact.

Furthermore, historical crises indicate that global markets are co-integrated, and a shock starting in one location can have a huge impact on other locations. Black Monday (October 1987), the East Asian financial crisis (1997), the collapse of long-term capital management (LTCM, 1998), the dot.com bubble, the IFC (2008) and the Eurozone crisis are evidence of such impacts. Jones (2013) also commented that the 'interlocking' of major offices is a consequence of globalisation and ICT innovations.

Researchers have also found evidence that European integration is significant yet gradual in its development. For example, D'Arcy et al. (1997) investigated 21 European office markets (1981–1990) and found a relationship between the movement of rent and gross domestic product (GDP), and Baum and Turner (2003) stated that cross-border investment in the European office market increased from US$5 billion to US$80 billion between 1997 and 2002. In addition, recent studies (Brooks and Tsolacos, 2008; Brounen and Jennen, 2009; Liow and

Schindler, 2017) have affirmed the existence of linkages between European cities. As a result, similar patterns are expected in office markets more generally, in other words, cycles and spreads. However, detailed rent movements may differ among selected cities depending on individual characteristics.

More than 10 years have passed since Jackson et al. (2008) examined the impact of globalisation on the real estate market. Therefore, the linkage between offices, and between space and capital may become much more close. The impact of a subprime mortgage crisis which hit asset markets globally provides empirically strong evidence that the assumption of globalisation works in the real-world economy. In consideration of the co-movement in European markets and economic global cointegration, it is reasonable to infer that the linkage relationship also exists in European real estate markets.

2.4 Linkage and Interaction of Subsectors

From an economic point of view, the four-quadrant model is an analytical tool which provides an explanation of the working process inside and between real estate submarkets, based on the mainstream economics approach. The model's mechanism therefore includes an adjustment process and convergence to the equilibrium, which is a transplantation of the investment-saving and liquidity preference-money supply (IS–LM) model, and the aggregate demand and aggregate supply (AD–AS) models in macroeconomics.

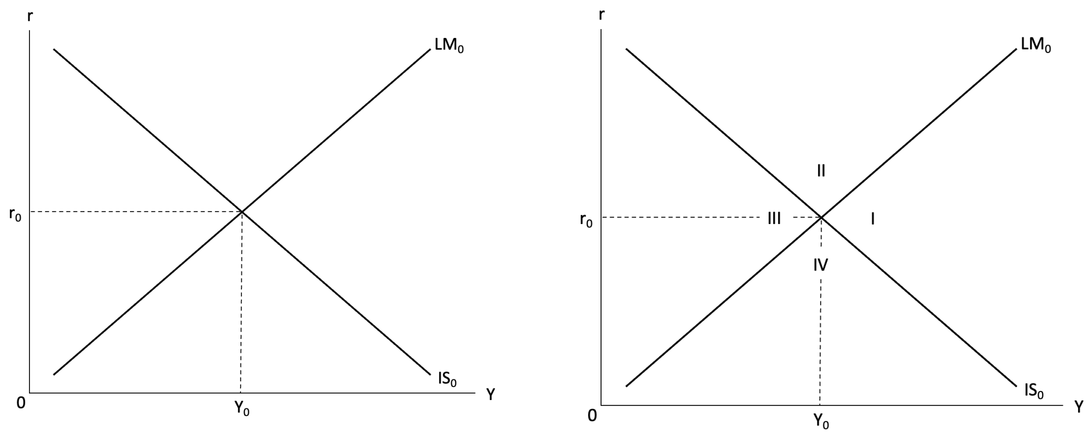

Figure 4. IS-LM curve

On the right side of Figure 4, zone I presents oversupply both in the real economy market (IS) and the financial market (LM); zone II presents oversupply in the real economy market (IS) and overdemand in the financial market (LM); zone III presents overdemand in the real economy market (IS) and overdemand in the financial market (LM); and zone IV presents overdemand both in the real economy market (IS) and the financial market (LM).

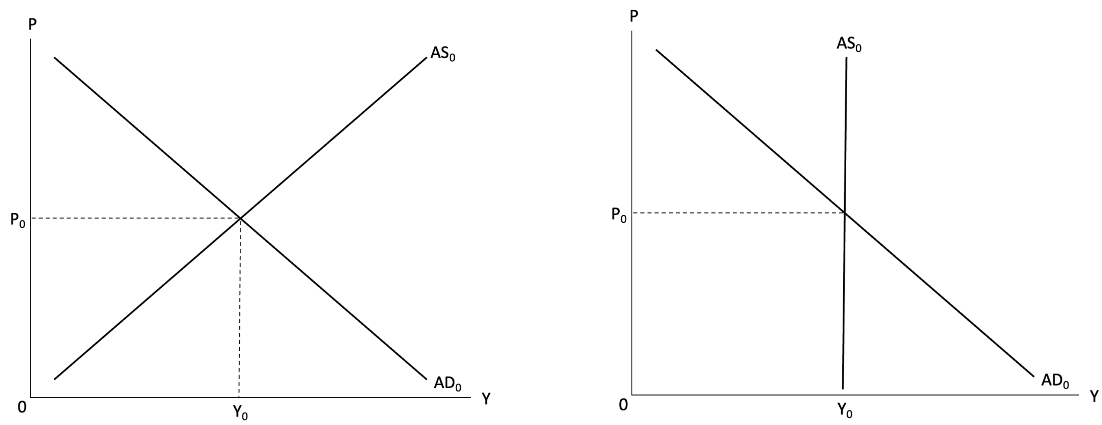

Figure 5. *AD-AS curve*

The right side of Figure 5 indicates a normal AD–AS curve when the aggregate demand and supply are elastic, and the left side describes an AD–AS curve under inelasticity of aggregate supply. Therefore, the four-quadrant model subsectors correspond to the IS–LM and the AD–AS models. Investment–saving, the production sector, corresponds to the occupier sector, and LM, the investment sector, equally corresponds to the investment sector, and these two subsectors correspond to the aggregate demand (AD) in the real estate market. The flow and stock development subsectors correspond to the aggregate supply (AS) curve.

The requirement for the structural approach has been previously raised in both theoretical (Maclennan, 1996; Watkins, 2008) and empirical (Nanthakumaran et al., 2000; McGough and Tsolacos, 1999) discussions.

In the real estate market, the start of construction does not relate to the immediate increase of additional space on the demand side. As is well known, there is delay on the supply side due to the time lag between the start of construction and its completion, which should be considered in the modelling process. Considering this point, the time lag is taken as relevant variables in the development subsector, and a model with lags and one without lags are both constructed in the regression analysis.

Since the real estate market consists of subsectors (i.e. space and capital markets) and individual actors (i.e. occupiers, investors and developers), links exists between these which have been defined by Henneberry (2005) in terms of the concept of 'dynamics'. Previous studies have considered these dynamics a key driver of market adjustment, and attempts have therefore been made to explore their role in and impact on the markets.

Dynamics, particularly in the short term, can be explained as a consequence of an imperfect market condition between the space and asset markets. A definition for 'perfect forecast of the market' was provided by Barras (2005) as 'developers and investors "perfectly understand the equations that govern market behaviour and can thus make correct forecasts of rents"'. In this sense, dynamics can be understood as an imperfection of the market, which results in a cycle in the short term involving boom-and-bust and cobweb processes before reaching a long-term equilibrium.

After presenting each market's nature and components, DiPasquale and Wheaton (1992) described the links between the space and capital markets. When it comes to ownership, they are not separate markets if ownership of the land (space) is acquired by an individual or a firm; it is the purchase of an asset, but it is also a purchase of the use of the space. In other words, the two markets become a combined decision.

In reality, rental values are likely to be determined by a process involving the simultaneous interplay of supply and demand; this relationship was investigated using multiple regression.

Fisher (1992) pointed out the need to consider interactions between the space and asset markets: A 'holistic' approach that simultaneously considers the space and capital markets is the most logical next step in explaining real estate performance. Attempting to explain both of these markets in a single model is difficult, but ignoring the interaction of these two markets limits our ability to understand real estate performance in general.

Fisher (1992) also claimed that existing research defers to other study areas; for example, rent determination is more of a concern for urban and regional economics, while pricing and risk measurement are concerns of the real estate market, and a comparison of the values with other markets is used to discover an optimum proportion of the real estate asset in the whole portfolio. Capital market research tends to focus on three key areas: the MPT, the capital asset pricing model (CAPM) and arbitrage pricing theory (APT). However, space market research focuses mainly on space demand and supply and rental adjustments. A valid relationship between space demand and rental adjustment is verified, but it is inconclusive for the supply side.

Regarding the level of spatial analysis and market cycles, Orr and Jones (2003) argued that the urban level is the most appropriate scale to analyse office property markets and is the most valuable for investment and policy decision-making. Jones (2013) pointed out that short-term fluctuations in real estate develop from international and regional factors and building depreciation. He observed that short-term fluctuating cycles accurately correct errors such as erroneous market forecast repeats, excessive new construction in the boom period and excessive recession in the following period (Jones, 2013). As topics that are relevant to macroeconomic and geographical impacts on the real estate market, these are reviewed in section 3.

2.4.1 Dynamics of the Space

As discussed in Chapter 2, the components of the real estate market create a temporary imbalance in the real estate market in the short term, leading to changes in the key variables in the market: rent, vacancy rate and price. This process continues until the variables converge to a new balance through an adjustment process, and in the long term each variable finds a new equilibrium point and stabilises. Changes in the following short-term perspective will repeat this process, and changes in the real estate market can be understood as a repetition of the adjustment process to reach this short- and long-term equilibrium.

Among the existing studies, that of DiPasquale and Wheaton (1992) presents a comprehensive explanation of the dynamics of the real estate market which explains the interrelation between the space and asset markets operating within the whole real estate market. The four-quadrant model explains how the space and asset markets work, and how a long-term equilibrium is achieved by the interactions between these two markets. This long-term equilibrium takes into account the time required to supplement the space to meet demand.

According to DiPasquale and Wheaton (1992), changes in space demand (NE) affect the other three quadrants and cause movement to a new equilibrium. For instance, when rent increases, prices increase, more constructions start and the amount of stock rises. However, in the long term, increased stock will cause the rent to decrease. Therefore, including dynamics inside the user market (i.e., SE and NE), linkages between the user and investment markets will also be investigated. Furthermore, as advised, the behaviour of user market actors and their motivation to engage in these dynamics will be considered in sections 3.1 and 3.2.

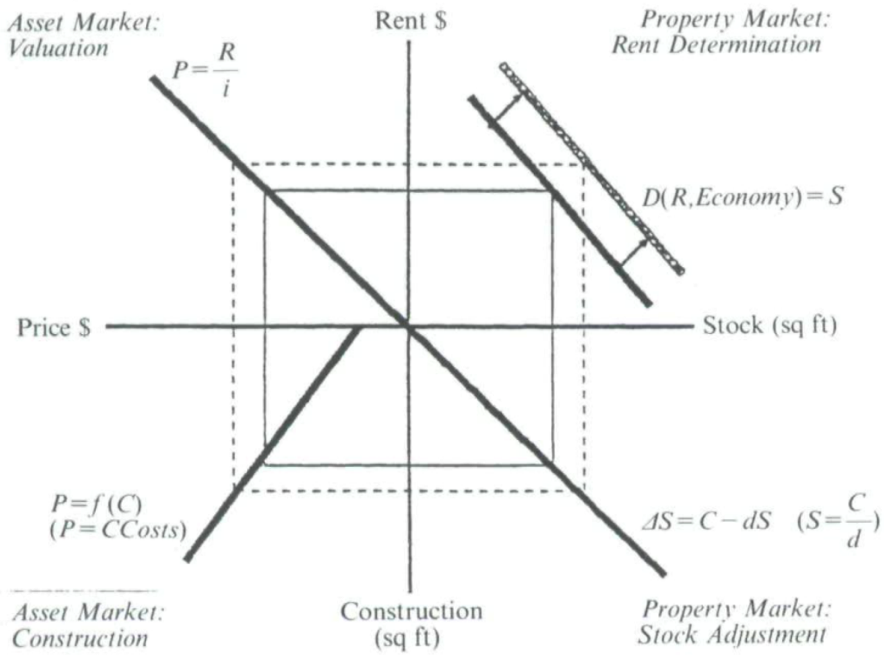

Figure 6. NE-side movement and its impact on other quadrants (source: DiPasquale and Wheaton, 1992)

Macroeconomic fluctuations in the first quadrant, especially those of exogenous factors, affect other quadrants. First, the increases in employment and output increase the demand for space, which increases the rent in the NE quadrant. The subsequent market fluctuations are effected anticlockwise. Next, the increase in rents raises the building prices in the asset market (NW quadrant). Then, the profitability of the development project increases due to an increase in price, which leads to increases in both new construction (SW quadrant) and total stock (SE quadrant). The linear slope of each quadrant affects this adjustment process; for example, the increases in new construction and stock will be relatively low if new construction has high elasticity to asset prices.

2.4.2 Dynamics of the Capital

DiPasquale and Wheaton (1992) also paid attention to changes in capital demand (NW). When capital demand increases, it means that investors are willing to pay for higher rental income or lower yields; this makes the slope in NW lower and property prices higher, which sequentially lead to more construction and stock, and lower rents.

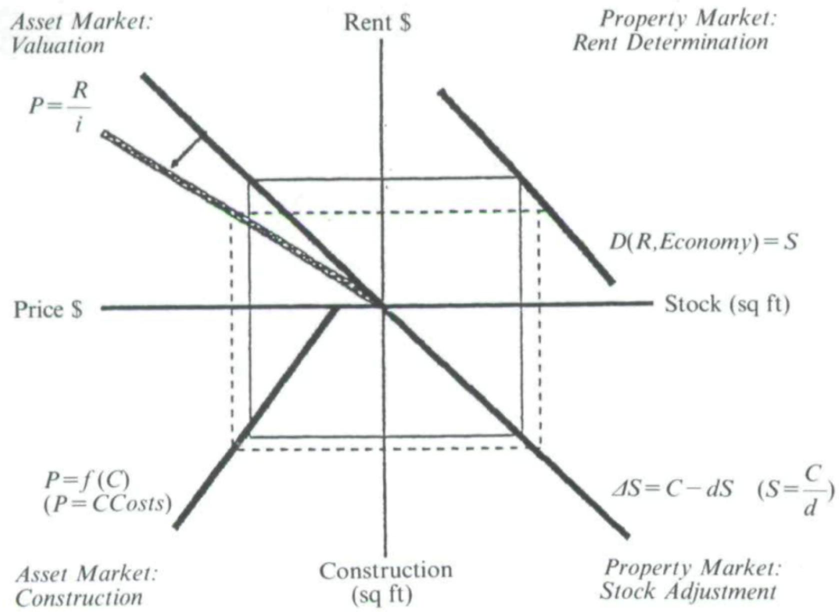

Figure 7. NW-side movement and its impact on other quadrants (source: DiPasquale and Wheaton, 1992)

The change in demand for the property market (or for the ownership) shows different characteristics from that for the space. When interest rates increase (decrease), investors take their capital back from (invest in) the real estate market because yield on the market is relatively lower (higher) than saving investors' capital in financial institutions. In addition, if the risk of real estate investment gets higher (lower), the yield will not be sufficient (will be above the required level) to purchase the asset.

Government policies also cause movement in asset market demand. Under the introduction of a favourable (unfavourable) tax system, such as a reduction of tax imposition periods and the adoption of accelerated depreciation methods, the demand for property investment will increase (decrease) because of higher (lower) expected returns. For the same reason, the required rate of return of investors will be lower under favourable policies while other conditions remain the same.

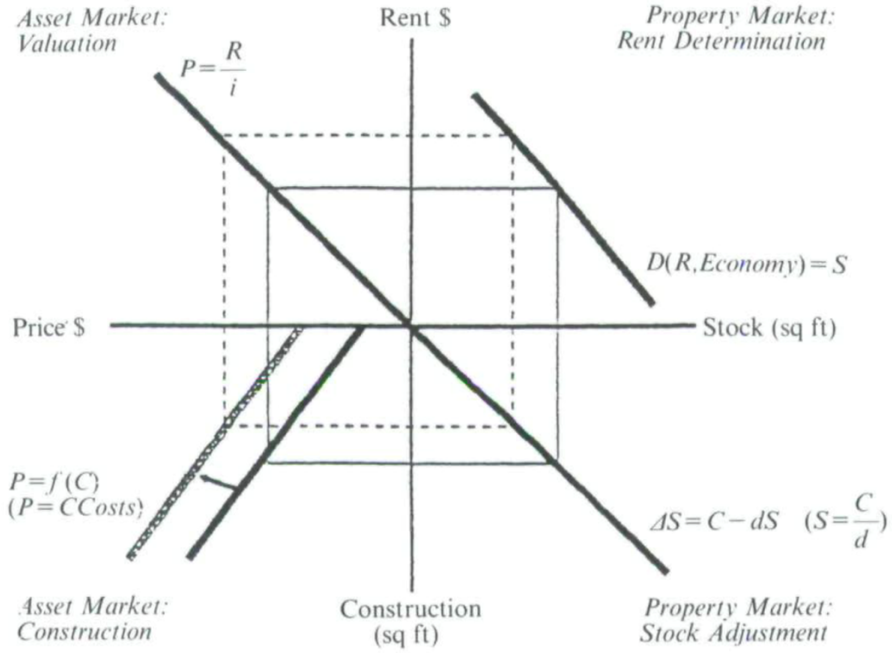

Figure 8. SW-side movement and its impact on other quadrants (source: DiPasquale and Wheaton, 1992)

Figure 8 illustrates the impact of supply. A rise in short-term interest rates increases the developer's burden of repayment for borrowings, thus raising the cost of new supply and decreasing new construction. However, if capital borrowing becomes easier or standards for development permits become less strict, new construction will increase. In conclusion, a negative (positive) change in the supply environment will cause the SW line to shift to the left (to the right).

Under the assumption that asset price is the same, negative (positive) changes in new space supply (SW) lowers (raises) the level of construction and causes a decrease (increase) in stocks (SE). When there is less (more) space in NE, rent increases (decreases), asset prices in NW increase (decrease), leading to lower (higher) levels of construction in SW and less (more) total stock in SE. In a recession (boom) period in the national economy, there are less (more) output and employment in NE. In normal cases, it increases (decreases) the interest rate in SW and results in a shift in property demand or a shift in asset costs. Multiple shifts would complicate the analysis; however, according to the DW model, the outcome should be a combination of individual factor changes.

Colwell (2002) criticised DiPasquale and Wheaton's approach. The DW model assumes that the 'cap' rate is exogenous. In addition, it glosses over the distinction between the 'cap' rate and the inverse of the gross income multiplier, it does not reveal the long-term equilibrium at a glance, it reveals little explicitly about the adjustment process and it ignores expectations and vacancies.

Colwell differentiated his framework from that of DiPasquale and Wheaton's by including (1) a cap rate linkage with net operating income (NOI), not with price, and (2) factors that cause a disproportionate movement of rent with cap rates – sticky operating expenses, mainly property taxes and utilities, constitute one factor and income taxes constitute the other, while their effects on the valuation of the NW quadrant is uncertain (Colwell, 2002).

Although Colwell (2002) assumed that the DW model is a long-term equilibrium model, he added that the model possibly involves multiple gestation (thus, a 'protracted adjustment process') and a dynamic cobweb, in other words, overshooting. This short-term adjustment process is mainly detected in the two southern quadrants, SW (determining gross investment) and SE (determining depreciation). Another argument is made on vacancies that break down into a transaction component (which determines the natural vacancy rate) and a speculative component (which causes fluctuation around the natural vacancy rate). Assumptions about landlords is that their expectations are a mixture of those two components and are myopic. Reservation demand is presented as a sum of the transaction and speculative demand. Rent is determined by an intersection of the supplier's reservation demand and the occupier's space demand.

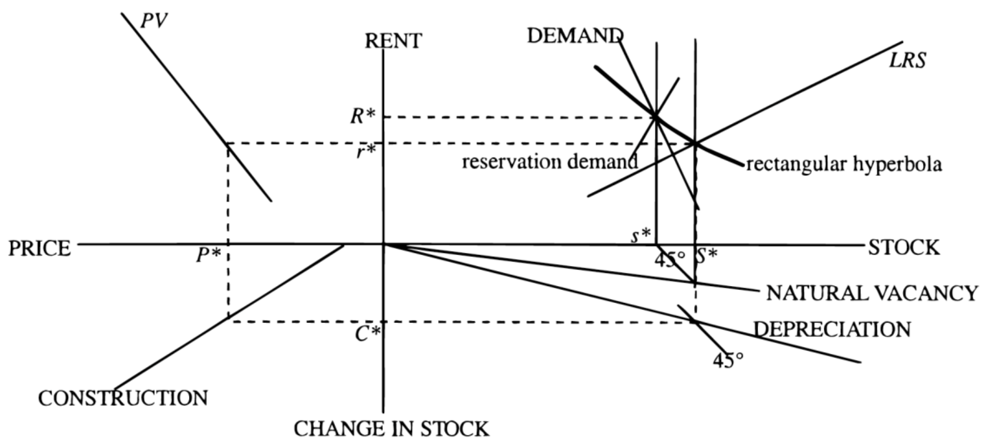

Figure 9. Amended four quadrant model (source: Colwell, 2002)

Derivation of rent in consideration of vacancies is somewhat problematic, but it can be solved by setting rent as potential gross income and effective rent as effective gross income. Effective rent is graphically derived from a rectangular hyperbola, which is a ray drawn from a set of equivalent values generated by rent times number of units. As a consequence, a revised model reflecting a long-term equilibrium process and natural vacancy is presented with equilibrium values of R (rent), r (effective rent), P (price), C (construction), S (total stock) and s (occupied stock) presented in asterisks.

2.5 The Review of the Empirical Literature

Lizieri (2009, p. 94), for instance, noted that current research links together supply of space, demand for space, vacancy rates, real interest rates and real rents in an interlocked system with feedback mechanisms that seek to correct imbalances in supply and demand. Although standards of classification are slightly different for different researchers (Orr and Jones, 2003; Lizieri, 2009), office market research can generally be grouped into two categories: single equation models and multi-equation models. First, a single equation (reduced-form) model, based on multiple regression, is an intuitive and basic method to understand the rent-adjustment process, but suffers from a weakness in terms of explaining the dynamics of the market (Gardiner and Henneberry, 1988, 1991; Shilling et al., 1987; D'Arcy et al., 1997). This area of research has been extended in terms of the methods used, such as the error correction model (ECM) (Hendershott et al., 1999, 2002a, 2002b; Farrelly and Sanderson, 2005; Mouzakis and Richards, 2007) and ARIMA. Second, a set of equations, which explain rent, new supply and space absorption, interact in a way that changes the impacts in rental level on new space development decisions and absorption, and vice versa (Rosen, 1984; Hendershott, 1996a, 1996b; Wheaton et al., 1999; Barras, 2005).

Despite advancements in quantitative office market research in terms of analytical techniques, the existing pan-European-level research remains limited. The main reason for this is the fundamental difficulty in collecting data on the supply side, which hinders applying a theoretically comprehensive real estate model to actual empirical analysis. For example, when mentioning this problem, Tsolacos et al. (1998) excluded a supply-side analysis and subsequently conducted research which does not necessarily require supply-side data. For the same reason, it should be considered to reduce or drop some parts of established equations that present difficulty in data collection.

2.5.1 Single-equation Model Application

In this subsection, two types of equation structures, single- and multi-equation, will be discussed, comparing their advantages and disadvantages.

The characteristics of the single equation model are as follows. First, the relationship between the dependent variable and the independent variable is clear as the determinant variable for rent is expressed as an independent variable on the right side, which provides an obvious causal relationship. The following research studies have been based on the single equation model: Gardiner and Henneberry (1989), Gardiner and Henneberry (1991), Orr and Jones (2003), Giussani et al. (1993) and Matysiak and Tsolacos (2003). The single equation model is simple in terms of its framework but it still captures rental change reflecting the supply and demand sides, and also lagged values, as demonstrated in earlier literature (Gardiner and Henneberry, 1988, 1991; D'arcy et al., 1997). In more recent studies, Schätz and Sebastian (2009) conducted an investigation at an international level, comparing the German and UK real estate markets considering macroeconomic factors, while McCartney (2012) explored the relationship between employment and rent, focusing on output-based measures.

However, the model has a fundamental weakness in terms of real estate market analysis with regard to the dynamics discussed in Chapter 3, in that simultaneous adjustment between subsectors is not reflected in this model. In particular, the movements of exogenous variables are not estimated in the model (Ball et al., 1999).

2.5.2 Multi-equation Model Application

In the office market, the simultaneous equation model was initially represented by the interaction of supply and demand in the early 1980s. Rosen (1984) and Hekman (1985) are early references for the econometric modelling of office rent using the multi-equation model. Rosen (1984) established seven equations, including rent, optimal vacancy rate, and a space supply and expressed rent adjustment mechanism which describes how change in space demand adjusts vacancy rate, and change in vacancy rate in turn impacts rental level. The analysis revealed the statistical significance of office stock and changes in rent, while it is not for the space supply. Hekman (1985) derived predictions for 14 US MSAs from 1979 to 1983 in a rent adjustment model; the construction was significantly affected by long-term office employment and real rent. Subsequently, Wheaton (1987) focused on vacancy rate as a variable that regulates market tightening and slackening, collected 25 years of vacancy rate data and developed a model using six equations.

Wheaton and Torto (1988) discovered that rental movement is proportionate to the actual vacancy rate above or below the structural vacancy rate. Hendershott et al. (1999) analysed the London office market using a dynamic rent adjustment model, linking construction, absorption, vacancy rate and rent to the employment growth rate and the real interest rate. This created a model in which the user, developer and investor markets interact. Following Wheaton et al. (1997) and Hendershott et al. (1999), it expanded into a three-equation model comprising demand function, supply function, and rent (new construction or completion).

Although research on simultaneous equations has not been actively conducted since the 2000s, notable studies include Nanthakumaran et al. (2000), Thompson and Tsolacos (2000), Henneberry et al. (2005), and Fuerst (2006). Nanthakumaran et al. (2000) focused on a two-equation model of capital value and demand. Thompson and Tsolacos (2000) examined the supply side of industrial real estate with a three-equation model consisting of stock supply, new supply, and rent. Thompson and Tsolacos (2000) used a simultaneous equation model to estimate the relationship between commercial building supply, rent and vacancy rates, where the vacancy rate is expressed as a function of GDP and new supply. Hendershott et al. (2002) investigated both the long-term equilibrium relationship between rent, office demand and supply and the short-term dynamic adjustment process by applying the error correction model to data on the number of workers in London, office stock and the vacancy rate. Mouzakis and

Richards (2007) modified the demand and stock variables of Hendershott et al.'s (2002) model, and measured rent change using panel data from 12 major office markets in Europe.

Henneberry et al. (2005) used a five-equation model comprising two demand equations for local economic activity and space utilisation, two supply equations for local supply of space and planning applications, and a rent equation. Their study expanded the analytical framework, using five endogenous variables and eight exogenous variables and contributed to real estate research by emphasising the importance of the planning sector—which has been previously overlooked—by including it as both a dependent and independent variable.

Fuerst (2006) adopted a three-equation model based on Hendershott et al. (1997, 2002) consisting of a demand function (absorption rate or occupied space), rent adjustment function, and supply function (new construction or supply) to analyse the New York office market. Although similar to previous studies in terms of theoretical background and model construction, Fuerst's work extended the spatial application of the model and empirically confirmed that the simultaneous equation model operated similarly in the New York market, thereby highlighting its empirical significance.

A series of studies were followed which investigated in detail the dynamic movement between rent and vacancy rate. For instance, an increase in the vacancy rate and a decline in the rental level can be due to excessive office supply and an economic downturn (Hendershott et al., 1999; Thompson and Tsolacos, 2000; Hendershott et al., 2002; McDonald, 2002; Mouzakis and Richards, 2007). McDonald (2002) used the rent structure model to confirm that the main variables affecting rent are the number of office workers and the rental space.

The multi-equation model introduced above serves as a precedent case study that is directly relevant to this research from the perspectives of both theoretical and office market analysis. Additionally, apart from the cited research cases, this study assumes simultaneity in the operational principles of the office subsector and cites. In this context, Meen (1996, 2000) can be referred as an important multi-equation study in the housing market context. Meen's research addresses the housing market rather than the office market, and despite significant differences in variable selection and theoretical framework, it is noteworthy as an early study that mentions the existence of simultaneity and adopts the three-stage least squares (3SLS) econometric methodology to estimate it.

Recent research by Marcato and Tong (2023) establishes an ECM as its base model, but proceeds with the assumption that simultaneous systems provide an appropriate empirical analysis method capable of capturing dynamic market changes. The regression analysis results support these assumptions. Therefore, while this study employs an ECM in model construction, it assumes the meaningful existence of simultaneity in estimation using 3SLS and reports that this hypothesis was significantly validated in empirical analysis focused on US metropolitan statistical areas (MSAs).

Overall, while the coverage of the single equation model has recently been expanded, it seems that the multi-equation model is more widely used in the U.S. and other markets where comprehensive consideration of real estate market subsectors is required.

2.5.3 Error Correction Model (ECM)

In the real estate market, a long-term equilibrium is established between rent, employment and stock. Shocks in stock and employment cause changes in rent, and the error correction model explains the adjustment process from the point of disequilibrium back to the real (long-term) equilibrium (Lizieri, 2009).

In practice, Hendershott et al. (1999) estimated the office market in the City of London using an adjustment model with supply and demand relationships to link construction, absorption, vacancy, and rents to employment growth and real interest rates from 1977 to 1996. It was found that the London office market experienced distinct office cycles in the late 1980s and early 1990s. The sharp increase in rents and capital values led to oversupply, high vacancy levels, and price declines that coincided with the onset of economic downturns and were associated with employment growth and movements in real interest rates.

The ECM has been modified and developed through Hendershott et al. (2002a, 2002b, 2013) and Englund et al. (2008), followed by Hendershott et al. (1999). Hendershott et al. (2002a) investigated rental adjustment in a comparative study of London and Sydney. They assumed employment, stock and vacancy as factors affecting rent, and used the ECM to measure the long-term equilibrium and dynamic corrections. They found that the ECM explains rent series movement better than the HLM model, and all variables' coefficients moved correctly in both long- and short-term models. They derived a model that integrated supply and demand factors within an error correction framework for the office market in the City of London. The model enabled the calculation of rent and employment elasticities and passed unit roots and cointegration tests in diagnostics. The researchers presented evidence that changes in real interest rates were not capitalised into actual land prices in London.

Similarly, Hendershott et al. (2002b) researched the UK retail and office market. They divided the UK into 10 regions and compared London with all the other regions. The results indicated that all variables were correctly signed and significant using the ECM, and that London's adjustment after outside shock was far faster than that of the other regions. They estimated long-term equilibrium relationships and short-term dynamic adjustments for the leasing model of retail and office real estate in the UK using panel data encompassing 11 regions over 29 years. In terms of data structure, they constructed a new supply series by combining stock data for supply with more frequent construction data.

Mouzakis and Richards (2007) and Brounen and Jennen (2009) attempted spatial expansion beyond the national level by applying ECMs to major cities within Europe. Based on the general theoretical formalisation of Hendershott et al. (2002a), Mouzakis and Richards (2007) used income variable measured by local market service production as a major determinant of office demand and stock derived from cumulative development completions in the ECM. Panel data is collected from 12 office markets in Europe and measured the rent changes of the samples. They attempted to further develop the rent adjustment model by updating the demand and stock variables of Hendershott, Macgregor and Tse (2002). Their model compared the behaviour of different markets across 12 office market locations in Europe using a full sequence of panel data and panel selection tests, empirically estimating the relative adjustment speed toward market interdependencies and long-term equilibrium. They demonstrate that the model explains short-term rental movements at a reasonably satisfactory level.

Brounen and Jennen (2009) divided 10 European cities into first-tier (core) and second-tier (periphery) cities, and analysed the panel data using the ECM. They applied the rental adjustment model to 10 major European office markets for the first and second-tier office market city groups across Europe from 1990 to 2006. They tested the regional characteristics of office markets when national markets do not move in tandem and employed long-term equilibrium relationships of demand and supply variables and short-term adjustment equations in the ECM. The results of the ECM indicate that international office rents are adjusted based on short-term changes in office-related economic activity, delayed rental changes, and deviations in rental values in the long term. This indicate that both prime rents and vacancy are more volatile in first-tier cities. However, the model does not provide the evidence that office rents are significantly improved by economic growth beyond the national aggregate level in the analysis since there was a strong correlation between national and local economic figures for the cities in both tiers.

Further, Englund et al. (2008) analysed the Stockholm office rental market from 1977 to 2002 using an ECM applied to approximately 2,400 lease datasets. Including rental series and lease term distributions, they employed the hedonic method to estimate the time series of average rents for existing leases. The key concept of the research is hidden vacancies, the difference between space occupancy, and demand at current lease rates. Due to tenants being constrained by long-term leases and adapting slowly to current rents for various reasons, the adjustment speed of the real estate market can be slow. Moreover, assuming a trend equilibrium, they found that most of the variation in hidden vacancies can be explained by the difference between current demand and average rents.

Ke and White (2009, 2013) demonstrated that the spatial extension and application of ECMs can be applied not only to cities in the US and Europe but also to cities in emerging markets. Ke and White (2009) analysed office rental prices and adjustment processes in Beijing and Shanghai from 1993 to 2009. They found that rents respond to demand and supply variables in long-term models, and error correction terms in short-term models are correctly signed and statistically significant in all model scenarios. In addition, they tested the difference in vacancy rates between the two cities and found that individual city components are statistically significant and distinct from each other. Shanghai has lower price elasticity but higher income elasticity compared to Beijing. Ke and White (2013) analysed the volatility of rents in the ECM as a long-term equilibrium model of the rental variation between rents and fundamental demand and supply aspect variables, using the ECM to test for the existence of a cointegrating vector. The model includes office vacancy, foreign direct investment, and changes in real interest rates affecting the office market as explanatory variables.

Considering the lack of research in the retail market and the regional panel data, Hendershott et al. (2013) analysed almost 30 years of annual retail data for 11 of the largest MSAs in the United States using an ECM. In the analysis of US retail markets, it was confirmed that the speed of adjustment in MSAs was consistent with that reported by other research studies.

Engle and Granger (1987) suggested the VECM, which contains one cointegration from the VAR model and is therefore a specific form of the ECM. Brooks and Tsolacos (2008) compared three global cities, London, New York and Tokyo. In the research, the Johansen cointegration methodology and the vector error correction model (VECM) were used. They indicated that New York tends to deviate more from the long-term path than the other two markets—London and Tokyo. The Johansen test established cointegration between the total return indices, indicating that economic and financial market connections have expanded and markets are interconnected due to cross-border capital flows. The divergences among the three cities could trigger portfolio reallocations to exploit opportunities or mitigate risks, and New York could benefit from these imbalances among the three cities since the prices in New York are lower than equilibrium ones. The results indicate the possibility of a long-term equilibrium between London and New York. Ibanez and Pennington-Cross (2013) empirically analysed the process whereby rent adjusts to the equilibrium in the long- and short-term using the VECM. They classified the commercial real estate of 34 major US MSAs into four types. The results indicated slower convergence for office buildings than for other types of real estate assets.

2.5.4 Other Modelling Approach (VAR and ARIMA)

This section discusses various statistical analysis methods, including the vector autoregressive model (VAR), the autoregressive integrated moving average (ARIMA). This is followed by a justification for adopting the error correction model in this study.

(1) The Vector Autoregressive (VAR) Model

The vector autoregression (VAR) model is an analytical method where all the variables are endogenous. In other words, not only several independent variables impact on the dependent variable, but the past value of the dependent variable and its impact on the other variables are also observed. Consequently, the model can find more possible features from the data and uses ordinary least squares (OLS) separately, so that the model often outperforms other models in terms of prediction (Brooks and Tsolacos, 2010). On the other hand, VAR has the disadvantage that the model is atheoretical by nature, and the determination of lag length is a critical issue to find the best VAR specification. To make the optimal choice, multivariate information criteria, such as the Akaike information criterion (AIC) or Schwarz's information criterion (SIC), should be used (Brooks and Tsolacos, 2010).

(2) The Autoregressive Integrated Moving Average (ARIMA) model

The ARIMA model refers to generalised AR(p) and MA(q) processes; ARIMA is assumed when the time-series is difference-stationary, that is, Δyt is assumed to be a process of ARIMA (p, q).

McGough and Tsolacos (1995) used the ARIMA to predict short-term office rents and their results indicated that the ARIMA (0, 2, 1) model is suitable for predicting short-term office rents. For other real estate sectors, the ARIMA (1, 2, 0) model was selected to predict retail rent, and the ARIMA (3, 2, 0) model in the case of industrial rent. Thompson and Tsolacos (2000) found that changes in new supply and rent in the London office market could be predicted by adjusting the natural and actual vacancy rates, and the effective and current rents, and empirically demonstrated that the number of office workers impacts on the demand and area of occupied office space. In this research, the reliable ARIMA time-series model was used for the forecasting.

2.5.5 Critique on Single-equation Model

One significant challenge faced in economically explaining the functioning of the real estate market is accounting for the short-term rigidity of the supply process. Modern economic theory, fundamentally rooted in the neoclassical synthesis, posits that market equilibrium is achieved through prices and quantities determined by aggregate demand and aggregate supply. This equilibrium shifts to a new balance with a change in aggregate demand and aggregate supply, based on the assumption that market participants behave rationally.

The adaptive expectations hypothesis and the rational expectations hypothesis are representative hypotheses that explain expectation formation. The adaptive expectations hypothesis suggests that although systematic errors may occur when forecasting the future, individuals recognise these errors as they acquire new information and gradually adjust their future predictions. Adaptive expectations imply that current behaviour is explained by past variables (Cagan, 1956). Muth's (1961) rational expectations hypothesis can be defined as conditionally formed expectations that are consistent with an economic model, using all available information. However, in the real estate market, the supply sector is not flexible, thereby raising questions regarding the appropriateness of the rational expectation assumption.

Researchers in the real estate and office markets (e.g. Gardiner and Henneberry (1989, 1991)) argue that it is more suitable to approach the decision-making process of suppliers regarding new construction based on adaptive expectations. This implies that suppliers rely on past demand information rather than rationally predicting future demand levels when making decisions regarding space supply, thus acting myopically.

As a recently developed single equation model, the ECM undergoes the following process: First, it consolidates the multi-equations into one equation to derive a reduced-form equation for long-term equilibrium. Second, it derives differenced equations from the reduced-form equation to reflect short-term market adjustments. Third, it explains the convergence of short-term imbalances to long-term equilibrium using two equations: a level equation and a difference equation (also using two equations, the long-term equilibrium function and the short-term adjustment function, to explain the convergence to equilibrium)

Considering that the rigidity in the supply sector has previously acted as a constraint on the efficient operation of the real estate and office markets in an econometric sense, the ECM can estimate long-term equilibrium with a level equation and short-term adjustments with a differenced equation, explaining how short-term imbalances on the supply side converge to a new equilibrium in the long term. In contrast, the multi-equation model is mainly expressed in the form of functions of demand, supply, and price. In the context of the real estate market, demand is primarily represented by absorption, supply by total supply, and price by rents.

From an econometric analysis perspective, the advantage of the ECM lies in its ability to explain deviations from the existing equilibrium, the adjustment process, and convergence to a new long-term equilibrium by considering the cointegration relationships among variables after confirming the existence of stationarity. On the other hand, the multi-equation model is an appropriate analytical tool for explaining simultaneity within the model. It achieves this by assessing the consistency among variables within multiple equations, determining whether the model is under-identified, precisely identified, or over-identified and considering the rank condition.

The introduction of the multi-equation model developed in the US can complement the ECM by addressing interactions and simultaneity during the explanation of dynamic equilibrium achievement. Therefore, it appears to be a useful tool to fill the gap in existing European real estate research, diversify the analytical methods for the real estate market, and enhance researchers' understanding of the market. Therefore, this study focuses on the explanatory power and usefulness of the multi-equation model in the empirical application of the four-quadrant model. It aims to develop further discussions by highlighting the relative advantages and disadvantages of the multi-equation model compared to the existing single equation models and the ECM.

Theoretically, without using a reduced form, multi-equations can be differenced for each equation to explain short-term adjustments. However, the problem with including short-term adjustment functions in the multi-equation model is in the excessive complexity of the estimation process. To be specific, assuming the use of multi-equations for three dependent variables—absorption rates, total supply, and rents—when using differenced short-term adjustment functions for each function, requires six equations to be estimated. This excessively complicates the estimation process and, thus, makes the ECM more convenient compared to using the multi-equation model. In other words, the ECM has a relative advantage over the multi-equation model in terms of estimation when it comes to the convergence of long-term equilibrium through short-term adjustment processes.

Therefore, the relative advantage of the multi-equation model over the ECM lies not in the adjustment process but in its implication on the endogeneity. Multi-equations contain error terms for each function, as such equations are not arranged in reduced form. From an econometric perspective, error terms represent the portion of the dependent variable that is not explained by the independent variables. Therefore, the existence of error terms for each equation in the multi-equation model means that there are portions of the real estate market's subsectors not explained by the adopted independent variables.

The complementarity between the multi-equation model selected as the subject of exploration in this study and the single equation model and ECM mentioned as comparison targets should be acknowledged. While the multi-equation has strengths in explaining the overall structure and dynamic operation of the real estate/office market, the traditional single equation model—despite its limitations in static analysis—has the advantage of relatively fewer variable constraints, thereby allowing for a more detailed exploration of individual markets or subsectors. The ECM is suitable for explaining short-term adjustments and long-term equilibrium achievement using the error correction term.

At this point, the dependent and independent variables of each subsector not only influence each other within their respective equations but also influence the error terms of other equations. In other words, it is assumed that the equations for absorption rates, total supply, and rents, as well as the equation for absorption rates affects the equations for total supply and rents. When one equation influences other equations, not only the dependent and independent variables but also the error terms are affected. In the reduced form equations, during the process of consolidating the multi-equations into a single equation, only one error term is left while the others are eliminated. In contrast, the multi-equation model has the advantage of being able to estimate the influence of each equation on other equations, considering the presence of error terms for each equation when there is interaction among subsectors. Further, considering that each equation represents a subsector of the real estate market and their interactions affect other subsectors, the portions not explained by the independent variables of each function are expressed as error terms. The presence of error terms in these multi-equations enables the estimation of endogeneity through simultaneous estimation using 3SLS (or SUR) in the econometric estimation process.

In conclusion, both the ECM and the multi-equation model have relative advantages in considering the interaction among subsectors compared to the conventional single equation model that focused on estimating the demand sector. Furthermore, while the ECM has a relative advantage in explaining short-term adjustment processes, the multi-equation model has an advantage over the ECM in that it can explain the interaction of each equation through econometric simultaneous estimation, thereby reflecting endogeneity.

In Chapter 2, Section 2.2 introduced the four-quadrant model as a conceptual framework for explaining the real estate market. Section 2.3 examined the functioning processes of each subsector, and Section 2.4 explored how these subsectors interact with each other. In Section 2.3, from the perspective of explaining each subsector, the existing single equation models have been deeply developed and have played a major role in the empirical analysis of the office market in research on European real estate. However, these models have limitations in explaining the interactive processes of the subsectors discussed in Section 2.4.

Therefore, to explain the equilibrium attainment and convergence as well as the integrated functioning process of the office market, which were presented as the research objectives in Chapter 1, an analytical tool that complements the existing single equation models is required. The ECM has shown excellent explanatory power as a theoretical and empirical analytical tool for explaining short-term adjustments and convergence to long-term equilibrium. However, in the process of using the reduced-form equations, the ECM leaves only one error term from the original multi-equations, thereby resulting in a loss of information regarding the error terms. To explain the integrated functioning process of the real estate market based on the interactions among subsectors, an approach that can overcome the limitations of the ECM appears necessary.

This focuses on the endogeneity of multi-equations and establishes a theoretical framework for the interaction of subsectors (Section 3.2 Modelling Subsectors) in subsequent sections. It then expresses this theoretical framework as a functional form for econometric estimation (Section 3.4 Derivation of Structural Equation). Subsequently, after the data collection process for the variables (Section 4.3.2 Data Sources and Key Variables), estimation using multi-equation models is conducted on sample data based on the quantitative research methodology (Section 4.4.1 Quantitative Methods) for an empirical analysis of the model. Following this, statistical results and violations of statistical tests will be examined, and appropriate explanations and implications will be derived for significant results based on the theoretical background.

2.6 Summary

This chapter examined the diverse players and their actions in three subsectors of commercial real estate, that is, the user, investment and development markets. This approach is based on microeconomic analysis, which focuses on individual submarkets. These submarkets consist of a demand and a supply side, and each participant's actions lead to movement in the submarket. This is a starting point from which to understand the structures and operating principles of the real estate market. Chapter 3 will discuss the interactions between the submarkets and additional concepts, such as macroeconomic and geographical factors.

In section 2.5, modelling approaches to real estate were presented and previous studies were reviewed. The approaches include the single equation model, the multi-equation model, the VAR, the ARIMA and the ECM. Each approach has its distinct advantages and disadvantages. Of these approaches, the multi-equation model has the advantage that it has strong ties with the theoretical background, and it uses a macro perspective which analyses real estate and the office market as a comprehensive market system consisting of several submarkets.

The multi-equation approach is indebted to the IS–LM and AD–AD models in macroeconomics and the four-quadrant model, which is basically an interpretation of the macroeconomic framework in terms of the real estate market. Empirical studies of the office market have been developed based on this theoretical background, but the theory has also evolved with more detailed specification of the submarkets. This started with the demand and supply models developed by Rosen (1984) and Hekman (1985), and transformed into the three equations system of Wheaton (1987), Wheaton et al. (1997) and Hendershott et al (1999).

This chapter also investigated the dynamics of the space and asset markets in the short and long term, in addition to providing a description of their static features. This is essential for understanding the operation of the real estate market, since the inelasticity of the space supply side causes an imbalance between supply and demand in both the space and asset markets. Various adjustment processes in the real estate market therefore seek to achieve a new equilibrium, which is brought about by these dynamics. This chapter also reviewed other exogenous but important factors, such as macroeconomic and geographical impacts. These factors exist outside of the real estate market framework, which should still be considered when establishing an empirical model. The following chapter reviews the literature on empirical analysis and develops a theoretical model.

3 Modelling Office Market

3.1 Introduction

Following a review in Chapter 2 of the components of the real estate market, their interaction and coordination and how this reflects or deviates from theory, this chapter offers a more detailed review of the approaches adopted to develop models of the real estate sector. The purpose of this chapter is to help inform the development of an applied model where the consistency with (or deviation from) previous theory is clear and that is also representative of best practice. The chapter looks in turn at attempts to model the different subsectors and then considers how these have been combined into more complex modelling frameworks. Although rarely acknowledged explicitly, it is clear from the literature that empirical strategies are often driven by data availability (or arguably, more precisely, lack of data). We also look at data structures and availability in this chapter, in the knowledge that this has been a major constraint in terms of how models have been developed and operationalised and, importantly, which model outputs have been prioritised.

3.2 Modelling Subsectors

Chapter 2 reviewed the early-stage development of the multi-equation approach. Despite the recent advancement of various modelling approaches, no significant change has been made to the basic structure of the multi-equation approach. The three equation system presented by Wheaton et al. (1997) and Hendershott et al (1999) has been widely adopted in relevant studies. Diverse variations of the approaches have been developed, such as the adoption of additional individual variables or the partial modification of equations, as well as the spatial adaption of the model to European or Asian office markets, but the fundamental structure of the approach has barely changed.

Based on the review conducted, this research proposes a multi-equation model to consider the interaction of three submarkets and the rent adjustment process to capture the imbalance between actual and equilibrium rent and its convergence in the long term. For the user, investment and development market sectors, selected dependent variables are presented, such as function forms, which are components of the model's multi-equations.

We saw that the early European literature focused on modelling how the demand and supply sides impact rent by building a rent-regression model using various market variables (Gardiner and Henneberry, 1989; D'Arcy et al., 1997). Although the impacts of the demand and supply variables vary depending on the researchers, the demand side often adopts the commonly used variables of GDP and employment representatively, while the supply side tends to use proxy variables, such as the number of building permits, due to data constraints. While this approach has the advantage of a clearer interpretation of the rent determination process (particularly in the short term), it is weak in terms of the explanation of the adjustment process that resolves the supply-demand disequilibrium due to limited availability of supply-side and vacancy-rate data (Hendershott et al., 2002). To solve this issue, after the 2000s, researchers have tended to use the error correction model in an attempt to build a more general model by integrating the U.S. rent adjustment and the European supply-demand regression model (Hendershott et al., 2002a, 2002b; Englund et al., 2005; Farelly and Sanderson, 2005; Mouzakis and Richards, 2007; De Francesco, 2008). This research study intends to build a model in consideration of this trend, with an understanding of the following points:

(1) In terms of structure, a multi-step equation model will be used in this study as it is expected to perform better in long-term real estate market analysis compared to a single equation model. Because of the heterogeneity of the development sector variables in 4.3, (1) six time-series models encapsulating all subsectors and (2) another six time-series models (or possibly a one-panel model) explaining all other sectors except the development sector will be established and analysed. Based on theoretical and empirical reviews, it is assumed that (1) would have a higher explanatory power than (2) because it contains more information about the development sector. This process intends to test the context of the four-quadrant model discussed in Chapter 2, in which it was explained that the quadrants are linked and thus one quadrant's movement impacts the others.

(2) The use and basis of the ECM should be able to explain the equilibrium between the long and short term better than non-theoretical models, such as the VAR and ARIMA which were explained in section 2.5.3. While the VAR and ARIMA models have strong predictive explanatory power, they are disadvantageous in that they are not theoretical. On the other hand,

the ECM is increasingly used to describe the rent adjustment process in the existing literature, and the theoretical part is empirically demonstrated for each of the dynamics described in Chapter 3, for both the long and short term.

(3) The inter-city integration effect will be measured to reflect intercity connectivity, including the GFCI/GaWC index as a variable. Relevant work on this topic was previously conducted by Lizieri and Pain (2014) and Stevenson et al (2014). This analysis intends to reflect the geographical effects described in 3.5 in the model and is expected to demonstrate that cities with higher connectivity indices exhibit greater integration.

(4) Considering the current data status and expected data availability, the cycle of the real estate market discussed in 3.4 seems difficult to analyse. However, it may be an alternative to focus, for example, on three cities with available data over a longer time period (e.g., more than 20 years) and analyse the existence of the cycle for the modified sample.

3.2.1 User Subsector

First, the user market considers rent and vacancy as the two main variables. Rent is expressed as a function of vacancy, economic activity, price, occupied stock, planning policy and regime and network connectivity (Rosen, 1984; Henneberry et al., 2005; Pereira and Derudder, 2010; Lizieri and Pain, 2014). Vacancy is a function of vacancy and growth in the service industry (Shilling et al., 1987) and can be derived from stock minus occupied stock divided by stock (DiPasquale and Wheaton, 1992). Natural vacancy, which is assumed to be the vacancy rate in the market equilibrium, is a function of interest rate and equilibrium rent (Rosen, 1984). Since the actual vacancy rate is derived from the equilibrium level in the short term, a difference exists between the actual and natural vacancy rates, which is adjusted in the long term:

$$r = f(v,\ \Delta \mathrm{EA},\ S,\ \Delta P, \Delta \mathrm{OS}, r_1,\ \ r_2,\ Pl,\ NC) \tag{9}$$

where r = rent, v = vacancy, EA = economic activity, P = price, OS = occupied stock, r1, r2 = relative rent in other sectors, Pl = planning policy and regime, and NC = network connectivity (general / financial service).

Equation (9) represents rent (r) as a function of vacancy (v), changes in economic activity (ΔEA), price (ΔP), changes in occupied stock (ΔOS), relative rent in other sectors (r_1, r_2), planning policy (Pl), and network connectivity between cities (NC).

$$v = f(r, I,\ \Delta EA,\ \Delta S,\ \Delta Pop,\ T) \tag{10}$$

where v = vacancy, I = growth in service industry, Pop = population, and T = tax.

Equation (10) represents vacancy (v) as a function of rent (r), growth in the service industry (I), changes in economic activity (ΔEA), changes in population (ΔPop), and taxes (T).

$$v = \frac{(S-OS)}{S} \tag{11}$$

where S = stock and OS = occupied stock.

Equation (11) is an identity equation where vacancy (v) is expressed as the ratio of the difference between total space (S) and occupied space (OS) to total space (S).

$$v^* = f(i,\ r^*) \tag{12}$$

where v* = natural vacancy rate, i = interest rate, and r* = rent in equilibrium.

Equation (12) represents the natural vacancy rate (v*) as a function of the interest rate (i) and the rent in equilibrium (r*).

3.1.2 Investment Subsector

For the investment market, yield and CV are mainly considered. Yield is a function of risk-free rate, risk premium, expected growth rate and depreciation (Henneberry and Mouzakis, 2014). Valuation of property, which is assumed to be the price, is calculated as rent divided by yield (DiPasquale and Wheaton, 1992). Capital value is a function of previous CV, office services output, stock and network connectivity (Nanthakumaran et al., 2002).

In this market, yield is first determined by its components (equation 13) and capital value is then derived by rent divided by yield (equation 14). This is the point where rent and information in the user market are converted into CV, presenting the property's value in the investment market:

$$y = f\left(r_f, r_p, g^e, d\right) \tag{13}$$

where r_f = risk-free rate, r_p = risk premium, g^e = expected growth rate, and d = depreciation rate.

Equation (13) represents the yield (y) as a function of the risk-free rate (r_f), the risk premium (r_p), the expected growth rate (g^e), and the depreciation rate (d).

$$\frac{r}{y} = CV \tag{14}$$

where r = rent, y = yield, and CV = capital value.

Equation (14) is an identity equation for valuation, indicating that dividing rent (r) by the yield (y) yields the capital value (CV).

Then, CV derived from equation (14) is specified with its determinant components. In equation (15), previous CVs positively impact on the current CV, as they provide past information about the property valuation (how much CV the property used to have). If output in the finance and business (service) industry is at a high level, it will stimulate the space demand of the industry, which is the main consumer of the office space, and thus increases CV. Amount of stock drives CV to the opposite direction, since the scarcity of the property decreases (and CV drops) as the stock increases. Geographical impact is assumed to positively impact CV, in that higher geographical linkage indicates that a city's property market connects more closely with others, which will attract further investment demand. Since equation (15) encapsulates the movement of the investment market, the equation is dealt with as a component of the multi-equation.

$$CV_t = f(CV_{t-i}, O, S, NC) \tag{15}$$

where CV = capital value, O = office services output (in financial and business), S = stock, and NC = network connectivity.

Equation (15) expresses the capital value (CV) as a function of the previous capital value (CV_{t-i}), office services output (O), stock (S), and network connectivity (NC).

3.2.3 Development Subsector - Flow

Occupied stock is a function of employment and rent is divided by price (Rosen, 1984); it is also expressed as total stock multiplied by absorption rate, or one minus vacancy rate (DiPasquale and Wheaton, 1992). Change in stock is a function of equilibrium rent, vacancy, interest rate, economic activity and tax (Rosen, 1984; Nanathakumaran et al., 2002), which is a stock adjustment between time t and t-1. As DiPasquale and Wheaton (1992) demonstrated, the new stock level is a sum of the last stock and a change in stock.

3.2.4 Development Subsector - Stock

Occupied space (OS) in equation (16) is displayed as a function of employment (E), and rent (r) divided by CV, and can also be expressed as a function of total supply (S) minus vacant space (S - v), as in equation (17).

$$\mathrm{OS} = f(E, \frac{r}{CV}) \tag{16}$$

where OS = occupied stock, E = employment, r = rent, and P = price.

Equation (16) demonstrates that the occupied stock (OS) is determined by the employment level (E) and the rent (r) divided by the capital value (CV), which represents the yield.

$$\mathrm{OS} = S(1 - v) \tag{17}$$

where S = supply, and v = vacancy.

Equation (17) is an identity equation showing that the occupied stock (OS) is derived from the stock (S) multiplied by the complement of the vacancy rate (1 - v).

As illustrated in equation (18), the amount of new supply will be determined by equilibrium rent in the long term; the equilibrium rental value signals how much the equilibrium CV will be, in consideration of office yield (equilibrium rent divided by yield would be equilibrium CV according to equation (14)). High vacancy implies less demand for space and thus weakens motivation to provide new supply, and the interest rate as the borrowing cost affects a developer's decision to launch a new development project. The lower the interest rate is, the more leverage is available, which promotes a greater amount of new supply. Construction cost (CC) is considered in line with CV, where CV minus CC is the profit of the construction company. A higher tax rate weakens space seekers' motivation to purchase office property as it functions as a type of penalty for them.

Equation (18) is regarded as a component of the multi-equation in the development sector. As equation (17) defines the relationship between occupied supply (lefthand side) and supply and vacancy rate (righthand side), equations (16) and (17) are linked to equation (18).

$$\Delta S = f(r^*(or\ CV^*),\ v, i,\ \Delta\text{EA},\ CC,\ T) \tag{18}$$

where ΔS = changes in stock, r* = equilibrium rent, v = vacancy, i = interest rate, EA = economic activity, CC = construction cost, and T = tax.

Equation (18) represents the changes in stock (ΔS) as a function of the equilibrium rent (r* or CV*), vacancy rate (v), interest rate (i), changes in economic activity (ΔEA), construction costs (CC), and taxes (T).

$$S_t = S_{t-1} + \Delta S_t \text{ (from DW, 1992)} \tag{19}$$

Equation (19) is an identity equation where the current stock (S_t) is expressed as the sum of the previous stock (S_{t-1}) and the change in stock (ΔS_t).

3.2.5 External Factors

Macroeconomic factors also affect the rent outside of the submarkets. Economic activity is formulated as a function of growth in the service industry, GDP, RGDP and rent (Henneberry et al., 2005), and employment is a function of economic activity, profit and growth in the service industry (Rosen, 1984).

In equation (20), economic activity (EA) is displayed as a function of growth in service industry employment (I), change in supply (S), change in gross domestic product (GDP), change in regional gross product (RGDP) and rent (r).

$$\Delta\text{EA} = f(I,\ \Delta S,\ \Delta GDP,\ \Delta RGDP,\ r) \tag{20}$$

where EA = economic activity, I = growth in service industry, GDP = gross domestic product, RGDP = regional domestic product, and r = rent.

Equation (20) indicates that changes in economic activity (ΔEA) are a function of the growth in the service industry (I), changes in supply (ΔS), changes in gross domestic product (ΔGDP), changes in regional domestic product (ΔRGDP), and rent (r).

$$\text{E} = f(\Delta EA, Pr,\ I) \tag{21}$$

where E = employment, Pr = profit generated in service industry, and I = growth in service industry.

Equation (21) expresses employment (E) as a function of changes in economic activity (ΔEA), profit generated in the service industry (Pr), and growth in the service industry (I).

The impact of globalisation, which has drawn attention recently, can be quantified as network connectivity. Lizieri and Pain (2014) used the network connectivity index as one of the determinants for rental and CV, and Pereira and Derudder (2010) adopted the concept in their derivation of growth as a service industry variable, while also considering column vectors as country- and city-level variables.

$$I = f(NC,\ X_1, X_2) \tag{22}$$

where I = growth in service industry, NC = network connectivity, X_1= column vector for country-level variables, and X_2 = column vector city level variable.

Equation (22) shows that the growth in the service industry (I) is determined by network connectivity (NC), a column vector for country-level variables (X1), and a column vector for city-level variables (X2).

3.3 Modelling Interaction Process

This model is featured with its use of (1) the multi-equation model, (2) theory in statistical methods, and (3) continent-level analysis. European market studies have rarely been conducted using (1) and (2), while Hekman (1984) and Rosen (1985) did use them for the US market. Although (3) has some precedents (Brounen and Jennen, 2008; Brooks and Tsolacos, 2008;

Giussani et al, 1993), they concentrated on specific topics of subsectors, not dealing with the comprehensive market. Therefore, as indicated in Table 4, it is more complex and theoretically solid compared to previous research.

Lastly, it has to be pointed out that an estimation issue is caused by simultaneity despite its advantage described so far. The following are examples of the multi-equation model.

$$y_{i1} = \alpha_1 + \gamma_1 y_{i2} + \beta_1 x_{i1} + e_{i1}$$
$$y_{i2} = \alpha_2 + \gamma_2 y_{i1} + \beta_2 x_{i2} + e_{i2}$$

Here, dependent variables of the two equations, y_{i1} and y_{i2}, are endogenous variables which are simultaneously determined. On the other hand, x_{i1} and x_{i2} are exogenous variables. In this type of multi-equation model, OLS cannot be estimated because:

$$cov\ (y_{i1}, e_{i1}) = cov\ (\alpha_2 + \gamma_2 y_{i1} + \beta_2 x_{i2} + e_{i2}) \neq 0$$

y_{i1} includes error term e_{i1} and thus covariance cannot be 0, which causes OLS not to be efficient. This is the same for y_{i2} and error e_{i2}. Therefore, a proper estimation method is required; 2SLS, GMM, 3SLS and SUR estimations are possible solutions instead of an OLS estimation.

3.4 Derivation of Structural Equation

A visualised framework with comprehensive consideration of the equations provided is presented in Figure 10. Numbers inside parentheses indicate equations above where each variable in the box was used.

The following five equations, (9.1), (10), (15), (18.1) and (20), were extracted from the development of the equations from (1) to (22) by the exclusion of identical equations, which simply defines the relationship between variables and equations which are unable to be analysed due to limited actual data (according to the following section 4.3). For the equation (9-1), rent in other real estate sectors (r_1 and r_2) is excluded from equation (9) because of data unavailability, while for equation (18.1), equilibrium rent is substituted by actual rent due to inability to perform the calculation.

$$r = f(v,\ \Delta \mathrm{EA},\ S,\ \Delta CV, \Delta \mathrm{OS}\ Pl,\ NC) \quad (22.1)$$
$$v = f(r, I,\ \Delta EA,\ \Delta S,\ \Delta Pop,\ T) \quad (23)$$
$$CV_t = f(CV_{t-i}, O, S, NC) \quad (24)$$
$$\Delta S = f(r, v, i,\ \Delta \mathrm{EA},\ CC,\ T) \quad (25.1)$$
$$\Delta \mathrm{EA} = f(I,\ \Delta S,\ \Delta GDP,\ \Delta RGDP,\ r) \quad (26)$$

In the reorganised equations, the expected impacts of the independent variables on the dependent variables are as follows:

- office rent (equation 9.1) is determined by vacancy rate (negative), change in economic activity (positive), supply (negative), change in capital value (positive), change in occupied stock (negative), generosity of the planning policy (negative) and geographical factor (positive);
- vacancy rate (equation 10) is determined by rent (negative), growth rate of service industry (negative), change in economic activity (negative), change in supply (positive), change in population (negative) and tax rate (positive);
- capital value (equation 15) is determined by past capital value (positive), growth in office service industry (positive), supply (negative) and geographical factor (positive);
- change in supply changes (equation 18.1) will affect rent (positive), vacancy rate (negative), interest rate (positive), construction cost (negative) and tax (negative); and
- change in economic activity (equation 20) is determined by service industry growth rate (positive), supply (positive), change in supply (positive), gross domestic product (positive), regional gross product (positive) and rent (negative).

Table 1. Operation of multi-equation in perspective of rent

Sector	dependent variable	Independent variable - Interdependent	Independent variable - predetermined
User	r	**v(-), ΔEA(+), S(-), ΔCV(+)**	***ΔOS(−), Pl(-), NC(+)***
	v	r(-), ΔEA(−), ΔS(+)	*I(-), ΔPop(−), T(+)*
Investment	**CV**	CV_{t-i}(+), S(-)	*O(+), NC(+)*
Development	**ΔS**	r(+), v(-), CV(+), ΔEA(+)	*i(+), CC(-), T(-)*
Macroeconomic impacts	**ΔEA**	r(-), ΔS(+)	*I(+), ΔGDP(+), ΔRGDP(+)*

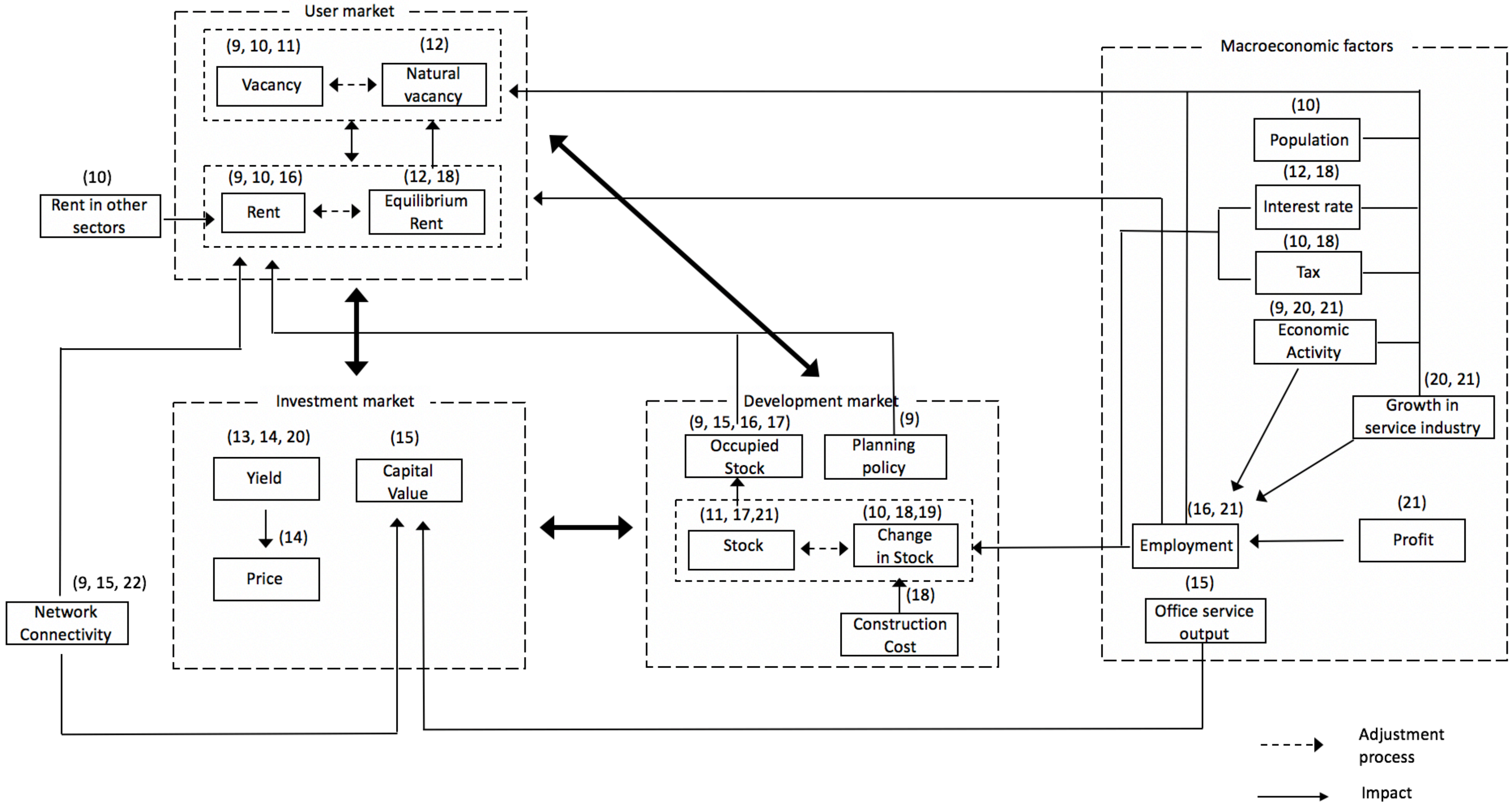

Figure 10. Real estate market framework

In Figure 10, the real estate market is divided into four components—user submarket, investor submarket, development submarket, and macroeconomic factors.

First, in the user submarket (equations 9–12), the adjustment process between rents (equations 9, 10, and 16) and equilibrium rents (equations 12 and 18) occurs as indicated by the dashed lines in the short term, as well as the adjustment between vacancy rates (equations 9, 10, and 11) and natural vacancy rates (equation 12). External factors such as rents in other sectors (i.e., housing, retail, and industrial sectors) (equation 10) also influence office rents.

Second, in the investor submarket (equations 13–15), prices (equation 14) are derived from yields (equations 13, 14, and 20). Capital values (equation 15) are influenced by office service output in the macroeconomic sector (equation 15) and interact with rents in the user market through the connectivity among cities (equations 9, 15, and 22).

In the development submarket (equations 16–19), inventory changes (equations 10, 18, and 19) are influenced by construction costs (equation 18), thereby leading to inventory adjustments (equations 11, 17, and 21) and the derivation of occupied inventory (equations 9, 15, 16, and 17). Occupied stock and planning policies (equations 9) function as variables that influence rents in the user sector from the development sector.

Based on these relationships, the user, investment, and development submarkets interact with and influence each other, thereby leading to a new equilibrium—as indicated by the thick dashed lines—in a long-term equilibrium attainment process.

Lastly, variables comprising the macroeconomic factors (equations 20–22) include population, interest rates, taxes, economic activity, growth in the service sector, employment, profits, and office service output. Population (equation 10), interest rates (equations 12 and 18), taxes (equations 10 and 18), and economic activity (equations 9, 20, and 21) are variables that affect the natural vacancy rate. Employment (equations 16 and 21) is influenced by economic activity (equations 9, 20, and 21), growth in the service sector (equations 20 and 21), and profits within the service industry (equation 21). Among the macroeconomic factors, interest rates, taxes, and employment affect stock changes in the development submarket (equations 10, 18, and 19).

Based on this modelling process, Table 1 presents the causal relationships and expected signs between dependent and independent variables in the submarkets.

In terms of the structural equation, Arestis and Hadjimatheou (1982) conducted a pioneering study which analysed the British macroeconomy using this approach and provided vector expression of the model:

$$By_t + \Gamma x_t = u_t$$

where Y_t: a vector of contemporaneous endogenous variables, X_t: a vector of contemporaneous exogenous variables and predetermined variables.

Each coefficient and variable above constitute a set of component vectors and can be expressed as follows:

$$y_t = \begin{bmatrix} y_{1t} \\ y_{2t} \\ \vdots \\ y_{Gt} \end{bmatrix} \quad x_t = \begin{bmatrix} x_{1t} \\ x_{2t} \\ \vdots \\ x_{Kt} \end{bmatrix} \quad u_t = \begin{bmatrix} u_{1t} \\ u_{2t} \\ \vdots \\ u_{Gt} \end{bmatrix}$$

$$B = \begin{bmatrix} \beta_{11} & \beta_{12} & \cdots & \beta_{1G} \\ \beta_{21} & \beta_{22} & & \beta_{2G} \\ \vdots & & \ddots & \vdots \\ \beta_{G1} & \beta_{G2} & \cdots & \beta_{GG} \end{bmatrix} \quad \Gamma = \begin{bmatrix} \gamma_{11} & \gamma_{12} & \cdots & \gamma_{1K} \\ \gamma_{21} & \gamma_{22} & & \gamma_{2K} \\ \vdots & & \ddots & \vdots \\ \gamma_{G1} & \gamma_{G2} & \cdots & \gamma_{GK} \end{bmatrix}$$

$t = 1, 2, 3, \dots, n$

The simultaneous equation model contains multiple equations that are interdependent and solved contemporaneously. Therefore, the model can be used to determine complex economic phenomena which involve interrelated variables and causal relationships, such as the relationship between supply and demand relationships in markets. The basic idea of a simultaneous equation model is that the values of several variables are determined simultaneously by a system of equations. Each variable is a function of other variables in the system. The solution to a system of equations model involves simultaneously solving all values of the endogenous variables in the system. This can be done by simultaneous equation estimation, which uses statistical methods to estimate the parameters of an equation and solve the endogenous variable values. Simultaneous equation models are statistical models that analyse the interdependency between multiple variables in a system, while single equation models analyse the relationship between two variables individually.

In the multi-equation structure, endogeneity is a key reason for using simultaneous equation models over single equation models. Endogeneity is a problem that can arise in econometrics when the independent variable of a regression model is correlated with an error term. This results in biased and inconsistent estimates of the regression coefficients, making it difficult to draw meaningful conclusions from the analysis. There are several ways in which endogeneity can occur in econometric analysis. One common cause is omitted variable bias, which occurs when an important variable that is correlated with both the independent and dependent variables is excluded from the regression model. Another common cause is inverse causality, where the direction of the causal relationship between the independent and dependent variables is unclear, leading to potential feedback loops. Endogeneity can also arise from measurement errors of the independent variables, synchrony (when two variables affect each other at the same time), or selection bias (when the sample selection process is biased).

3.5 Expected Outcome of the Model

At the current stage, the expected results based on theoretical discussion, literature review and the modelling process are as follows:

(1) By taking advantage of the multi-step equation model, the statistical output is expected to have a high explanatory power (therefore, a high level of R^2). It was suggested in a previous section (4.5) to use two models: the first one tests all subsectors, including development-sector variables (i.e., stock [S], take-up [OS], construction cost [CC] and planning policy [Pl]), while the other model excludes these variables. Of these two, it is thought that the first model should perform better than the second, since the use of development sector variables provides further information about supply, which was discussed in section 3.2 and Figure 8 (movement of SW and SE quadrants). In addition, the overall explanatory power (R^2) and statistical significance of the independent variables of the two models will be compared with that of the previous European single equation model. While it is assumed that the multi-step equation model better explains the market than the single equation model, both models are expected to outperform the model used in the previous European studies.

(2) The five equations of the model will reflect the process of convergence to market equilibrium in the long term as a consequence of adopting an error-correction term. The adjustment process refers to the discussions about the dynamics of the real estate market in Chapter 3. Although adoption of the ECM method may be less distinctive than that of the multi-step equation model (because of its relative abundance in existing studies), the result provided by the fourth (ΔS) and fifth (ΔEA) equations will still be interesting as they have been investigated less often. The error-correction terms in the equations will be able to explain the extent of correction in the development market and the macroeconomic sector over time. Because of the inelasticity of space supply and the long-term influence of macroeconomic factors' impact on the real estate market, the error-correction term is assumed to adjust substantially in based on the theory explained in sections 3.3 and 3.4. As a result, there will be a large gap between the adjustment and non-adjustment processes for the development market and macroeconomic factors.

(3) The integration effect of European cities will be measured by the proxy of the geographical factor, the network connectivity (NC) variable. Very few attempts have been made to measure the geographical variable's impact on the real estate market (Lizieri and Pain, 2014). This variable captures the extent of how closely one city is connected with other cities. Based on the concept of this variable, it is expected that more highly integrated cities with bigger NC values (namely, London, Paris and Frankfurt) will have similar movement over time compared to the others. This would be particularly the case for rent and CV equations, since they have NC variables as their determinants. As was the case for Lizieri and Pain (2014), NC is expected to be significant to rent and CVs. Also, the time-series movement of rent and CV will share a

similar pattern in the three more integrated cities than the remaining ones during the sample periods.

3.6 Summary

This chapter reviewed a series of previous empirical research studies and established an empirical model in the form of multi-equations in consideration of a practical quantitative analysis. The following step is to conduct an empirical analysis using a statistical package. The process will involve testing hypotheses based on basic assumptions of econometrics and interpreting the statistical outcomes. The variables' numerical signs and values will be compared with theoretical expectations and the results of other empirical studies, and the adequacy of the model will be evaluated on that basis.

4 Research Design & Methods

4.1 Introduction

Following a review of the components of the real estate market and their interaction and coordination in Chapters 2 and 3, this chapter describes the approach that was used for model setting, data collection and sources, and the research methodology of this study. These details relate to the overall aim of this thesis, which is to explore the determinants and dynamics of commercial real estate, especially office rents, and apply them to the European office market.

4.2 Overall Approach

This section provides an introduction to the overall research process. It includes a description of the characteristics and advantages of quantitative research compared to qualitative research. Quantitative research uses a statistical methodology with a theoretical background in economics, and this econometric estimation has the advantage of being able to draw conclusions with statistical reliability for a given hypothesis.

(1) Theoretical discussion: In Chapters 2 and 3, the theoretical discussions and previous studies involving office research were examined, with a focus on the four-quadrant model.

(2) Theoretical modelling: Based on the previous studies, theoretical modelling was attempted; it was represented as a systematic format to explain the overall working process of the office market.

(3) Descriptive statistical analysis: The next stage is data collection and descriptive statistical analysis. In descriptive statistics, outlines of the data are provided in the form of basic statistics, and the time-series movement of key data is visually presented.

(4) Quantitative modelling: In quantitative modelling, an empirically eligible quantitative model is constructed based on the data availability and their suitability for a regression model. In this step, the concepts of economic equilibrium and adjustment processes are discussed and a review of existing studies is incorporated into the model. The theoretical system is reconstructed in a multi-equation system form with multiple functions, involving both dependent and independent variables. Dependent and independent variables will be selected referring to the variable selection process in previous studies and data availability, and then the expected signs for the effect of each independent variable on the dependent variable will be determined based on a theoretical discussion.

(5) Regression analysis and diagnostic test: In this stage, a population estimation for multi-equations is performed using various regression analysis techniques, following econometric methodology. Regression analysis is performed using six estimation methods, in order to find estimation techniques which appropriately reflect the endogeneity inherent in the multi-equations and the characteristics of panel dataset as a combined structure of time-series and cross-section.

(6) Interpretation of empirical analysis and conclusion: The summary and interpretation of the regression analysis is provided according to each estimation method, and the advantages and disadvantages of each estimation method are also examined. Then, the regression results will be compared with the theoretical explanations of the office market, and the implications from the empirical analysis will be derived. The results will also be compared with other empirical cases in previous studies, to demonstrate the distinctiveness of the research findings. Finally, the expected academic contribution to the advancement of the European office market research will be presented.

4.3 Structure and Data

4.3.1 Study Area

The spatial scope of the study consists of six selected cities which function as economic and financial centres in Europe: London, Paris, Frankfurt, Amsterdam, Madrid and Milan. Giussani et al. (1993) pointed out GDP as a key determinant of rental value, and this perspective can be applied to the selection of study area. According to the GDP data in Table 3, Germany, UK, France, Italy, Spain and Netherlands are six biggest economies in Europe, which is an indication of strong office demand. Brounen and Jennen (2009) takes similar approach in terms of study area, which selected ten cities and classified them to first and second tier cities. They chose five countries except Italy, and first tier cities was identical to the cities above except Milan. In addition, RGDP / GDP ratio in Table 8 also supports the selection criteria, which presents 20% - 30% of GDP shares except Frankfurt (approximately 7%). It should be noted that German cities are not as concentrated as that of other countries, and Frankfurt records the highest office rent among major German cities for 2012-2017 (KPMG, 2012, 2013, 2014, 2015, 2016, 2017).

The city selection criteria is based on the assumption that financial centres would be more closely linked than administrative centres in terms of economic activity. The assumption is also relevant in the context of the adoption of network connectivity variable, which is an indicator of global openness and interaction with other cities. The evidence for this can be found in the significance of network connectivity in both rent and yield equations in the alternative model (Table 25), and strong cointegration among real rent, employment, GDP, and network connectivity (Table 41). Based on the evidence, the selected European cities are integrated for these factors, although rental levels of cities are differentiated in accordance with the level of space demand and economic openness (Figures 11–17).

Table 2. Correlation of key variables

	real rent	yield	GDP	network connectivity
real rent	1.0000			
yield	-0.4360	1.0000		
GDP	0.4493	-0.4487	1.0000	
network connectivity	0.6456	-0.2962	0.5297	1.0000
number of observations	332	332	332	332

The correlation presented in Table 2 provides insights into how key variables (real rent, yield, GDP, and network connectivity) relate to each other across the cities. The number of observations indicates that 332 samples are included in the correlation analysis.

Strong positive correlations (closer to +1) indicate variables that tend to increase together, while strong negative correlations (closer to -1) indicate variables that tend to change in opposite directions. Weak correlations (closer to 0) suggest little to no linear relationship among the variables. Further, there is a moderate negative correlation (approximately -0.44) between real rent and yield. This suggests that, in general, as real rent increases, yield tends to decrease, and vice versa. There is a moderate positive correlation (approximately 0.45) between real rent and GDP. This indicates that there is a tendency for real rent to increase as GDP increases across the cities. Moreover, there is a strong positive correlation (approximately 0.65) between real rent and network connectivity. This suggests that cities with higher real rent tend to also have higher levels of network connectivity.

4.3.2 Data Sources and Key Variables

For the statistical analysis, proxies of each variable and its sources are required to be specified. The limitations of data collection are commonly acknowledged as a challenging factor in

European real estate market research, and this study also encountered such issues in the stage of the data collection. The initial data were collected on an annual basis for the purpose of empirical analysis of the theoretical models, and they represent a relatively short time series and a wide cross-sectional structure. As is evident from Table 3, the number of available time-series observations for individual cities was limited to only 18. Considering that reliable statistical estimation typically requires a minimum of 30 observations, the lack of time-series data poses a fundamental problem that undermines the reliability of quantitative estimates. Therefore, in an effort to address this issue, quarterly data were collected as a substitute for the initially collected annual data. The second data, primarily collected by Colliers International, a real estate services company, have a longer time series and a relatively shorter cross-sectional dimension, as indicated in Table 4.

In this stage, it is essential to maintain consistency with the quadrant models (from Chapters 2 and 3) and the theoretical model (derived in Chapter 3), while also ensuring the reliability of the estimates in the empirical analysis within the constraints of the limited data availability. Furthermore, individual equations representing each subsector within the real estate market are advised to avoid including too many variables in one equation, considering the principle of parsimony. Taking these constraints into account, the individual equations have been reconfigured through modification and simplification processes for the empirical analysis.

Table 3 provides a detailed overview of the initial variables used in the research, their proxies, units of measurement, availability periods, and sources of data. The table lists various variables and their data sources used in the study, encompassing user, investment, development subsectors, as well as macroeconomic and geographical factors. When using this annual data, assuming no missing values, the time series sample comprises 18 observations. However, with fewer than 30 observed samples, it is difficult to derive statistical significance from the data.

(1) User subsector: The user subsector has two variables of rent and vacancy rate—rent (r) is measured in euros per square meter, and data is from BNP Paribas, encompassing the period from 2001 to 2018. Vacancy rate (v) is measured in percentage, and the data source is again BNP Paribas, encompassing the period from 2001 to 2018.

(2) Investment subsector: The investment subsector has two variables of yield and capital value—yield (y) and interest rate (i) are both measured in percentage. Data sources are Colliers International for Q1 2007–Q4 2018 period for yield, and Bloomberg terminal for Q1 2007–Q4 2018 for interest rate. Capital value (cv) is measured in million euros, and the data source is BNP Paribas for the period from 2001 to 2018 (2003–2018 for Milan).

(3) Development subsector: The development subsector has the following four variables. 1) stock (s) is measured in various units and is taken from various data sources. It is measured in terms of the number of building sales and the data is from the UK from HM Revenue & Customs for 2001–2018. In case of Germany, stock is proxied by building permits in value (million euros) and building permits in number; the data has been taken from the German Federal Statistical Office for 2003 to 2018. In France and Spain, stock is proxied by building

permits in a specific area (thousand square meters). Data sources are INSEE National Statistics Office of France and Ministerio de Fomento, for 2001 to 2018, respectively. 2) Take-up (tkp) is measured in thousand square meters and data is sourced from BNP Paribas for the 2001–2018 period. 3) Construction cost (cc) is measured in USD per square feet, and data is taken from real capital analytics (RCA) but only available for the UK, France, and Spain. 4) Planning policy (pl) is measured as the number of planning permissions, and the data is only available for the UK from the UK planning authority.

(4) Macroeconomic factors: The following eight variables are collected as macroeconomic factors; gross domestic product (GDP) and regional gross domestic product (rGDP) are measured in million euros, taken from Bloomberg terminal for 2001 to 2018 and from Eurostat for the 2005–2016 period, respectively. Employment (e) is measured in terms of the number of employed people from the UK Office for National Statistics (ONS), German Federal Statistical Office, and Eurostat (in case of other countries) for the period Q1 2007–Q4 2018. Tax rate (t) is corporate tax measured in percentage, sourced from KPMG for the period 2002–2018 (2003–2018 for the UK). Inflation (inf) is measured in terms of the index which sets the inflation of 2010 as 100, and the data is taken from the Organisation for Economic Cooperation and Development (OECD) for 2001 to 2018. Office services output (o) is measured in million euros and the data is sourced from Bloomberg terminal for the 2001–2018 period. Growth in service industry (I) is measured in percentage and is based on data taken from Bloomberg terminal for the period 2001–2014 (2001–2012 for Germany). Population (pop) is measured in terms of the number of people in each country and data was sourced from OECD for the period 2001–2018.

(5) Geographical factors: Network connectivity is selected as a geographical factor. Network connectivity (nc) is a semi-annual index from Z/Yen report index for the period 2009 H1–2018 H2. The global city index is an annual index from the GFCI report index for the period 2009–2018, which is collected as an alternative for the network connectivity variable.

Table 3. Initial variables and data sources (annual basis)

Sector	Variable / Notation	Proxy	Unit	Availability	data sources
User subsctor	rent (r)	prime office rent	EUR per sq. m.	2001-2018	BNP Paribas: European Office Market report
	vacancy rate (v)	prime office vacancy rate	percent	2001-2018	BNP Paribas: European Office Market report
Investment subsctor	yield (y)	prime office yield	percent	2001-2018 (2003-2018 for Milan)	BNP Paribas: European Office Market report
	interest rate (i)	10-year government bond yield	million EUR	2001-2018	Bloomberg terminal
	capital value (cv)	office investment by city	thousand sq. m.	2001-2018 (2003-2018 for Milan)	BNP Paribas: European Office Market report
Development subsctor	stock (s)	building sales	building unit (number)	2001-2018 UK	HM Revenue & Customs
		building permits in value	million EUR	2003-2018 (Germany)	German Federal Statistical Office
		building permits in number	permits in number	2003-2018 (Germany)	German Federal Statistical Office
		building permits in area	thousand sq. m.	2001-2018 (France and Spain)	INSEE National Statistics Office of France; Ministerio de Fomento
	take-up (tkp)	amount of annual take-up by city	thousand sq. m.	2001-2018	BNP Paribas: European Office Market report
	construction cost (cc)	construction input cost by country	USD per sq. ft.	2001-2018 (UK, France, Spain)	RCA
	planning policy (pl)	number of planning permissions	number of applications	2001-2018 UK	UK planning authority
Macroeconomic factors	gross domestic product (GDP)	gross domestic product by country	million EUR	2001-2018	Bloomberg terminal
	regional gross domestic product (rGDP)	regional gross domestic product by country	million EUR	2005-2016	Eurostat
	employment (e)	number of employment by country	number in person	2008-2018	OECD
	tax rate (t)	tax rate by country	percent	2002-2018 (2003-2018 for UK)	KPMG
	inflation (inf)	CPI	index, 2010=100	2001-2018	OECD
	office services output (o)	GDP in service	million EUR	2001-2018	Bloomberg terminal
	growth in service industry (I)	employment growth in service by country	percent	2001-2014 (2001-2012 for Germany)	Bloomberg terminal; other available sources
	population (pop)	population by country	number in person on	2001-2018	OECD
Geographical factors	network connectivity (nc)	network connectivity index	semi-annual index	2009 H1-2018 H2	Z/Yen report index
		global city index	annual index	2009-2018	GFCI report index

Table 4 lists various variables and their data sources used in the study, including user, investment, and development subsectors as well as macroeconomic and geographical factors on a quarterly basis. When using this quarterly data, assuming no missing values, the time series sample consists of 12 years × 4 quarters = 48 observations. For the panel data, a sample that combined cross-sections with 7 regions (6 cities) was used; the estimation was conducted using 48 × 7 = 336 samples.

(1) User subsector: The user subsector has two variables—rent and vacancy rate; rent (r) is measured in EUR per square meter, and data from Colliers International encompasses the period from Q1 2007 to Q4 2018. The specification of vacancy rates remains unchanged from that presented in Table 3.

(2) Investment subsector: The investment subsector has two variables—yield and capital value; yield (y) is measured in percentage and the data source is Colliers International for the period Q1 2007–Q4 2018. Specification of interest rate (i) and capital value (cv) is the same as that given in Table 3.

(3) Development subsector: The development subsector has five variables—occupied stock (os), take-up (tkp), and development completion (dev) are measured in thousand square meters; the data source is Colliers International for the period Q1 2007–Q4 2018. New construction (cons) is proxied by the number of construction orders, and the data source is Colliers International for the period Q1 2007–Q4 2018. Details of construction cost (cc) variable is the same as that given in Table 3.

(4) Macroeconomic factors: There are eight variables included as macroeconomic factors, and details of the data specification remain unchanged from that given in Table 3.

(5) Geographical factors: There is one variable of network connectivity (nc), and details of the data specification remain unchanged from that given in Table 3.

Table 4. Modified variables and data sources (quarterly and annual basis combined)

Sector	Variable / Notation	Proxy	Unit	Availability	data sources
User subsector	rent (r)	prime office rent	EUR per sq. m	2007 Q1-2018 Q4	Colliers International
	vacancy rate (v)	prime office vacancy rate	percent	2001-2018	BNP Paribas: European Office Market report
Investment subsector	yield (y)	prime office yield	percent	2007 Q1-2018 Q4	Colliers International
	interest rate (i)	10-year government bond yield	percent	2007 Q1-2018 Q4	Bloomberg terminal
	capital value (cv)	office investment by city	thousand sq. m	2001-2018 (2003-2018 for Milan)	BNP Paribas: European Office Market report
Development subsector	occupied stock (os)	amount of total occupied stock by city	sq. m. in thousands	2007 Q1-2018 Q4	Colliers International
	take-up (tkp)	amount of gross take-up by city	sq. m. in thousands	2007 Q1-2018 Q4	Colliers International
	new construction (cons)	space under active construction construction orders	number of construction orders	2007 Q1-2018 Q4	Colliers International
	development completion (dev)	development completions	sq. m in thousands	2007 Q1-2018 Q4	Colliers International
	construction cost (cc)	construction input cost by country	USD per sq feet	2001-2018 UK, France, Spain	RCA
Macroeconomic factors	gross domestic product (GDP)	gross domestic product by country	million EUR	2001-2018	Bloomberg terminal
	regional gross domestic product (rGDP)	regional gross domestic product by country	million EUR	2005-2016	Eurostat
	employment (e)	number of employment by country	number in person	2007 Q1-2018 Q4	UK ONS (UK) German Federal Statistical Office (Germany) Eurostat (France, Netherland, Italy, Spain)
	tax rate (t)	tax rate by country	percent	2002-2018 (2003-2018 for UK)	KPMG
	inflation (inf)	CPI	index, 2010=100	2001-2018	OECD
	office services output (o)	GDP in service	million EUR	2001-2018	Bloomberg terminal
	growth in service industry (I)	employment growth in service by country	percent	2001-2014 (2001-2012 for Germany)	Bloomberg terminal
	population (pop)	population by country	number in person on	2001-2018	OECD
Geographical factors	network connectivity (nc)	network connectivity index	semi-annual index	2009 H1-2018 H2	Z/Yen report index
		global city index	annual index	2009-2018	GFCI report index

Table 5. Single equation models

Author	Model specification	Variable explanation	Key result
(1) Gardiner and Henneberry (1988)	$\Delta RR_{it} = \beta_0 + \beta_1 GDP_{it-2}\beta + \beta_3 FRS_{it}$	RR it = the office rent index for the ith region in time period t divided by the rent index for all English regions in time period t; GDP it = gross domestic product for the ith region in time period t divided by gross domestic product for all English regions in time period t; FSR it = total commercial (office) floorspace in the ith region in time period t divided by total commercial floorspace in all English regions.	R^2: 0.465 - 0.978
(2) Gardiner and Henneberry (1991)	$\Delta R_t = \alpha + \beta D_t^* + u_t$, subject to $D_t^* - D_{t-1}^* = (1-\lambda)(D_t - D_{t-1}),\ \ 0 < \lambda < 1$ $R_t = \alpha(1-\lambda) + \lambda R_{t-1} + \beta(1-\lambda)D_t + (u_t - \lambda u_{t-1})$ $RR_{it} = \beta_0 + \beta_1 RR_{it-1} + \beta_2 GDP_{it} + (u_t - \lambda u_{t-1})$	R_t = the occupier's rent bid in time period t; Dt = the occupier's observed level of demand; D*t = the occupier's expectation, in time period t, of their trend level of demand; D*t-1 = last year's expectation of the occupier's trend level of demand; λ = an adjustment parameter; ut = disturbance term.	R^2: 0.850 - 0.971
(3) D'Arcy et al. (1999)	$\Delta RR_t = \alpha_0 + \sum \alpha_{1i}\Delta GDP_{t-i} + \sum \alpha_{2i}\Delta SSE_{t-i} + \sum \alpha_{3i} NC_{t-i} + \varepsilon_t$	ΔRR_t = change in the natural log of the real rental index in time period t from t - 1 (first difference on the log of the real rental index); ΔGDP_{t-i} = real GDP index (first log difference); ΔSSE_{t-i} = service sector employment index (first log difference); NC_{t-i} = volume of new office completions (log levels); α_0 = constant; α_{1i} = parameters for the different lag structures on the real GDP index (first log difference); α_{2i} = parameters for the different lag structures on the service sector employment index (first log difference); α_{3i} = parameters for the different lag structures on the new office completions index (logs); ε_t = error term.	Sample: 22 cities, 1982 - 1994 Adj. R^2: 0.32 - 33 DW statistic: 1.61 - 1.65 Breusch-Pagan Chi2: 5.99 - 9.49
(4) Orr and Jones (2003)	$d\ ln\ (R_{it}) = \mu_3 \left\{\mu_0 - \mu_1 d\ ln\ (V_{it-n}) + \mu_2 d\ ln\ \left[\frac{(TU_{it-n})}{(OS_{it-n})}\right] - (1-\mu_3)\ d\ ln\ (R_{it-n})\right\}$	Six endogenous variables, Rit: real rent, Vit: vacancy rate, TUit: take-up as satisfied demand for office space, OSit: occupied stock, ABit: net absorption, ASit: available floorspace, and exogenous determinants, It: interest rates, RCt: real construction costs, Et: employment in service industries, EAit: unsatisfied demand approximated using a measure of general economic activity	1979-2000, bi-annual data (CB Hiller Parker) (i) Edinburgh $d\ ln\ (R_{Et}) = 0.531\left\{0.031 - 0.427\ d\ ln\ (V_{Et-1}) - 0.134\ d\ ln\ \left[\frac{(TU_{Et})}{(OS_{Et})}\right] - (1-0.531)\ d\ ln\ (R_{Et-1})\right\}$ R^2 = 0.25, DW = 2.18 (ii) Glasgow $d\ ln(R_{Gt}) = 0.791\left\{0.242 - 0.081\ d\ ln\ (V_{Gt-1}) - 0.31\ d\ ln\ \left[\frac{(TU_{Gt-2})}{(OS_{Gt-2})}\right] - (1-0.791)\ d\ ln\ (R_{Gt-1})\right\}$ R^2 = 0.34, DW = 1.58

Author	Model specification	Variable explanation	Key result
(5) Mouzakis and Richards (2007)	$\Delta r_t = d_0 + d_1 \Delta r_{t-1} + d_2 \Delta y_t + d_3 \Delta s_t + d_4 r_{t-1} + d_5 y_{t-1} + d_6 s_{t-1} + u_t$ (eq. 1) , where $d_4 = \delta_4, d_5 = -\gamma_1 \delta_5, d_6 = -\gamma_2 \delta_5$ $\Delta r_{it} = a_i + b_1 \Delta r_{it-1} + b_2 \Delta y_{it} + b_3 \Delta s_{it} + b_4 r_{it-1} + b_5 y_{it-1} + b_6 s_{it-1} + e_{it}$ (eq. 2)	rit: the logarithm of the rents of centre i for year t, yit: the logarithm of market services output (the proxy of the local income that drives demand for prime space), sit: the logarithm of the local stock measurement (the development completions based stock index) (eq. 2): All coefficients over cross-sections (variable coefficients) – FE, the main model. The ECM specification is based on the principle of co-integration, namely the estimation of the appropriate co-integrating vector for the I(1) variables.	Samples: 200-261 (i) Estimates of the unrestricted ECM (H5): $R^2 = 0.71$, DW = 2.25 (ii) Table 7. Estimates of the two step ECM (In comparison of unrestricted ECM): $R^2 = 0.71$, DW = 2.01, Long run $R^2 = 0.90$
(6) Brounen and Jennen (2009)	$ln\ R_t = \gamma_0 + \gamma_1\ ln\ EA_t + \gamma_2[(1-\hat{v}_t) * SU_t] + u_t$ (eq. 1) $\Delta\ ln\ R_t = \alpha_0 + \alpha_1 \Delta\ ln\ EA_t + \alpha_2[(1-\hat{v}_t) * SU_t] + \alpha_4 u_{t-1} + \alpha_5 \Delta\ ln\ R_{t-1} + \varepsilon$ (eq. 2)	R: rent, EA: economic activity, SU: available office space $\hat{v}$: vacancy rate which enters error correction model as a fitted variable model 1: EA is measured as FTE employment in the service industry / model 2: EA is measured as GDP, the result indicates model 2 (local) is the main model.	10 European cities, 1991-2006 annual data from Jones Lang LaSalle, Eurostat and Experian (i) long-run model (local), model 2 $ln\ R_t = 22.974 + 2.538\ ln\ GDP_t + 0.045[(1-\hat{v}_t) * SU_t]$ N=75, adj. R^2=0.905, DW=0.679 (ii) short-run model (local), model 2 $\Delta\ ln\ R_t = -0.000 + 2.184\ \Delta\ ln\ GDP_t - 0.048[(1-\hat{v}_t) * SU_t] - 0.390 u_{t-1} + 0.372 \Delta\ ln\ R_{t-1}$ N=70, adj. R^2=0.572, DW=2.050
(7) Bruneau and Cherfouh (2015)	$lnR_t = \varphi_0 + \varphi_1\ ln\ EA_t + \varphi_2(1-v_t) + \varphi_2 S_t$ (eq. 1) $ln\ R_t = \delta_0 + \delta_1\ ln\ EA_t + \delta_2 lnS_t + \delta_3 DUM_{t_0} + \delta_4 ln\ EA_{t-1} \times DUM_{t_0} + \delta_5 \Delta\ ln\ R_{t-1} \times DUM_{t_0} + Z_t$ (eq. 2)	where R: ln (Real rents), EA: economic activity, V: vacancy rate, S: stock, DUMt0 is the dummy variable indicating the date t0 of the structural break identified from the Gregory–Hansen test: $DUM_{t_0} = 1$ if $t > t_0$ and =0 otherwise.	(i) Long-run equilibrium rent model, ln (Real rents) $lnR_t = -15.00 + 4.71\ ln\ Emp_t + \varphi_2(1-v_t) - 1.84 S_t - 4.91 DUM_{03Q4} - 1.51 DUM_{03Q4} * ln\ Emp_t + 0.51 DUM_{03Q4} * ln\ S_t$ N=95, Adj. R^2 =0.93 (ii) Short-run rent adjustment model, Δln (Real rents) $\Delta lnR_t = 0.00 + 1.86 \Delta ln\ Emp_{t-2} - 0.03(1-v_{t-2}) + 0.22 \Delta lnR_{t-2} + 0.24 \Delta lnR_{t-2} - 0.15 ECT_{t-2}$ N=89, Adj. R^2=0.49, DW=2.00 (iii) Vacancy adjustment model, Δ(Vacancy rate) $\Delta v_t = 0.02 + 0.28 \Delta v_{t-1} - 0.36 \Delta lnR_{t-1} + 0.41 \Delta lnS_{t-3} - 0.22 \Delta ln\ Emp_{t-3} - 0.07 ECT_{t-2}$ N= 89, Adj. R^2=0.49, DW=2.03 (iv) Supply adjustment model, Δln (Stock) $\Delta lnS_t = 0.00 + 0.02 \Delta lnR_{t-10} + 0.70 \Delta lnS_{t-9} + 0.12 \Delta ln\ Emp_{t-11} + 0.07 ECT_{t-10}$ N=83, Adj. R^2=0.52, DW=2.03

Author	Model specification	Variable explanation	Key result
(8) Marcato and Tong (2023)	ln(RRIl,t) = d0 + d1 ∗ ln(Sl,t) + d2MSA ∗ ln(Sl,t) + d3SELl,t + d4EMMl,t+ d5 MSA ∗ EMMl,t + d6Δln(EMPl,t) + d7Δln(RIPCl,t) + d8ln(POPIl,t) +d9AHOt + d10ATl + d11AHOt × ATl + d12PORTl+ d 13TTWDl + μlRRI ,t (eq. 1) ln(Sl,t) = e0 + e1ln(RRIl,t) + e2MSA ∗ ln(RRIl,t) + e3SELl,t + e4EMMl,t+ e5MSA ∗ EMMl,t + e6Δln(ROPEXl,t) + e7ΔCTl,t + e8AHOt + e9ATl+ e10AHOt × ATl + e11PORTl + e12TTWDl + e13NRG40l,t + e14UDAl+ e15WRIl + e16UDAl × ln(RRIl,t) + e17WRIl × ln(RRIl,t)+ e18NFBl,t + e19NFDl,t + μlS,t (eq. 2) EMM l,t = f0 + f1ln(RRIl,t) + f2MSA ∗ ln(RRIl,t) + f3ln(Sl,t) + f4MSA ∗ ln(Sl,t)+ f5SELl,t + f6Δln(EMPl,t) + f7Δln(RIPCl,t) + f8ln(POPIl,t) + μlMR ,t (eq. 3)	(eq. 1) ln(RRIl,t): rents, ln(Sl,t): supply, EMMl,t: economic mismatch, SELl,t: search effort level, Δln(EMPl,t): ratio of employment in office-related sectors to population, Δln(RIPCl,t): real income per capita, ln(POPIl,t): population index, AHOt: the Atlantic hurricane occurrence dummy, ATl: the Atlantic dummy for MSAs facing the Atlantic Ocean, PORTl: port cities, TTWDl: reflection of a lack of transportation. (eq. 2) Δln(ROPEXl,t): property management firms, ΔCTl,t: difference between capitalization and risk free rates, WRIl: Wharton regulatory index, UDAl: geographically undevelopable land area, NFBl,t: new firm births, NFDl,t: new firm deaths. (eq. 3) employment function, notations are same as above. four endogenous variables—real rent index (RRIl,t), office stock (Sl,t), economic mismatch rate (EMMl,t), search effort level (SELl,t) five exogenous variables —real operating expense (ROPEXl,t), real personal income per capita (RIPCl,t), difference between capitalization and Treasury yield (CTl,t), ratio of employment in office-related sectors to population (EMPl,t), and population index (POPIl,t). M3 NRG40 PORT & TTWD / I3, NRG40(in) PORT TTWD (port city and travel time to work dummies (TTWD) included), is the main model.	2005 q1 - 2018 q4, 2280 panel observations (60 quarters by 38 MSAs) (i) Long-run ln(RRIl,t): coef. (Sl,t) = -0.018, coef. (SELl,t) = 0.055, coef. (EMMl,t) = -1.274, F-stat 25.23 (ii) Long-Run ln(Sl,t)): coef. (EMMl,t) = -4.065, coef. (SELl,t) = 0.055, coef. (RRIl,t) = 0.711, F-stat 7195 (iii) Long-Run EMMl,t: coef. (Sl,t) = -0.187, coef. (RRIl,t) = -0.044, coef. (SELl,t) = 0.004, F-stat 35.05 (iv) Short-Run ln(Sl,t)): coef. (ECT(RRIl,t-1)) = -0.0.16, coef. (ECT(Sl,t-1)) = -0.019, coef. (ECT(EMMl,t-1) = -0.150, F-stat 16.94 (v) Short-Run ΔEMMl,t: coef. (ECT(RRIl,t-1)) = -0.001, coef. (ECT(Sl,t-1)) = -0.011, coef. (ECT(EMMl,t-1) = -0.097, F-stat 4.52 (vi) Short-Run ΔSELl,t: coef. (ECT(RRIl,t-1)) = -0.062, coef. (ECT(Sl,t-1)) = -0.063, coef. (ECT(EMMl,t-1) = 0.366, F-stat 6.63 (vii) Panel error correction models (Long-Run) Eq. ln(RRIl,t): coef. (S l,t) = -2.489, coef. (SELl,t) = 0.104, coef. (EMMl,t) = 3.016, F-stat 66.24; Eq ln(Sl,t): coef. (EMM l,t) = -1.164, coef. (SEL l,t) = -0.021, coef. (ln(RRI l,t)) = 0.186, F-stat 18785, Eq. EMMl,t: coef. (ln(S l,t)) = -5.556, coef.(ln(RRI l,t)) = 0.436, coef. (SEL l,t) = -0.017, F-stat 22.10

Table 6. Multi-equation models

Author	Model specification	Variable explanation	Key result
(1) Rosen (1984)	$OS_t = \gamma_0 + \gamma_1 RR_t + \gamma_2 E_t$ $\Delta NR_t/NR_{t-1} = \beta_0 + \beta_1(VR^n - VR_t) + \beta_2 IN_t$ $CD_t = \alpha_0 + \alpha_1(VR_t + VR_{t-1} + VR_{t-2} + VR_{t-3}) + \alpha_2 RR_t^e + \alpha_3 CC_t + \alpha_4 NC_t + \alpha_5 T_t$	OS_t: occupied stock; RR_t: real rent; E_t: employment; NR_t: nominal rent; VR^n: natural vacancy rate; VR_t: actual vacancy rate; IN_t: price inflation rate; CD_t: new office completion; VR_t: vacancy rate; RR_t^e: expected rent; CC_t: construction costs; NC_t: interest rate.	Occupied stock, R^2: 0.97 Rent adjustment, R^2: 0.55 New construction, R^2: 0.19
(2) Hekman (1985)	$RR_t = \beta_0 + \beta_1 VR_t + \beta_2 GP_t + \beta_3 E_t + \beta_4 U_t$ (1) $P_t = \alpha_0 + \alpha_0 RR_t^f + \alpha_2 G + \alpha_3 CC_t + \alpha_4 NC_t$ (2)	RR_t: real rent, VR_t: vacancy rate; GP_t: gross national product; E_t: employment; U_t: unemployment rate; P_t: amount of new office permits; RR_t^f: fitted value of rent; G: ratio of finance, insurance and real estate, service and government employment in 1980 to that of 1970; CC_t: real construction costs; NC_t: nominal interest rate.	Samples: 14 cities, 1979 - 1983 Rent, R^2: 0.37 Building permits, R^2: 0.61 Rent elasticities: -0.08 (VR), 4.43 (Y), 0.24 (E)
(3) Shilling et al. (1987)	$\delta R_t = \alpha_0 + \alpha_1 \delta EX_t + \alpha_2 V_t^*$	R_t = office rent level time period t; EX t = operating expenses. Here, the authors have assumed that landlords grant gross leases such that their true returns are a partial function of commercial real estate operating costs; V_t = vacancy rate in time period t. The superscript '*' denotes natural vacancy rate as before.	Samples: 17 cities R^2: 0.66 - 0.98; DW: 1.09 - 2.77
(4) Wheaton (1987)	$K_t^* = \gamma_0 + \gamma_1 E_t + \gamma_2 RR_t + \gamma_3(E_t/E_{t-1})$ $A_t = \mu[\gamma_0 + \gamma_1 E_t + \gamma_2 RR_t + \gamma_3(E_t/E_{t-1})] - \mu OS_{t-1}$ $P_t = \alpha_0 + \alpha_1 RR_t + \alpha_3 VR_t + \alpha_4 K_t + \alpha_5(E_t/E_{t-1}) + \alpha_6 CC_t + \alpha_7 NC_t$ $\Delta RR_t/RR_{t-1} = \lambda[VR_{t-n} - VR^n]$	K_t^*: desired space for occupancy; E_t: office employment; RR_t: real rent; E_t/E_{t-1}: expected growth rates; P_t: new development permits; RR_t: real rent; VR_t: vacancy rate; K_t: space stock; CC_t: construction costs; NC_t: interest rate; VR_{t-n}: vacancy rate with lags.	Absorption, R^2: 0.82; DW: 1.13; N: 39 Construction Cost, R^2: 0.91; DW: 0.96; N: 39
(5) Hendershott (1996a)	$\frac{\Delta g_{t+j}}{g_{t+j-1}} = (v^* - v_{t+j-1}) + \beta(g_{t+j}^* - g_{t+j-1})$	g* = equilibrium gross rents; g = actual gross rents; v* = natural vacancy rate; v = actual vacancy rate.	Samples: 1970 - 1992 R^2: 0.317 - 0.679
(6) Wheaton, Torto and Evans (1997)	$A_t = \tau_t(\gamma_0 + E_t[\gamma_1 + \gamma_2 RR_{t-1}]) - \tau_1 OS_{t-1}$ $TD_t = \alpha_0 + \alpha_1 RR_t + \alpha_2 VR_t + \alpha_3 NC_t + \alpha_4 CC_t$ $VR^n = \beta_0 - \beta_1 VR_{t-1} + \beta_2(A_{t-1}/OS_{t-1})$ $RR_t = \beta_3[\beta_0 - \beta_1 VR_{t-1} + \beta_2(A_{t-1}/OS_{t-1})] - (1 - \beta_3)RR_{t-1}$	TD_t: construction level; RR_t: real rent; VR_t: vacancy rate; NC_t: interest rate; CC_t: construction costs; RR_t: real rent; RR_n: equilibrium rent; A_t: absorption; OS_t: occupied space; VR_{t-1}: vacancy rate.	Absorption, R^2: 0.71; DW: 1.81; Chi2: 0.46; N=21 Rent, R^2: 0.89; DW: 1.38; Chi2: 3.72; N=21 Construction, R^2: 0.88; DW: 2.46; N=19
(7) Hendershott, Lizieri and Matysiak (1999)	$\Delta RR_t/RR_{t-1} = \lambda(VR^n - VR_{t-1}) + \beta(RR_t^n - RR_{t-1})$ $CD_t = \alpha_0 + \alpha_1(GR_{t-1} - GR_{t-2}) + \alpha_2 D_{89}$ $A_t/OS_{t-1} = \mu_1 A_{t-1}/OS_{t-2} + \mu_2 \Delta RR_{t-1}/RR_{t-2} + \mu_3 \varepsilon_{t-1}$	ΔRR_t: change in real rent; RR_{t-1}: real effective rent; VR^n: natural vacancy rate; VR_{t-1}: vacancy ; GR_{t-1}: $[RR_t^n - RR_{t-1}]$ if negative, and zero if positive; D_{89}: dummy variable for 1989; K_t^*: desired space for occupancy; ε_t: demand-side error term (used as a correction term).	Samples: 1977-1996 Space demand, Adj. R^2: 0.64 - 0.69 Completion, Adj. R^2: 0.77 - 0.82
(8) Nanthakumaran et al. (2000)	$\dot{V} = \alpha_1 V + \alpha_2 S + \alpha_3 D$ $\dot{S} = \beta_1 V^* + \beta_2 C + \beta_3 I$	V: measure of real capital value, S: supply as measured by stock, $\alpha_1, \alpha_2, \alpha_3$: coefficients, D: a proxy for demand which will usually reflect the fact that demand for industrial and commercial property is derived from demand for industrial output, office services, or retail goods, V*: the long-run equilibrium price, C: the construction cost, $\beta_1, \beta_2, \beta_3$: coefficients, I: the cost of borrowing.	(i) office property $ln\, V^{off.} = 2.84\, ln\, O^{FBS} - 4.54\, ln\, S^{tot.off.}$ $ln\, S^{off.} = 0.72\, ln\, P^{CTPI} - 1.92\, ln\, I$ (ii) retail property) $ln\, V^{ret.} = 2.84\, ln\, O^{ret.} - 4.54\, ln\, S^{tot.ret.}$ $ln\, S^{ret.} = 0.72\, ln\, P^{CTPI} - 1.92\, ln\, I$ (iii) industrial property $ln\, V^{ind.} = 0.15\, ln\, O^{ind.} - 2.85\, ln\, S^{tot.ind.}$ $ln\, S^{ind.} = 3.29\, ln\, P^{ITPI} - 0.29\, ln\, I$

Author	Model specification	Variable explanation	Key result
(9) Thompson and Tsolacos (2000)	$NIBSUP_t = \alpha_0 + \alpha_1 \Delta RENT_t + \alpha_2 CC_t + u_t$ $\Delta RENT_t = \beta_0 + \beta_1 \Delta RENT_{t-1} + \beta_2 \Delta AVFS_t + e_t$ $\Delta AVFS_t = \gamma_0 + \gamma_1 \Delta GDP_t + \gamma_2 \Delta GDP_{t-1} + \gamma_3 NISUP_t + \varepsilon_t$	NIBSUP = new industrial building supply, Rent = industrial rents, CC = construction cost, AVFS = availability for industrial floorspace, GDP = gross domestic product.	(i) new supply equation $NIBSUP_t = 6532.45 + 25.07\Delta RENT_t - 34.44CC_t$ NIBSUP: Adj. R^2: 0.78; DW: 1.72 (ii) rent equation $RENT_t = 2.40 + 0.62\Delta RENT_{t-1} - 0.01\Delta AVFS_t$ ΔRENT: Adj. R^2: 0.55; DW: 1.07 (iii) floorspace availability equation $\Delta AVFS_t = 2856.02 - 94.43\Delta GDP_t - 83.79\Delta GDP_{t-1} - 0.05NISUP_t$ ΔAVFS: Adj. R^2: 0.82; DW: 0.99
(10) Henneberry et al. (2005)	Yi = aY + cYS Si + cYR Ri + bYI Ii + bYU Ui + bYL Li + u1i (i) Ti = aT + cTY Yi + cTS Si + cTRRi + u2i (ii) Si = aS + cSP Pi + bSC Ci + bSG Gi + bSX1 Xi1 + bSX2 Xi2 + u3i (iii) Pi = aP + cPY Yi + cPR Ri + bPC Ci + PGGi + u4i (iv) Ri = aR + cRY Yi + cRT Ti + cRS Si + bRX1 Xi1 + bRX2 Xi2 + u5i (v)	The proposed system of five equations has 5 endogenous and 8 exogenous variables, where Y = local economic activity, T = space utilisation, S = local supply of space, P = planning applications, G = planning regime (proportion of decisions that were approvals), R = rent, I = industrial structure, U = urbanisation economies, L = localisation economies, C = developers' costs, X1 and X2 = relative rents in other sectors (ratios).	(i) local economic activity equation R2 = 96.4; P-value = 0.00 (ii) space utilisation equation R2 = 60.1; P-value = 0.00 (iii) local supply of space equation R2 = 50.3; P-value = 0.00 (iv) planning applications equation R2 = 58.0; P-value = 0.00 (v) rent equation R2 = 55.2; P-value = 0.00
(11) Fuerst (2006)	$OS_t^* = \alpha_0 + E_t\left(\phi_1 \frac{(E_t - E_{t-1})}{E_t} - \phi_2 R_{t-1}\right) + Z_1$ (eq. 1) $OS_t - OS_{t-1} = A_{t-1} = \delta(OS_t^* - OS_{t-1}), 0 < \delta < 1$ (eq. 2) $A_t = \delta_0(\alpha_0 + E_t\left(\alpha_1 + \phi_2 \frac{(E_t - E_{t-1})}{E_t} - \phi_3 R_{t-1} + Z_1\right) - \delta_0 OS_{t-1} + \delta_1 Z_2 + \delta_2 Z_3$ (eq. 3) $R_t - R_{t-1} = \mu_3(R^* - R_{t-1})$ (eq. 4) $R^* = \mu_0 - \mu_1 V_{t-n} + \mu_2 \frac{A_{t-n}}{S_{t-n}} + \mu_3 B_{t-n} + \mu_4 U_{t-n}$ (eq. 5) $C_t^* = \beta_0 + \beta_1 R_{t-n} + \beta_2 A_{t-n} + \beta_3 CC_t + \beta_4(CA_{t-n})$ (eq. 6)	E: office employment in thousands, Et - Et-1: change in office employment in percent, S: inventory in million sq.ft., OS: occupied space in million sq.ft., S/W: space per worker in sq.ft., U: sublet as % of total vacant, R: asking rent per sq.ft. in constant 1996 dollars, B: Class B rents as a percentage of Class A rents, A: absorption rate as a percentage of total stock, C: annual delivery of new space in million sq.ft.	Samples: 47, 1992-2004 (quarterly data); Source: Grubb and Ellis (i) occupied space (eq. 1 and 3) $OS_t^* = 2200000 + E_t\left(339.542 \frac{(E_t - E_{t-1})}{E_t} - 0.838R_{t-1}\right) - 29.622Z_1 - 18.029Z_2$ -8.185 $Z_3 - 0.223T$, Adj. $R^2 = 0.78$ (ii) space absorption (eq. 2) $A = 0.280(OS^* - OS_{t-1}) - 25478610$, Adj. $R^2 = 0.78$ (iii) the equilibrium rent (eq. 5) $R^* = 50.201 - 1.151V_{t-3} + 0.328\frac{A_{t-2}}{S_{t-2}} + 0.092B_{t-2} - 0.969U_{t-2}$, Adj. $R^2 = 0.78$; DW = 0.795 (iv) change in rental rates (eq. 4) $R_t - R_{t-1} = 0.685(R^* - R_{t-1})$, Adj. $R^2 = 0.5753$ (v) new space construction (from eq. 6) $C = 0.002 - 0.879V_{t-6} + 0.006\beta_1 R_{t-6} - 0.017CA_{t-6}$, Adj. $R^2 = 0.6008$

Referring to the previous examples of single- and multi-equation models above, it should be noted that they went through simplification processes in the modelling process and the models were estimated to draw out the statistically significant output.

Table 5 presents case studies of a single equation model. Gardiner and Henneberry (1988, 1991) are among the early studies that set GDP and supply variables as determinants of rent in the office market. They demonstrate that the development subsector does not immediately respond to demand but rather behaves according to habit persistence based on adaptive expectations, thereby revealing the existence of supply lags. This study model used lag and non-lag models depending on the speed of supply's response to the changes in demand; the cases support the existence of lag based on the assumption that the supply is rigid. It can also be anticipated that the explanatory power of the supply model will be low due to the existence of the lag effect in the supply. D'Arcy et al. (1999) selected gross domestic product (GDP), service sector employment, and office completions as determinants of rent; their study yielde a high r-squared (0.850–0.971) in the user subsector. The approach of exploring key determinants—such as economic activity, employment, and supply—centred around rent characterises the single equation models in terms of their theoretical validity and high explanatory power regarding the user subsector, as discussed in subsection 2.5.1; the case provides a prime example of the model's features.

Orr and Jones (2003), using a reduced form model, showed that an ECM is applicable to the UK in the analysis of Edinburgh and Glasgow. Since the 2000s, there has been a spatial expansion of research subjects from single cities or countries to the European office market, with the studies conducted by Mouzakis and Richards (2007) and Brounen and Jennen (2009) being two such examples. Additionally, Bruneau and Cherfouh (2015)—applying the ECM to the Paris CBD—demonstrate that the model can function in cities other than London. This research trend emphasises the significant spatial expansion of office research and justifies the city selection criteria of this study (given in subsection 4.3.1).

Marcato and Tong's study (2023) is a rare example that applies the ECM as the main model while also considering the endogeneity and simultaneity inherent among dependent (rent, supply, economic mismatch) and key independent variables. Therefore, this study contributes to bridging the gap between the ECM and multi-equation models and provides critical insights into the strengths, weaknesses, and complementarities of these approaches, which are discussed in subsection 2.5.5.

Table 6 summarises the case studies of the multi-equation model. Rosen (1984) and Hekman (1985) are early examples of applying a demand–supply model to the U.S. office market based on the two-equation structure. The multi-equation model expands from the demand–supply model and is developed into the three-equation model composed of rent, construction, and absorption rates in Wheaton (1987), Wheaton, Torto, and Evans (1997), and Hendershott, Lizieri, and Matysiak (1999). Fuerst (2004) adopted Hendershott, Lizieri, and Matysiak's (1999) approach and applied the model to the New York office market, extending the spatial applicability and providing additional valid evidence of the three-equation model. These cases share a close commonality with the approach of this study in terms of modelling strategy in section 3.3, as their models are based on DiPasquale and Wheaton's (1992) theoretical background and consider the interaction among subsectors as a key objective of the research.

Further, Shilling et al. (1987) is one of the early US studies that used the natural vacancy rate as a determinant of rent, and Hendershott (1996a) also selected equilibrium rent and the natural vacancy rate as rent determinants in his study on Sydney, thereby providing insight into the concept of equilibrium in the office market. This approach introduced the concept of the non-accelerating inflation rate of unemployment (NAIRU) proposed by Modigliani and Papademos (1975), into the real estate market (Lizieri, 1999). Since this study assumes that equilibrium is achieved through the interaction of the four quadrants (or subsectors), the approach on the interpretation of equilibrium is different from that of Shilling et al. (1987) and Hendershott (1996a). However, the achievement of equilibrium through equilibrium rent and the natural vacancy rate is a key feature of US office research, and the two models provide important clues to understand this approach.

Further, Nanthakumaran et al. (2000) references Poterba's (1984) asset-market model to compare and analyse the submarkets in the UK, suggesting a direction for model expansion. The model structure is basically in a two-equation (demand-supply) form, but it provides a comparative analysis of the office, retail, and industrial submarkets. This is comparable to the modelling strategy in this study, which expands from the user subsector to investment and development (both flow and stock), and Nanthakumaran et al. (2000) suggests alternative direction in terms of model expansion.

Thompson and Tsolacos (2000) and Henneberry et al. (2005) used two-stage least squares (2SLS) and 3SLS, respectively, to address identification and endogeneity issues and, therefore, provide relevant references for the estimation and interpretation of Chapter 5. Thompson and Tsolacos (2000) focused on the industrial subsector with a three-equation model, which is similar to that of Wheaton et al. (1997) but with a greater emphasis on the supply side as the model comprises new supply, rent, and available space equations. Henneberry et al. (2005) criticised the empirical analysis models for overlooking the importance of planning variables in the real estate market. Their model has a unique structure with five equations and focuses on local economic and supply factors as well as planning applications. The empirical model is designed considering the endogeneity of variables, and 3SLS is performed after identification. The results reveal an explanatory power of 90% for the local economic equation and 50%–60% for the other equations, thereby highlighting the importance of local and planning factors in the UK office market. With regard to the outcome, this study adopts Henneberry et al.'s (2005) perspective on incorporating supply and planning variables.

As mentioned in the literature review, the UK and European studies rely heavily on single equation models (Gardiner and Henneberry, 1988; Gardiner and Henneberry, 1991; D'Arcy et al., 1999). Rent is usually treated as a main dependent variable on the demand side, so the single equation model is composed by placing rent on the left hand and the relevant explanatory variables on the right side. On the other hand, in the case of multi-equation models, Rosen

(1984) and Hekman (1985) started with relatively simple models consisting of supply and demand equations. Since Wheaton (1987), a four-quadrant model and the subsectors of the real estate market have been considered.

Looking at these empirical cases, it should be noted that empirical analysis of the office market is performed in a far more simplified form compared to the diverse and complex explanation of the theory. Empirical analysis involves a modelling process which converts the theoretical background into a concise form with several important dependent and independent variables. There are two reasons for this: One is the limitation of data availability and the other is the principle of parsimony.

The principle of parsimony means that all other things being equal, simpler explanations or models are generally better than more complex models in statistics. Parsimony is based on the idea that the most accurate explanation of a phenomenon is the one that requires the least number of assumptions or variables.

The principle of parsimony is important in statistical modelling because it helps prevent overfitting and avoids including unnecessary or irrelevant variables in a model. Overfitting occurs when a model is too complex and fits the sample data too closely, resulting in poor performance when applied to new, unseen data. Parsimony can be achieved in a number of ways, depending on the type of statistical analysis performed. For instance, parsimony can be achieved by including only the variables most relevant to the outcome of interest, instead of including all possible variables. In hypothesis testing in regression analysis, parsimony can be achieved by choosing the simplest explanation that matches the data instead of more complex explanations that require additional assumptions.

A model that is too simple may not accurately capture the complexity of the phenomenon under study, while a model that is too complex may be too difficult to interpret and may not generalise well to new data. Therefore, it is important to use judgment and consider underlying theory, sample size and other relevant factors when determining an appropriate level of savings for statistical analysis.

In this study, it is difficult to analyse the theoretical model described in Chapter 3 as it is, so the theoretical model introduced above is simplified as follows for the econometric analysis, reflecting the limitations of the data collection.

In terms of the structure, the real estate market can be divided into the supply and demand sides, and the four-quadrant model again breaks down into user and investor subsectors on the demand side, and flow and stock development subsectors on the supply side. In the modelling process, the intention is to reflect this theoretical expression of the four subsectors into a functional form and these are expressed as four equations in the multi-equation system.

The modelling process of subsectors into a functional form has been presented above. Here, the explanation is provided, taking a closer look at the individual variables. Within the model system, real rent, new construction and spatial stock are both dependent variables and independent variables in different sectors. This reflects the theoretical explanation of the systematic interrelation described in the four-quadrant model. After one dependent variable within a subsector is determined by the independent variables, it becomes an explanatory variable for the dependent variables in the other subsectors. This represents the interaction between subsectors within the overall system.

Therefore, the model system consisting of four multi-equations is composed of exogenous variables that are determined externally and only affect one sector, and endogenous variables are determined within one subsector and affect other subsectors. The existence of endogeneity, that is, the impact of real rent, new construction and occupied stock on other subsectors as endogenous variables, is an element which justifies the use of the multi-equation model rather than the single equation model, from an economic perspective. From an econometric perspective, these three endogenous variables should be treated as dependent variables within the subsector and as independent variables in other subsectors, and for this reason, simultaneity should be reflected in the estimation process.

This research started from the four-quadrant model and developed with the inclusion of macroeconomic variables and consideration of the interaction of submarkets. While it shares similarities in terms of its multi-equation structure with its predecessors, namely Rosen (1984), Hekman (1985), Wheaton et al. (1997), and Hendershott et al. (1999), the model still differs from these in three main respects: the model formulation, the data structure and the estimation process.

Real rent is a determinant of new construction and occupied stock within the flow and stock development subsectors. The positive impact of rental fees on new construction represents the stimulation of new development in the supply flow subsector of the third quadrant when real rent increases. The negative impact of real rent on occupied stock indicates the decrease in occupied stock in the fourth quadrant due to increased vacancy caused by the high rental level.

New construction is a determinant of rent and occupied stock. The negative impact of new construction on rent indicates that when new supply increases, there is an oversupply of space demand, leading to a decrease in rent as the price paid for space use in the first quadrant. The positive impact of new construction on occupied stock signifies that the flow of new supply being supplied to the stock development subsector in the fourth quadrant increases the overall stock and, as a result, the occupied stock also increases.

Occupied stock is a negative determinant of real rent. Here, an increase in occupied stock does not occur under the condition of a constant total inventory, but rather represents an increase in occupied stock when the total stock itself is increasing. Therefore, it reflects an increase in the supply of space in response to spatial demand and, as a result, the excess supply in the first quadrant causes the rent to drop.

Each variable can be grouped in accordance with its subsectors. Real rent and take-up are classified as user subsector variables, yield and interest rate as investor subsector variables, and new construction, occupied stock and development permits as development subsector variables, respectively. Within the development sector variables, new construction represents the flow of supply changes within a specific period, while occupied stock represents the total supply:

- dependent variables: real rent, yield, new construction and occupied stock
- independent variables: gross domestic product (GDP), real rent, take-up, interest rate, new construction, occupied stock and development permits

(1) Dependent variables:

1) Real rent is a variable that is extensively discussed in the literature as the intersection of space supply and demand (Rosen, 1984; Hekman, 1985; Shilling et al., 1987; Wheaton and Torto, 1988; Gardiner and Henneberry, 1988, 1991; Dobson and Goddard, 1992; Hendershott et al., 1999; Wheaton, 1999; Chaplin, 1999; Tsolacos and McGough, 1999).

2) Yield is the least explored variable among the components of the four quadrants, and the probable reason for this is the difficulty of data collection and of reliable estimation from yield and explanatory variables (Hendershott et al.,1997; Dunse et al., 2007).

3, 4) Space supply has been modelled as flow and stock equations. While new construction (or construction orders) is largely adopted as the dependent variable (Wheaton, 1987; Giussani et al.,1993; D'Arcy et al., 1999; Hendershott et al., 1999; Tsolacos and McGough, 1999; Viezer, 1999), occupied stock (or total stock) is relatively less often used in the research (Rosen, 1984; Gardiner and Henneberry, 1988; Wheaton, 1999; Viezer, 1999).

(2) Independent variables:

1, 2) Gross domestic product (GDP) and employment are external macroeconomic variables that appear to have a positive impact on real rent in the office market (GDP: Gardiner and Henneberry, 1988; Giussani et al., 1993; D'Arcy et al., 1999 / Employment: Hekman, 1985; Wheaton, 1999).

3) Take-up represents the additional space consumed by demand-side users within the space supply and appears as a determinant of real rent (DiPasquale and Wheaton, 1999; Tse and Webb, 2003).

4) Interest rate is a positive determinant, and construction costs a negative determinant, of new construction. When interest rates increase, it raises construction costs and creates a burden for borrowers, leading to a decline in new construction (Rosen, 1984; Dobson and Goddard, 1992; Hendershott et al., 1996; Matysiak and Tsolacos, 2003; Tse and Webb, 2003). Risk-free interest

rates are also a component of yield. However, not many previous studies have addressed this variable, as previously mentioned.

5) Development permits comprise a key variable, closely related to office supply according to the theory, but, in empirical research, it has been considered in only a handful of studies due to difficulties in data collection and quantitative measurement (Hekman, 1985).

Construction costs (or replacement costs) comprise a variable frequently used as a key factor in previous studies but not included in this study due to the limited data availability (Rosen, 1984; Hekman, 1985; Hendershott et al., 1996; Tse and Webb, 2003).

Considering the variable selection criteria of previous studies, data availability and the principle of parsimony, the theoretical model established in Chapter 3 was reconstructed into the following four equations in a more suitable form for the regression analysis:

Initial model from section 3.2:

$r = f\,(v, \Delta EA, S, \Delta CV, \Delta OS\ Pl, NC)$ (9.1)
$v = f\,(r, I, \Delta EA, \Delta S, \Delta Pop, T)$ (10)
$CV_t = f\,(CV_{t-i}, O, S, NC)$ (15)
$\Delta S = f\,(r, v, i, \Delta EA, CC, T)$ (18.1)
$\Delta EA = f\,(I, \Delta S, \Delta GDP, \Delta RGDP, r)$ (20)

From section 3.2 (modelling subsections), equation (9) and (10):

$$r = f(v,\ \Delta \mathrm{EA},\ S,\ \Delta P, \Delta \mathrm{OS}, r_1,\ r_2,\ Pl,\ NC) \quad (9)$$

where r = rent, v = vacancy, EA = economic activity, P = price, OS = occupied stock, r1, r2 = relative rent in other sectors, Pl = planning policy and regime, and NC = network connectivity (general / financial service).

$$v = f\,(r, I, \Delta EA, \Delta S, \Delta Pop, T) \quad (10)$$

where v = vacancy, I = growth in service industry, Pop = population, and T = tax.

lrr = f (lgdpr (+), le (+), ltkpr (+), lcons (-), los (-)) (9.1)

Rent equation is derived considering the independent variables of equations (9) and (10). The dependent variable, real rent, represents the changes in the space subsector. As indicated in the Figure 10, changes in the external macroeconomy have an impact on spatial changes, and the proxies of economic activity, gross domestic product (GDP) and employment transmit their effects to the space subsector in the rent equation. Take-up explains how changes in the space subsector are transmitted to rents. New construction and occupied stock are flow and stock variables within the development subsector, indicating the effects of short-term and long-term changes in the development subsector on space, as illustrated in the Figure 10.

From equation (13):

$$y = f\left(r_f, r_p, g^e\ , d\right) \qquad (13)$$

where r_f = risk-free rate, r_p = risk premium, g^e = expected growth rate, and d = depreciation rate.

ly = f (li (+))   (13.1)

In the second equation, yield is the dependent variable which represents the functioning process of the investment subsector, and the risk-free interest rate is selected as an independent variable based on equation (13). Due to data limitations, the transmission process of effects from the space or development subsectors shown in the Figure 10 is not included in this equation. Instead, the independent variable of the interest rate is expressed as having an impact on the flow and stock variables in the development subsector, representing the transmission of effects from the investment to the development subsector.

From equation (17):

$$\mathrm{OS} = S(1 - v) \qquad (17)$$

where S = supply, v = vacancy.

From equation (18):

$$\Delta S = f(r^*(or\ CV^*),\ v, i,\ \Delta \mathrm{EA},\ CC,\ T) \qquad (18)$$

where ΔS = changes in stock, r* = equilibrium rent, v = vacancy, i = interest rate, EA = economic activity, CC = construction cost, and T = tax.

lcons = f (lrr (+), le (+), li (-), ldev (+))   (16.1)

In the third equation, new construction is used as a proxy for the development flow, which represents changes in the stock. As shown in Figure 10, changes in the space subsector are transmitted to the development subsector in the short term, and in this equation, real rent represents the transmission effect. Since employment is identified in Figure 10 as an external macroeconomic variable affecting spatial changes, it stimulates new construction. The effect of changes in the investment subsector on the development subsector in the short term is expressed through the interest rate. Additionally, the development variable, serving as a proxy for planning policy, influences new construction within the development subsector.

In the third equation, new construction is used as a proxy for the development flow, which represents changes in the stock. As shown in Figure 10, changes in the space subsector are transmitted to the development subsector in the short term, and in this equation, real rent represents the transmission effect. Since employment is identified in Figure 10 as an external macroeconomic variable affecting spatial changes, it stimulates new construction. The effect of changes in the investment subsector on the development subsector in the short term is expressed through the interest rate. Additionally, the development variable, serving as a proxy for planning policy, influences new construction within the development subsector.

From equation (16):

$$OS = f\left(E, \frac{r}{CV}\right) \qquad (16)$$

where OS = occupied stock, E = employment, r = rent, and P = price.

los = f (lrr (-), li (-), lcons (+), ldev (+)) (18.1)

In the fourth equation, occupied stock represents the stock variable in the development subsector. Changes in the space subsector, as shown in Figure 10, are transmitted to the development subsector in the long term, and in this equation, real rent represents the transmission effect. The effect of changes in the investment market on the development sector in the long term is expressed through the interest rate. Additionally, within the development sector, long-term adjustments in the stock variable occur, and in the equation, development, serving as a proxy for new construction and planning policy, is assumed to fulfil this role.

The changes below have been made following the empirical modelling processes.

- Rent equation (equation 1): This equation considers factors such as economic activity, space stock and occupied stock to determine rental rates. Vacancy rate and capital value are excluded from this equation, while connectivity is not considered.

- Vacancy rate equation: In consideration of the autocorrelation with rent equation, the vacancy rate equation is excluded from the empirical model.

- Yield equation (equation 2): This equation replaces capital value with yield as the dependent variable. It takes into account the relationships with the interest rate and previous capital value. Variables such as office output, space stock and connectivity are excluded.

- New construction equation (equation 3): This additional equation examines the flow aspect of the development sector. It includes variables such as rent and employment, along with the interest rate and development permits, to determine the level of new construction.

- Occupied stock equation (equation 4): This equation considers rent and employment as variables, replacing economic activity. The construction cost is replaced with the interest rate, and the tax rate is excluded. This equation also incorporates development permits.

- Economic activity: The empirical model excludes economic activity as an endogenous variable within the system. Instead, economic activity is treated as an exogenous variable due to limited data availability.

Thus far, the modelling process for empirical analysis has been modified in the following manner:
In the user subsector, the rent equation (9) is modified to equation (9.1), and vacancy rate identity (11) and natural vacancy rate equation (12) are excluded. The reason for the exclusion of the vacancy rate in (11) and (12) are in consideration of multicollinearity with the rent variable and limitation of vacancy data, as it is collected on an annual basis (Table 4). In the investment subsector, yield equation (13) is modified to equation (13.1), and valuation identity (14) remains the same, while the capital value equation (15) is excluded due to data limitations (annual-based). In the development subsector, occupied stock (16) and stock change (18) equations are respectively modified to equation (16.1) and (18.1). Occupied stock (18) and stock adjustment equations are retained to explain the changes in space stock. With regard to external factors, the economic activity change (20), employment (21), service industry growth (22) equations are excluded because independent variables are unavailable for these equations. Consequently, the external factors play their role as exogenous variables in the system equations.

Thus, the modified model now operates with the following rent (9.1), yield (13.1), new construction (16.1), and occupied stock (18.1) equations:

lrr = f (lgdpr (+), le (+), ltkpr (+), lcons (-), los (-)) (9.1)
ly = f (li (+)) (13.1)
lcons = f (lrr (+), le (+), li (-), ldev (+)) (16.1)
los = f (lrr (-), li (-), lcons (+), ldev (+)) (18.1)

In addition, vacancy rate (11), valuation (14), occupied stock (17), and stock adjustment (19) defines the relationship between variables and subsectors:

$$v = (S - OS) / OS \quad (11)$$
$$r / y = CV \quad (14)$$
$$OS = S (1 - v) \quad (17)$$
$$S_t = S_{t-1} + \Delta S_t \quad (19)$$

With regard to the inclusion of identities in the empirical model, Wheaton (1987) adopts three identities of net absorption, occupied space, stock; moreover, Wheaton et al. (1997) used three identities—capital stock, vacancy rate, and occupied stock. In contrast, Hendersott et al.'s (1999) model has four identities—capital stock, vacancy rate, occupied stock, and equilibrium rent. Their fourth identity, $RR_t^n = (RC_t + \delta + OE_t)CR_t$, links the user and investment subsector; thus, their model has an advantage in the explanation of the operation of the investment subsector (Hendersott et al., 1999; Ball et al., 1999). In comparison, equation (13.1) links investment and development (flow and stock) subsectors, and identity (14) connects user and investment subsectors in the system.

As earlier discussed in this subsection, this study is based on a theoretical background and conceptual framework that is similar to that in Wheaton et al. (1997) and Hendershott et al. (1999) in terms of the use of the four-quadrant model. However, recognising the gap between the theoretical background and empirical analysis from existing research, as attempted by Henneberry et al. (2005), a four-equation system is constructed that includes the investment subsector. Additionally, following Henneberry et al.'s (2005) suggestion that planning factors play a significant role in the real estate market—despite the lack of empirical analysis cases reflecting this—we included planning variables in the supply sector as part of the factors that constitute the system.

Multi-equation models primarily deal with single subsectors and are differentiable from static single equation models. More recent single equation models, such as ECMs, aim to empirically demonstrate the process of achieving equilibrium—including short-run adjustments and long-term convergence toward balance—while analysing dynamic factors. In contrast to ECMs, multi-equation models are fundamentally different in that they establish endogenous and exogenous variables based on the theoretical background of the office market within the system. These multi-equation models approach the explanation of sectoral linkage and interaction assuming simultaneity among subsectors, thereby aiming to explain these aspects through their methodology.

Regression models which analyse the relationships among variables assume independence in general. Campbell and Shiller (1987, 1991) proposed a method for simultaneously analysing changes in variables using cointegration when each variable is an integrated time series of order one, but their differences form a stationary time series. Analysing variables that exhibit endogeneity using such models can lead to biased estimators. In contrast, the 2SLS or 3SLS methods can account for the dependence among endogenous variables. As the sample size increases, the estimators of endogenous variables eliminate the correlation among error terms and produce consistent estimates.

Taking into account the changes in the data (section 4.3), the operational process of the modified multi-equation econometric model, with real rent as the focal point, can be expressed as presented in Table 7. Key variables in each subsector are included in this system, based on the four-quadrant theory, and macroeconomic variables and less important variables are presented in the descriptive statistics.

Table 7. Operation of multi-equation in perspective of rent

Sector	dependent variable	Independent variable - Interdependent	Independent variable - predetermined
User	real rent	**new construction (+), occupied stock (+)**	***GDP (+), employment (+), take-up ratio (+)***
Investment	**yield**		*interest rate (-)*
Development	**new construction**	real rent (+), employment (+)	*interest rate (-), development completion (+)*
	occupied stock	real rent (-), new construction (+)	*interest rate (-), development completion (+)*

Table 7 presents how the subsectors, independent variables, and dependent variables interact under the modified four-equation system, centring on the rental rates in the user market (shaded). Variables in bold are those that directly affect rental rates, including the independent variables of the rent equation and the dependent variables of other subsectors (note that yield does not directly affect rental rates within this equation system, but is presented in bold because it is a component of the identity capital value = rent/yield). Variables that are underlined are the independent variables in the equations for yield (investment sector), new construction (development sector, flow), and occupied stock (development sector, stock). These variables first act as determinants of the dependent variables in their respective subsectors. Further, the dependent variables, excluding rental rates, are presented in bold because they directly influence rental rates. Thus, the underlined variables indirectly affect rental rates by first influencing the dependent variables in their subsectors, which then serve as determinants of the actual rental rates.

Additionally, among the independent variables, those on the left with interdependent characteristics are endogenous, while those on the left in italics are predetermined variables with exogenous characteristics. For example, rent is determined by the independent variables in the rent equation, which include new construction and occupied stock variables. Rent affects these dependent variables in the new construction and occupied stock equations, thus creating an interdependent relationship. The same applies to the employment variable in the new construction equation and the new construction variable in the occupied stock equation. Thus, interdependent variables not only directly impact the dependent variables in their respective sectors but also indirectly influence other sectors through these dependent variables.

On the right, the interest rate and development completion are not determined within the system; thus, they do not directly impact rent but only have indirect effects. For example, the interest rate acts as a determinant in the yield, new construction, and occupied stock equations. Since new construction and occupied stock variables serve as independent variables in the rent equation, the interest rate indirectly influences rent through new construction and occupied stock.

The structure of the model, composed of four equations, is based on the simultaneity of the simultaneous equations mentioned earlier. This foundation allows for reflecting the direct and indirect impacts of constituent variables on rent within the office market's functioning process, thereby explaining the complexity of the rent determination process. Consequently, considering the simultaneous equations in the forthcoming econometric estimation process becomes a crucial task to ensure the consistency of the estimates.

4.4 Methods of Estimation, Diagnostic Testing and Modelling Strategy

This research was conducted using (1) the multi-equation model, (2) theoretical in statistical methods, and (3) a continent-level analysis. European market studies have rarely been conducted using (1) and (2), while Hekman (1984) and Rosen (1985) used these for the US market. Although (3) has some precedents (Brounen and Jennen, 2008; Brooks and Tsolacos, 2008; Giussani et al, 1993), these researchers concentrated on specific topics of subsectors, and did not deal with the comprehensive market. Therefore, this research study is more complex and theoretically solid compared to previous studies.

4.4.1 Quantitative Methods

When it comes to qualitative research, (at least) one central question and several sub-questions are posed. These tend to focus on one major phenomenon of interest, and comprehensive and general research questions are presented for research participants to explain their ideas well.

By comparison, quantitative research starts with research questions or hypotheses in general. In contrast to qualitative research, the research questions or hypotheses contain variables, which are measurable and classified into groups for comparison. Hypotheses can be stated in the form of null hypotheses, indicating that there is no expected difference or no relationship between the two groups and the dependent variable (Creswell, 2017).

Parameters, that is, the properties of the sample population, are of interest for quantitative researchers: A sample is observed instead of the population because observation of the entire population is impossible. In empirical research, the properties of the sample are required to be identified after the process of data collection and the building of a model. Estimation refers to the process of obtaining the number of participants corresponding to the parameters of the sample, and the estimate is a value obtained from the actual data through estimation.

The main purpose of regression analysis is the prediction of the dependent variable based on the given explanatory variables. The presence or absence of explanatory power can be obtained from the analysis, and the explanatory power of regression model will increase when more explanatory variables are included, unless the explanatory variables are in a perfectly linear relationship with each other.

In empirical analysis, the cyclicality of the real estate market is a consideration factor related to the selection of the observation period.

If the observation period is too short, it may not sufficiently reflect the phenomenon of short-term adjustments in the real estate market converging to long-term equilibrium. This can prevent the achievement of research objectives aiming to explain the overall market equilibrium due to the rigidity of supply in the real estate market. Moreover, economic cycles within the real estate market are known to occur based on cycles ranging from four to five years (Barras, 1994) to nine to ten years (Wheaton, 1987; Leitner, 1994). Considering this aspect, obtaining time-series data for at least 10 years is meaningful.

Compared to qualitative research, quantitative research has the advantage of sample selection and comparison, as this study conducts analyses based on established theories. The availability of the main variables mentioned in Figure 10 are reviewed. To further explain the advantage of the quantitative method from the perspective of levels of measurement—that is, nominal, ordinal, interval, and ratio—the dataset in this study is constructed in the form of ratios; this feature differentiates it from a qualitative method in terms of sampling from the population, derivation of the statistical result and its significance (for example, 95% significance level), and the validity of the model determined by conducting various diagnostic tests.

Generally, data can be classified into categorical (qualitative) and numerical (quantitative) types. Based on the scale, categorical data can be further divided into nominal and ordinal scales, while numerical data can be divided into interval and ratio scales. Among these, the nominal scale represents categories; the ordinal scale represents categories and ranks; the interval scale represents categories, ranks, and intervals; and the ratio scale represents categories, ranks, intervals, and an absolute zero. Interval and ratio scales—which are types of numerical data—can be quantified and averaged, thereby enabling the transformation or manipulation of data (Shadish et al., 2002).

Tables 3 and 4 in Section 4.3.2 present the proxy variables, data sources, availability, and units that will be used in this study, corresponding to the theoretical variables. All these variables commonly employ the ratio scale.

Additionally, the basic condition for using ordinary least squares (OLS), the most common estimation method in regression analysis, is the assumption that the model is linear. More specifically, linear regression requires that the parameters are linear, but it does not necessarily require that the variables are linear (Brooks and Tsolacos, 2009). In linear regression analysis, the function is typically composed in the form of a dependent variable y and an explanatory variable x, with the aim of exploring the influence of x on y. When there is only one explanatory variable, it is called simple linear regression, and when there are multiple explanatory variables, it is called multivariate linear regression. By using multivariate linear regression, multiple explanatory variables can be included to explain the dependent variable. This enables a detailed analysis of the phenomenon based on the results of regression analysis and estimation using the linear model, thereby enabling the acceptance or rejection of hypotheses.

Therefore, this study aims to explore the dynamic determinants of office rents in Europe by implementing an experimental design phase based on the characteristics of the collected data as continuous data and ratio scales. Using real estate economics as the theoretical background and econometrics as the empirical analysis tool, this study assumes the existence of simultaneity (which is a particular type of endogeneity) as an analytical tool to identify dynamic factors in the office market. Then, to explain the subsectors, functions for empirical analysis are formulated in the form of multi-equations.

After deriving the results from the empirical analysis through the above process, implications are drawn to ensure the internal validity of the study. Given the nature of experimental research, the research model operates under the economic constraint of ceteris paribus, which may limit its external validity. Nevertheless, the objective is to demonstrate that this research can possess a certain level of external validity by suggesting how it can be expanded and applied in the future.

From the methodological perspective of quantitative research, the ECM is based on time series analysis. Consequently, it has advantages in testing the stability of the sample and in explaining the convergence process to long-term and short-term equilibrium using reduced form equations.

On the other hand, the multi-equation model—based on the structural equation analysis method—is useful for explaining the endogeneity and exogeneity of variables within the model and their interactions. This advantage arises because—unlike the ECM, which uses a reduced-form equation and cannot adequately explain the correlation between error terms—the multi-equation model considers the correlations among error terms within each equation. Therefore, to estimate this model using econometric methods, it is appropriate to simultaneously estimate the model using 3SLS. Additionally, to verify the validity of the multi-equation model, it is important to conduct a model identification test to determine whether the model is adequately identified or overidentified.

4.4.2 Methods of Estimation

As mentioned, the purpose of estimation is to infer the sample most closely resembling the population, that is, a set of unobserved actual values. In regression analysis, ordinary least squares (OLS) is the most efficient estimator when the given assumptions are satisfied but it is often the case in empirical studies that the assumptions are violated. Therefore, generalised least squares (GLS), which eases the strict assumptions of OLS, will be estimated and compared with OLS. Since this research aims to investigate the rental determinants of multiple cities over more than a decade, it needs to consider the combined impacts of cross-section and time-series in the estimation process. Random effects and fixed effects panel models will be estimated based on this perspective. The linkage and interaction of real estate submarkets is another interest of the analysis, and multi-equation will be simultaneously estimated for this reason. The estimation result will be compared with other single equation estimations, which present submarket estimation results individually. Lastly, the generalised method of moments (GMM) based on the maximum likelihood estimation (MLE) will be performed in comparison with the least squares estimation methods.

4.4.2.1 OLS

(1) Characteristics of OLS Estimation

First, the characteristics of the least squares method and OLS estimation will be introduced.

The least squares method draws a straight line for given data. With this method, the intercept and slope are determined to make the sum of the squares of the vertical distances from each point to the straight line the smallest.

There are numerous possible straight lines which represent the relation between the dependent variables and the independent variables, and the straight line passing through the centre of all data is the closest (i.e., most suitable) line to all data, on average. Therefore, the degree of prediction error is the least if the straight line passes through the centre of the data, $\hat{Y} = aX + b$. Since predicted errors of the total sum of squares are minimised, the slope a and intercept b satisfy the least squares criterion. A least squares regression line is the prediction line with a slope and an intercept which meet this mathematical condition. A basic form of least squares is called the ordinary least squares (OLS), meaning that it is the standardised estimation method of least squares.

When deviated estimators from the sample observation are squared and summed, this value indicates the extent to which predicted dependent variables deviate from the sample mean, which is called the total sum of squares (TSS). The TSS is composed of two components, the explained sum of squares (ESS) and the residual sum of squares (RSS).

TSS = ESS + RSS

$$R^2 = \frac{RSR}{TSS} = 1 - \frac{ESS}{TSS}$$

$$adjusted\ R^2 = 1 - \frac{ESS/(N-K)}{TSS/(N-1)}$$

Basic assumptions are required for the regression model to ensure estimators have desirable properties and to test the hypothesis of the model. For this reason, the following assumptions of the classical linear regression model (CLRM) are necessary for the multiple regression analysis (Judge et al., 1985; Gujarati, 2004; Maddala and Lahiri, 2009; Hill, 2017):

1. x_j are observations of the random variable X, and X is a non-stochastic constant or independent of the error term ($Cov(\varepsilon_i, x_j) = 0$).
2. The error term ε_i is a random variable, and its mean is 0 ($E(\varepsilon_i) = 0$).
3. Error terms ε_i are not correlated with each other ($Cov(\varepsilon_i, \varepsilon_j) = E(\varepsilon_i, \varepsilon_j) \neq 0$).
4. Variances of the error term ε_i are all the same for all x_j, which means variances are homogeneous ($Var(\varepsilon_i) = E(\varepsilon_i^2) = \sigma^2$).
5. Error terms ε_i are not correlated with each other, and ε_i should be normally distributed to conduct a hypothesis test (non-autocorrelation).

Linear relations do not exist between the independent variables. Under this assumption, it is impossible to find a set $c_0, c_1, c_2, \cdots, c_k$ which satisfies $c_0 + c_1x_1 + c_2x_2 + \cdots + c_kx_k = 0$ and non-zero (non-multicollinearity).

Under the condition that CLRM assumptions are satisfied, OLS estimators are the best linear unbiased estimators (BLUE). This theoretical property is called the Gauss–Markov theorem.

(2) OLS Diagnostic tests

The previous subsection explains that OLS estimators are BLUE in terms of the Gauss–Markov theorem. However, these basic assumptions can often be violated in empirical research. For this reason, it is important to understand the problems and to find appropriate solutions for the violation of one or more of the basic assumptions.

1) Multicollinearity

Multicollinearity is detected when there is no perfect linear relationship between the independent variables and a set of non-zero numbers is found. In other words, multicollinearity exists if the explanatory variables are correlated with each other. Although the least squares estimator is BLUE, the standard error of estimators tends to increase in this case. As a result, it is more likely that the inference of regression parameters goes wrong under these circumstances.

The VIF test provides a statistic which determines the presence of multicollinearity. It is defined as the ratio of actual coefficients variance to coefficients with complete variance (i.e., no multicollinearity) (Gujarati, 2004; Hill, 2017).

$$VIF = \frac{1}{(1-R_k^2)}$$

R_k^2 is a determinant coefficient which takes the k-th independent variable as its dependent variable, and all other independent variables as explanatory variables. As R_k^2 approaches 1, the VIF value increases and there is a greater possibility that multicollinearity exists in the regression model.

VIFs range from 1 to infinity, where a VIF of 1 indicates no multicollinearity and a VIF greater than 1 indicates an increasing level of multicollinearity. A VIF of 1-2 indicates low or no multicollinearity, and a VIF greater than 5–10 indicates a high degree of multicollinearity. Generally, VIFs greater than 10 are considered problematic and may require remedial action, such as removing one or more highly correlated variables or combining them into a single variable (Marquardt and Snee, 1975).

The Ramsey regression equation specification error (RESET) test is another statistical test used to determine whether a linear regression model correctly captures the relationship between independent and dependent variables. Specifically, the RESET test examines whether there is evidence of missing variables, functional form errors, or non-linearity in the regression model (Gujarati, 2004):

$$RESET\ test = \frac{(R^2_{new} - R^2_{old})/number\ of\ new\ regressors}{(1-R^2_{new})/(n - number\ of\ parameters\ in\ the\ new\ model)}$$

To perform the test, the linear regression model is fitted to the data, and residuals are obtained. A new regression model is then estimated by adding a polynomial or interaction term containing the original regressor and the residuals from the first regression. If the new regression model significantly improves the fit compared to the original model, it indicates that the original model is misspecified.

The RESET test can be performed using a variety of statistical tests, such as F-tests, t-tests, or likelihood ratio tests, depending on the specific form of the surrogate model being tested. This test is used as a diagnostic tool to evaluate the validity of a linear regression model and to identify potential sources of bias or problems with omitted variables. The RESET test is a useful technique in statistics to check the adequacy of a linear regression model by detecting the presence of omitted variables, non-linearity, or functional morphological specifications. If the RESET test indicates that the original model has problems, one may need to modify the model to get better results (Ramsey, 1969).

2) Normality

The normal distribution of error terms is an assumption required for regression model inferences, including parameters' significance test and confidence intervals' estimation. Even though error terms are not normally distributed, OLS is still BLUE if it satisfies the properties of a desirable estimator.

The Jarque–Bera test measures degrees of asymmetry (skewness) and flatness (kurtosis) of random variables, and the normality assumption can be tested by the following test statistic (Bera and Jarque, 1981):

$$Jarque - Bera\ test = \frac{n}{6}\left[S^2 + \frac{(K-3)^2}{4}\right]$$

where n is the sample size, S is the sample skewness, and K is the sample kurtosis. Under the null hypothesis of normality, the Jarque–Bera test statistic follows a chi-square distribution with two degrees of freedom.

The Jarque–Bera test is based on the skewness and kurtosis of the data. Skewness indicates how skewed the data are, and kurtosis measures the peaks or flatness of a distribution compared to a normal distribution. For a normal distribution, the skewness is 0 and the kurtosis is 3. If the computed test statistic exceeds the critical value of the chi-square distribution table, then the null hypothesis of normality is rejected, indicating that the sample is not normally distributed (Bera and Jarque, 1981).

3) Heteroscedasticity

If the variances of the error terms are not the same for all independent variables, the assumption of homoscedasticity is violated. A violation of this assumption is called heteroscedasticity, and the distribution of the residuals tends to either increase or decrease, since variances of error terms are not constant. Under the condition of heteroscedasticity, OLS is still unbiased but not an efficient estimator.

The Breusch-Pagan and Cameron-Trivedi tests are used to check for heteroscedasticity, and the tests confirmed the existence of heteroscedasticity in all subsectors (Breusch and Pagan, 1979; Cameron and Trivedi, 1990). The Breusch-Pagan test involves regressing the squared residuals of the original regression model on the independent variable. Statistically significant independent variable coefficients in the new regression model indicate heteroscedasticity in the original regression model, that is, the variance of the residuals is related to the value of the independent variable.

The test statistic for the Breusch-Pagan test is calculated as follows:
$BP = n \cdot R^2$
$nR^2 \sim \chi^2_k$

where n is the sample size and R^2 is the coefficient determined from the regression of the squared residuals on the independent variable.

Under the null hypothesis of equal variance, the test statistic follows a chi-square distribution with degrees of freedom equal to the number of independent variables in the regression model. If the computed test statistic exceeds the critical value of the chi-square distribution table, then the null hypothesis of equal variances is rejected, indicating that the regression model has evidence of heteroscedasticity (Breusch and Pagan, 1979).

The Cameron-Trivedi test involves estimating a Poisson regression model and comparing it to a negative binomial regression model. Poisson regression models assume equal variances, while negative binomial regression models allow for overdispersion. Testing involves comparing the variance statistics of the two models.

Deviance is a measure of goodness of fit of a model and is calculated as the difference between the log likelihood of the full model and the log likelihood of the null model. The null model is the model with only the intercept, and the full model is the model under test with all predictors included.

The Cameron-Trivedi test statistic is calculated as follows:

$CT = (D_P - D_{NB}) / (df_{PP} - df_{NB})$

where D_P and D_{NB} are the deviation statistics for Poisson and negative binomial models, respectively, and df_{PP} and df_{NB} are the degrees of freedom for Poisson and negative binomial models, respectively.

Under the null hypothesis of equal variances, the test statistic follows a chi-square distribution with degrees of freedom equal to the difference in degrees of freedom between the Poisson and negative binomial models. If the calculated test statistic exceeds the critical value of the chi-square distribution table, then the random hypothesis is rejected, indicating evidence of overdispersion in the count data (Cameron and Trivedi, 1990).

4) Autocorrelation

Autocorrelation happens when error terms are correlated with each other; this is possibly caused by a slow adjustment process or inertia of sample data, or errors in the modelling process. The existence of autocorrelation implies that residuals are in a certain functional relationship. Durbin-Watson's d statistic is a test for autocorrelation which detects such functional relations. The d statistic is defined as the sum of squares of residuals' increments divided by the sum of squares of residuals (Durbin and Watson, 1950, 1951, 1971).

$$d = \frac{\sum_{t=2}^{n}(e_i - e_{i-1})^2}{\sum_{i=1}^{n} e^2{}_i}$$

4.4.2.2 GLS

(1) Characteristics of GLS Estimation

It is hard to detect the existence of heteroscedasticity and autocorrelation in the error term. Certain assumptions are usually made about the structure of heteroscedasticity and autocorrelation, and unknown parameters are then estimated. The estimation would be inefficient when the assumption is not correct, but at least still more efficient than OLS. If the sample is large enough, reasonable inference in the approximate level can be made with a robust standard deviation.

When the variances of error terms are different from each other, the assumption of equal variance is violated, and the distribution of errors is called heteroscedastic. Under the assumption that the sample of explanatory variables is fixed, it can be expressed that the VAR ($u \mid X_1, \ldots, X_k$) depends on $X_1, \ldots, X_k$ in the population.

If all other OLS assumptions are satisfied while the error term is heteroscedastic, the least squares estimator is still unbiased. However, t and F statistics are not distributed properly and thus invalid under the null hypothesis because the variance equation derived under the assumption of equal variance is incorrect. The problem cannot be solved, even if sample size is large enough. The assumption of the equal variance of error terms is an essential part of the Gauss–Markov theorem, and OLS is no longer BLUE if the error term is heteroscedastic. As a result, there is a more efficient linear unbiased estimator than the OLS.

Generalised least squares is a method used to estimate models with heteroskedasticity and/or serial correlation in the error terms. It generalises the OLS by weighting the squared residuals with a weight matrix that takes into account the correlation and heteroscedasticity of the errors. Generalised least squares aims to transform the error term into a form that satisfies the classical linear regression assumptions, so that the OLS estimator can be applied to the transformed model (Maddala, 1971). Weight matrices can be estimated using a variety of approaches, such as the feasible GLS (FGLS) or maximum likelihood (ML) methods. In FGLS, the weight matrix is estimated using the residuals estimated from the preliminary OLS regression, whereas in ML, the weight matrix is estimated by maximizing the likelihood function of the model.

Generalised least squares is more efficient than OLS when the errors are heteroskedastic or correlated because it takes account of information in the covariance structure of the errors. However, GLS requires knowledge of the covariance structure of the errors, which can be difficult to obtain in practice. Conversely, OLS is easy to implement and is widely used when classical assumptions are met.

4.4.2.3 Panel Fixed Effects

(1) Characteristics of Panel Fixed Effects Estimation

Panel estimation is a method which observes individual cross-sectional units (i) over multiple time periods (t). That is, time-related effects should be considered in panel estimation, as they are different from previous estimations, which only take account of cross-section individuals. In the cross-section model, variables are classified as endogenous or exogenous variables according to their correlation with an error term. Since the time dimension is also considered in the panel estimation, it yields additional correlation issues between variables and time-variant (i.e., past, current or future) error terms.

Apart from the explained variables, each subject can have missing components for each period which constitute random errors. In the panel model, it is possible to identify the unobserved effects in several ways:

(i) Unobserved, subject-specific random error factors (u_i). They are unobserved and/or unmeasurable, time-invariant individual properties, and also called unobserved heterogeneity.

(ii) Unobserved and/or unmeasurable individual time-varying factors (e_{it}). They are unobserved and/or unmeasurable individual time-varying factors, and also called idiosyncratic errors.

(iii) Time-specific (i.e., varies over time) but individual invariant elements (m_t) (Hill, 2017).

The following are numerical expressions of a simple panel regression model and its error term in order:

$$y_{it} = \beta_1 + \beta_2 x_{2it} + \alpha_1 w_{1i} + (u_i + e_{it}) = \beta_1 + \beta_2 x_{2it} + \alpha_1 w_{1i} + v_{it}$$

$$v_{it} = u_i + e_{it}$$

The equation above is an error components model, and it presents two types of errors, the individual time-invariant (u_i) and the random error (e_{it}) components model. The time-invariant term has a random effect, and a random error does not have heteroscedasticity or autocorrelation. The variable should not be correlated with both time-invariant and random error terms to fulfil the assumption that a variable is independent of the error term. If a time-invariant error does not exist, this means that the pooled OLS is BLUE, so that there is no advantage in a panel estimation over OLS. On the other hand, pooled OLS estimators are not efficient if temporal correlation exists between error terms, even though error terms are not correlated with independent variables.

Panel models are classified into two types, random effects and fixed effects models, according to the existence of correlation between time-invariant errors and explanatory variables. They are referred to as fixed effects panel models if the time-invariant error term is correlated with independent variables, and as random effects panel models if it is not.

If the unobserved heterogeneity term u_i is correlated with more than one explanatory variable, fixed effects is used because the estimators converge to the true population parameter as the sample size increases. Under the fixed effects model, a potential endogeneity issue (due to the correlation between unobserved heterogeneity and explanatory variables) is eliminated by removing unobserved heterogeneity. Subject-specific dummy variables are included in the model to control for unobserved heterogeneity. The fixed effects model is also called a least squares dummy variable model for this reason. The numerical expression of the model is as follows (Hill, 2017):

$$y_{it} = \beta_{11}D_{1i} + \beta_{12}D_{2i} + \beta_{1N}D_{Ni} + \cdots + \beta_2 x_{2it} + \beta_K x_{Kit} + e_{it}$$

Assumptions required for fixed effects estimation are as follows:

1. The regression function of the population is $y_{it} = \beta_1 + \beta_2 x_{2it} + \cdots + \beta_K x_{Kit} + (u_i + e_{it})$, where x_{kit} is time and individual variant, e_{it} is time and individual invariant, and u_i is individual-variant but time-invariant variable.
2. $E(u_i|\boldsymbol{X}_i, \boldsymbol{w}_i) \neq 0$. There is no information to predict e_{it} in either explanatory variable values or unobserved heterogeneity. This is a strict exogeneity assumption.
3. $var(e_{it}|\boldsymbol{X}_i, u_i) = var(e_{it}) = \sigma_e^2$. The random error e_{it} is homoscedastic.
4. (i) Since variables are randomly extracted from the population, e_{it} and e_{js} are statistically independent.
   (ii) If $cov(e_{it}, e_{js}|\boldsymbol{X}_i, u_i) = 0$ and t≠s, then random error e_{it} is serially uncorrelated.
5. Exact collinearity does not exist, and all observable variables exhibit fluctuations.

(2) Panel Fixed Effects Diagnostic Tests

1) Lagrange Multiplier (Breusch-Pagan) Test

The Lagrange multiplier (LM) test is a hypothesis test which measures how well the estimated value obtained under constraints satisfies the estimation conditions of an unconstrained model. Lagrange multiplier statistics can be obtained by following the following steps (Gujarati, 2004; Brooks and Tsolacos, 2010):

(i) Estimate the constrained model;
(ii) Regress the obtained residuals for all explanatory variables of the unconstrained model (unconstrained auxiliary regression); and
(iii) Multiply the sample size by the R^2 obtained from the auxiliary regression (nR^2_{aix}).

The residuals under constraints should be similar to the residuals without constraints if the constraints are correct. The values of R^2 and nR^2_{aix} will be small when residuals under constraints are regressed for all explanatory variables (Breusch and Pagan, 1980).

Under the null hypothesis that the constrained model is correct, the test statistic follows a chi-square distribution equal to the difference in the estimated number of parameters between the model with unconstrained degrees of freedom and the constrained model. If the calculated test statistic exceeds the critical value of the chi-square distribution table, the null hypothesis is rejected, indicating that the unrestricted model fits the data better than the restricted model.

Lagrange multiplier tests can be used to test a wide range of hypotheses in regression analysis, including the importance of individual variables, the overall goodness of fit of the model, and the presence of misspecification or heteroscedasticity. However, although the LM test assumes that the model is correctly specified under the null hypothesis, this may not be the case under some circumstances. Additionally, tests can be sensitive to small sample sizes and outliers in the data. Therefore, it is important to evaluate the assumptions of the test and the properties of the data before applying the LM test (Breusch and Pagan, 1980).

2) Wald Test

The purpose of the Wald test is to measure how well the unconstrained estimate fits the constrained equation. This test is based on the maximum likelihood estimation principle, which involves finding a set of coefficients that maximize the likelihood of the observed data for a given model. The Wald test compares the estimated coefficients with their respective standard errors (Judge et al., 1985; Hill, 2017).

The test statistic is calculated as the ratio of the square of the estimate coefficient to the square of the standard error:

$$W = (b - b_0)^2 / (SE^2)$$

where b is the estimated coefficient, b0 is the assumed value (typically 0) and SE is the standard error of the coefficient.

Under the null hypothesis that the coefficient is equal to its hypothesized value, the test statistic follows a chi-square distribution with one degree of freedom. If the computed test statistic exceeds the critical value of the chi-square distribution table, the null hypothesis is rejected, indicating that the coefficient is significantly different from zero. The Wald test is often used in regression models to test hypotheses about the significance of individual coefficients or to test the significance of groups of coefficients. It is used to test a wide range of hypotheses in regression analysis.

3) Hausman Test

In the random effects model, parameters of OLS and the GLS estimators are biased and do not coincide when the random error $v_{it} = u_i + e_{it}$; they are correlated with the explanatory variables. Since the subject-specific error u_i can be correlated with explanatory variables, this problem can often occur in the random effects model.

The Hausman test compares estimated values of fixed and random effects models, and this is valid if the following random effects covariance assumptions are true (Hausman, 1978; Hausman & Taylor, 1981, 1983; Hill, 2017):

$$E(u_{it}, u_{js}) = \sigma_\mu^2 + \sigma_\varepsilon^2, \; i = j, t = s$$
$$E(u_{it}, u_{js}) = \sigma_\mu^2, \quad i = j, t \neq s$$
$$E(u_{it}, u_{js}) = 0, \quad i \neq j$$

$$t = \frac{b_{FE,K} - b_{RE,K}}{[(se(b_{FE,K})^2 - se(b_{RE,K})^2]^{1/2}}$$

$$var(b_{FE,K} - b_{RE,K}) = var(b_{FE,K}) - var(b_{RE,K})$$

The fixed effects (FE) model assumes that individual effects are fixed and do not change over time. On the other hand, random effects (RE) models assume that individual effects are random and change over time. The Hausman test compares the difference between FE and RE estimators to determine whether the random effect assumption is appropriate. It tests whether the coefficients of the FE model are consistent (efficient) with those of the RE model. The test statistic for the Hausman test is calculated as the difference between the coefficients of the two models divided by the standard error of the difference. If the test statistic is statistically significant, this indicates that the RE model is inconsistent, and the FE model should be used instead.

4.4.2.4 Panel Random Effects

(1) Characteristics of Panel Random Effects Estimation

A random effects model refers to a panel model with unobserved heterogeneity (u_i) because differences of individual variables are probabilistic. It takes account of the covariance of errors within observations for each subject resulting from unobserved heterogeneity. Under the random effects, GLS is an efficient estimator with minimum variance, and a GLS estimator can be obtained from OLS transformation (Hill, 2017).

The assumptions required for random effects estimation are as follows:

1. $y_{it} = \beta_1 + \beta_2 x_{2it} + \cdots + \beta_K x_{Kit} + \alpha_1 w_{1i} + \cdots + \alpha_M w_{Mi} + (u_i + e_{it})$, where x_{kit} is time and the individual variant, w_{mi} is time-invariant, e_{it} is time and individual invariant variables, and u_i is the unobserved heterogeneity.
2. (i) $E(e_{it}|\boldsymbol{X}_i, \boldsymbol{w}_i, u_i) = 0$; and
   (ii) $E(u_i|\boldsymbol{X}_i, \boldsymbol{w}_i) = E(u_i) = 0$. There is no information to predict e_{it} in either explanatory variable values or unobserved heterogeneity according to condition (i), and there is no information to predict u_i in the values of independent variables. Both are exogeneity assumptions.
3. (i) $var(e_{it}|\boldsymbol{X}_i, \boldsymbol{w}_i, u_i) = var(e_{it}) = \sigma_e^2$; and
   (ii) $var(u_i|\boldsymbol{X}_i, \boldsymbol{w}_i) = var(u_i) = \sigma_u^2$. These are homoscedasticity assumptions.
4. (i) Since variables are randomly extracted from the population, e_{it} and e_{js} are statistically independent.
   (ii) Random errors e_{it} are u_i are statistically independent.
   (iii) If $cov(e_{it}, e_{js}|\boldsymbol{X}_i, u_i) = 0$ and t≠s, then random error e_{it} is serially uncorrelated.
5. Exact collinearity does not exist, and all observable variables exhibit fluctuations.

4.4.2.5 GMM

(1) Characteristics of GMM Estimation

In the OLS assumption, it was assumed that explanatory variables and error terms are not correlated but the distribution of error terms was not considered. Maximum likelihood estimation (MLE) is an estimation method which assumes the distribution of error terms as well as variance and covariance. The assumption of the distribution of error terms is very strong, and properties of the estimator can be very good if properly estimated.

Maximum likelihood estimation generates likelihood function and maximises it, based on the distribution of error terms. The likelihood function considers the joint probability density function in the observed dependent variables as a function of unknown parameters. The likelihood function implies the chance that observed independent variables will appear, and MLE is a method which maximises this probability.

The generalized method of moments (GMM) is a flexible econometric technique used to estimate models when the distributional assumptions of the data are unknown or the model is nonlinear in its parameters. The GMM is an estimation method that exploits the instantaneous conditions of data to estimate unknown parameters.

With the GMM, moment terms are used to form the objective function. Moment conditions are derived from the economic theory underlying the model. Moment conditions are a set of equations that describe the relationship between the parameters of the model and the moments of the data. Moments are a function of data that can be expressed as a linear combination of model parameters. The objective function of the GMM is the difference between the theoretical moments and the sample moments weighted by a positive definite weighting matrix. The goal of the GMM is to choose parameter values that minimise this objective function. This method involves finding a parameter that makes the distance between the sample moment and the model moment as close to zero as possible.

One of the advantages of the GMM is that it is a very flexible estimation method that can handle a wide range of data situations. Generalized methods of moments can also provide consistent estimates of model parameters, even when the distributional assumptions of the data are unknown. However, GMM estimation can be computationally demanding, and the choice of moment conditions and weighting matrices can affect the estimation results.

(2) GMM Diagnostic Tests

1) Sargan Test

The Sargan test is a statistical test used to evaluate the validity of instrumental variable (IV) regression models (Sargan, 1958). Instrumental variable regression models are used when the relationship between the dependent and explanatory variables is endogenous, that is, there is a correlation between the error term and one or more explanatory variables. Instrumental variable regression uses instrumental variables to estimate the relationship between the dependent variable and endogenous explanatory variables.

The Sargan test is an out-of-limits identification test that tests whether the IV regression model is specified correctly and whether the tool used for the model is valid. The test is based on the difference between the observed and predicted values of the dependent variable and compares this difference between the original model and the modified model excluding the tool. The null hypothesis of the Sargan test is that the tool used in the model is valid, and the alternative hypothesis is that the tool is not valid.

If the null hypothesis is not rejected, it indicates that the IV regression model is correctly specified and the tool is valid. However, if the null hypothesis is rejected, it suggests that there is something wrong with the IV regression model, such as the model's specification being incorrect or an invalid tool. Modification of the model or an additional identification process may be required in this case.

4.4.2.6 SUR / 3SLS

(1) Characteristics of SUR/3SLS Estimation

Four equations are established in the modelling process to account for the space, investment and development subsectors in this research. The variables of real rent, new construction and occupied stock are simultaneously determined in the estimation process, and therefore they are endogenous. In regression analysis, the direction of influence goes from the side of explanatory variables and error terms to dependent variables. Since the adjustment process is missing in the simple regression method, it cannot present the interaction process between the endogenous variables (real rent, new construction and occupied stock) and their convergence to the equilibrium.

Real rent, for example, is an endogenous variable on the right side of new construction and occupied stock equations. The variable is stochastic and correlated with random errors in the flow and stock development equations, which can be written as $cov(lrr_i, e_{lcons}) = E(lrr_i, e_{lcons}) \neq 0$ and $cov(lrr_i, e_{los}) = E(lrr_i e_{los}) \neq 0$. When the explanatory variables are correlated concurrently with the regression error term, the OLS estimator is biased and inconsistent.

Suppose there is a change in the error term of the new construction equation, Δe_{cons}. It has a direct and negative linear effect on the real rent (lrr_i), as the coefficient of the new construction variable to the rent is expected to have a minus sign. When Δe_{cons} changes, only lrr_i is observed under the OLS estimation because the change of the error term is unobservable. As a result, the coefficient of lrr_i is underestimated compared to the true value of the parameter. In other words, OLS is negatively biased in this example, and the bias does not improve even if the sample is large enough.

In the multi-equation system, a change or fluctuation transfers from one equation to the others.

(2) 3SLS diagnostic tests

1) Order Condition of Identification

In a multi-equation model, variables are omitted in some equations and included in others. There is a general rule to enable parameter estimation, known as requirements for identification. Under a system of M equations which includes endogenous variables, at least M-1 variables should be omitted to properly estimate parameters. When parameter estimation is available, the multi-equation is called 'identified', and it can be estimated consistently. If fewer than M-1 variables are missing from the equation, the condition is called 'unidentified', and parameters cannot be estimated consistently (Hill, 2017).

2) The Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC)

Comparing the AIC and the BIC, the AIC gets smaller as SSE decreases as the extra variable is added, while the BIC gets larger as K increases. With a reasonable sample size (N ≥ 8), the BIC more heavily penalises extra variables than the AIC as Kln(N) > 2K/N. A model with the smallest AIC or BIC is considered a good one (Hill, 2017).

$$AIC = ln(\frac{SSE}{N}) + \frac{2K}{N}$$

$$BIC = ln(\frac{SSE}{N}) + \frac{Kln(N)}{N}$$

The Akaike information criterion (AIC) and the Bayesian information criterion (BIC) are statistical measures used to compare the performance of different models based on their ability to fit data while considering the number of parameters used in the model. Both criteria aim to select the best-fit model from a set of candidate models, but have different penalties for model complexity and sample size.

The key difference between AIC and BIC is the penalty term for model complexity. The AIC penalizes less complex models than the BIC. That is, the AIC tends to select models with more parameters compared to the BIC, which generally selects models with fewer parameters. The BIC has a stronger penalty for models with more parameters than the AIC, that is, it is more effective at avoiding overfitting and choosing the most concise model.

Another difference between the AIC and the BIC lies in the sample size penalty term. Both criteria penalize model complexity, but the BIC's penalty for complexity increases with sample size, while the AIC's penalty remains constant. That is, the BIC tends to be more selective with larger sample sizes, whereas the AIC tends to select more complex models.

4.4.3 Statistical Package

As the structure of data becomes more complex and larger in size, the role of statistical software packages that can replace quantitative analysis tasks that are difficult for researchers to process manually has become more important than before. In the social sciences, Stata, SPSS, and R are widely used. Of these, Stata is a statistical package that performs statistical analysis by entering commands. It can calculate panel data and simultaneous equations, so it is more suitable for this study than SPSS, which is relatively intuitive and has advantages such as being able to perform one-way ANOVA and two-way ANOVA. R is an open-source program provided free of charge and has a high level of extensibility, but the statistical analysis function is not provided by default, and the user must write a command for statistical analysis. Also, since it operates from the command line rather than a graph user interface, it requires a high level of programming ability and presents a high barrier to entry for social science researchers.

4.5 Evaluation & Comparison

In previous studies, the inefficiency of the real estate market (especially the supply side in the short term) has consistently been pointed out as a major cause of difficulties in econometric analysis. A similar problem was expected to appear in this empirical analysis as well, and an appropriate diagnostic test was required to resolve the issue.

Since OLS is an estimation method which presupposes strict assumptions (i.e., no multicollinearity, normality, homoscedasticity and no autocorrelation), diverse aspects of the validity of the assumptions should be tested. The process includes various violation tests for each assumption, namely the VIF test (for multicollinearity), the RESET test (functional form), the Jarque-Bera test (normality), the Breusch-Pagan test, the Cameron-Trivedi test (for homoscedasticity) and the Durbin-Watson test (for no autocorrelation). It is expected that GLS performance will be better than OLS in terms of one or more of the violations, and diagnostics will also be conducted for GLS based on this assumption.

In the panel analysis, the validity of random and fixed effects models will be individually checked using the Wald test and the Breusch-Pagan test. Next, the Hausman test will be used to decide the better performed effects between the two.

In the multi-equation model, an identification issue arises due to simultaneity and endogeneity, which are features of its modelling structure. The GMM also requires an identification test, and the Sargan test will be used for the estimation. For both the multi-equation model and the GMM, statistical estimation is valid on condition that each individual equation is overidentified or just identified, and invalid if unidentified.

(1) Consistency with Expected Signs of Variables

As discussed above, the system consists of four equations, and these equations have dependent variables on the left side and explanatory variables on the right side. Each independent variable is assumed to have a positive or negative effect on the dependent variable, based on the theoretical discussions of real estate and office literature.

(2) Explanatory Power and Model Performance

Model performance is measured by R^2 (or adjusted R^2) and the standard presents the extent of the dependent variable explained by the selected independent variables. Therefore, high R^2 value is often presented as evidence that the empirical model has successfully explained the theoretical discussions. Based on the analysis of previous studies, it can be observed that there is a general tendency for higher R^2 values in the space demand and lower R^2 values in the space supply. In other words, the models explaining factors influencing the demand side have relatively high explanatory power (R^2 values), while the models explaining factors influencing the supply side have demonstrated lower explanatory power. However, this can vary depending on each specific case, and it implies that there are diverse results depending on the empirical model rather than a general trend.

When it comes to space supply, Rosen (1984) found an adjusted R^2 of 0.19, indicating that only 19% of the variation in new supply is explained by the independent variables. However, most studies have shown higher explanatory power, ranging from 0.49 to 0.91. Frew and Jud (1988) reported values of 0.49 to 0.58, Henderhsott et al. (1996) reported 0.58, DiPasquale and Wheaton (1996) reported 0.61, and Tsolacos and McGough (1999) also reported 0.61, indicating a level of explanatory power in the range of 0.5 to 0.6. On the other hand, Henderhsott et al. (1996) reported an adjusted R^2 of 0.82, Viezer (1999) reported 0.83, Wheaton et al. (1997) reported 0.88, and Wheaton (1987) reported 0.91, indicating a high explanatory power in the range of 0.82 to 0.91. These results could be attributed to successful selection of variables and consideration of time lags in the supply sector. However, it should be noted that some of the research findings were not subjected to diagnostic tests and thus one should be cautious when interpreting the results.

(3) Statistical Properties

Two types of standards are presented above as criteria for model evaluation: comparison of expected and actual signs, and measurement of a model's explanatory power. However, since these results cannot be trusted unless a statistically appropriate estimation method is used, a diagnostic test should also be conducted to determine whether the statistical properties violate the econometric assumptions. For this reason, a diagnostic test is also included as the third standard of model evaluation.

4.5 Summary

This chapter has set out the area of study, the data considerations and the modelling strategy (including software) used to develop a series of real estate models. The approach adopted was intended to ensure that due consideration is given to the statistical robustness and rigour of the modelling processes. The chapter concludes by highlighting that the different models developed can be evaluated and compared on the basis of their theoretical consistency, their ability to model the key outcomes and their statistical properties. The next chapter will illustrate that researchers often find themselves trading off strengths and weaknesses in relation to the different evaluation criteria.

5 Modelling Result

5.1 Introduction

This chapter analyses the selected market areas. It begins with a brief market overview, focusing on descriptive statistics. It then seeks to model key market outcomes using the best available data, different model structures (informed by theory and the previous literature) and using the various methods of estimation described in the previous chapter. As we note above, model performance can be evaluated in terms of theoretical consistency, model performance and statistical reliability.

This empirical analysis was thus conducted with three main objectives. First, it intends to determine a more appropriate transformation of original variables between log and first-differenced log conversion. Second, it aims to determine better econometric estimation methods, particularly between ordinary least squares (OLS) and three-stage least square (3SLS). Lastly, the performance of the panel in comparison with individual time series will be explored to determine whether the analysis of European office markets provides stronger statistical results than that of each city.

5.2 Market Overview (Descriptive Statistics)

While regression analysis involves a relatively complex process which requires a sufficient sample size and diagnostic tests to derive statistically reliable in-depth results, descriptive statistics provide a more convenient way to examine overall attributes of variables, such as mean, maximum, minimum and standard deviations. It does not necessarily require a large number of observations and can produce interpretable results using a small amount of data collected for market analysis. In addition to descriptive statistics for dependent variables in the empirical analysis model, it is necessary to derive descriptive statistics for variables that were not included in the empirical analysis model. Therefore, time-series trends of dependent variables (real rent, yield, new construction and occupied stock) in individual cities, and also independent variables not included in the empirical model, are reviewed in this section prior to the regression analysis.

Table 8. Descriptive statistics of dependent variables (quarterly basis)

		London, West End	London, City	Paris	Frankfurt	Amsterdam	Milan	Madrid
Real rent	average	1210.71	696.33	789.71	471.68	360.99	547.00	365.97
	maximum	1491.39	887.13	884.00	521.17	425.24	647.64	530.01
	minimum	931.13	543.75	692.74	440.74	299.34	495.05	286.67
	std. dev.	150.98	79.70	48.69	21.46	34.29	52.78	76.78
	no. of samples	48	48	48	48	48	48	48
Yield (%)	average	4.1%	4.9%	4.2%	4.8%	5.6%	4.8%	5.1%
	maximum	6.0%	6.8%	6.3%	5.4%	6.8%	5.6%	6.3%
	minimum	3.2%	6.3%	3.0%	3.3%	3.2%	3.4%	3.3%
	std. dev.	0.0073	0.0086	0.0089	0.0066	0.0114	0.0080	0.0113
	no. of samples	47	48	48	48	47	47	47
New construction (square ft.)	average	441.59	913.22	1201.77	303.27	191.28	370.94	278.21
	maximum	2523.3	5762.94	1681.85	471.17	325.00	651.00	580.00
	minimum	118.45	83.48	608.00	148.00	38.00	210.00	82.00
	std. dev.	564.5	1370.72	269.43	73.85	93.14	121.05	137.16
	no. of samples	45	45	48	48	48	48	48
Occupied stock (square ft.)	average	7171.29	8323.28	32448.6	10060.42	5207.10	10741.10	14335.15
	maximum	7526.39	9237.92	34336.49	10961.94	5531.53	11103.06	15387.31
	minimum	6617.32	7498.36	30627.29	9502.23	4894.00	10192.70	13853.46
	std. dev.	277.19	504.32	1113.07	345.68	165.19	232.71	391.90
	no. of samples	48	48	35	47	47	46	44

Table 8 provides descriptive statistics of the dependent variables, and each row of the table presents statistical properties including average, maximum, minimum, standard deviation and number of samples. These statistics provide an indication of the range of the dependent variables that are typically observed, as well as how much they vary from the average.

In the case of London, West End, for instance, each row provides the following information: For real rent in the first row, the average real rent is €1,210.71, the highest real rent is €1,491.39 and the lowest real rent is €931.13. Standard deviation is a measure of the degree of variation or dispersion of real rent values around the mean. The standard deviation of real rent in London, West End, is €150.98. The number of samples is the number of data points or observations used to calculate the above statistics for each city. There are 48 observations for real rent in London, West End.

For yield in the second low, the average yield is 4.1%, with a maximum of 6.0% and a minimum of 3.2%. The standard deviation is 0.0073, indicating that the yield data are relatively tightly clustered around the mean. The sample size is 47.

For new construction in the third row, the average new construction size is 441.59 sq. ft., the maximum is 2523.3 sq. ft. and the minimum is 118.45 sq. ft. Standard deviation measures the degree of variation from the average of new construction sizes; the higher the standard deviation, the more widely dispersed the sizes are from the average. The standard deviation of new construction in London's West End is 564.5 sq. ft., and the sample availability is 45 for this variable.

For occupied stock in the fourth low, the average occupied stock of space is 7,171.29 sq. ft., with a maximum of 7,526.39 sq. ft. and a minimum of 6,617.32 sq. ft. The standard deviation is 277.19, indicating that the data are spread out around the average. There are 48 samples in this data group.

The observations of dependent variables range from 35 to 48, which is a manageable sample size in terms of regression analysis. On the other hand, independent variables collected on the annual basis only range from 9 to 18, apparently an insufficient sample size to conduct an estimation using regression.

London, West End, is the office centre which has the strong demand and openness to other centres, backed by the highest rent (Table 8) and network connectivity index (Table 9), respectively. The City of London also records the third highest rent level, followed by Paris (Table 8), and high data availability. In contrast, consequently, the other cities show weaker evidence of submarkets and limited data availability. For example, the submarkets of Paris can be classified as CBD and La Defense, and there is partial evidence of data availability although the observations are not sufficient to derive meaningful outcomes in the multi-equation system. The other cities may have multiple centres, but their existence is not sufficiently supported by either empirical studies or the availability of time-series data.

Table 9. Descriptive statistics of independent variables (annual basis)

		London	Paris	Frankfurt	Amsterdam	Milan	Madrid
RGDP / GDP ratio	average	24.4%	33.1%	7.0%	22.1%	23.7%	20.3%
	maximum	26.1%	34.1%	7.3%	23.4%	24.2%	20.8%
	minimum	22.9%	31.2%	6.8%	21.4%	23.0%	19.7%
	std. dev.	0.0110	0.0107	0.0019	0.0065	0.0044	0.0040
	no. of samples	12	14	14	12	14	14
tax rate	average	25%	33.5%	32.5%	26.9%	32.4%	30.3%
	maximum	30%	34.3%	39.6%	34.5%	38.3%	35.0%
	minimum	19%	33.3%	29.4%	25.0%	24.0%	25.0%
	std. dev.	0.0453	0.0034	0.0450	0.0327	0.0431	0.0350
	no. of samples	16	17	16	16	16	16
office service output	average	82895	627907	1651170	107512	259053	259053
	maximum	98489	744822	2083702	137984	291055	291055
	minimum	64697	474743	1354040	79919	208537	208537
	std. dev.	12004	88663	223763	16601	23494	23494
	no. of samples	18	18	18	18	18	18
population	average	62369928	64337355	81815785	16563573	58963461	44964641
	maximum	66273576	66926166	82520176	17181084	60795612	46818219
	minimum	58999781	60979315	80274985	15987075	56960692	40665545
	std. dev.	2386498	1928769	790670	347727	1361356	2159822
	no. of samples	18	18	16	18	18	18
network connectivity - Z/Yen (NC)	average	786	662	685	633	611	602
	maximum	801	689	719	662	655	636
	minimum	774	640	641	581	554	560
	std. dev.	9	17	25	28	30	21
	no. of samples	10	9	10	10	10	10
global city index - GPCI (NC)	average	1164	1091	775	844	678	727
	maximum	1692	1394	1140	1266	987	1089
	minimum	314	303	212	227	184	203
	std. dev.	587	447	384	424	339	356
	no. of samples	10	9	10	10	10	10
vacancy (v)	average	7.4%	6.6%	11.4%	16.6%	9.5%	10.8%
	maximum	12.4%	8.3%	15.2%	21.6%	13.3%	15.8%
	minimum	4.3%	3.4%	3.5%	7.3%	5.2%	4.2%
	std. dev.	0.0239	0.0132	0.0295	0.0407	0.0272	0.0313
	no. of samples	18	18	18	18	18	18
office investment (CV)	average	14945	15476	3079	1132	1375	1607
	maximum	26035	26076	8419	3208	2735	3065
	minimum	7214	7267	322	330	315	292
	std. dev.	5895	6027	2183	795	746	920
	no. of samples	18	18	18	17	15	18

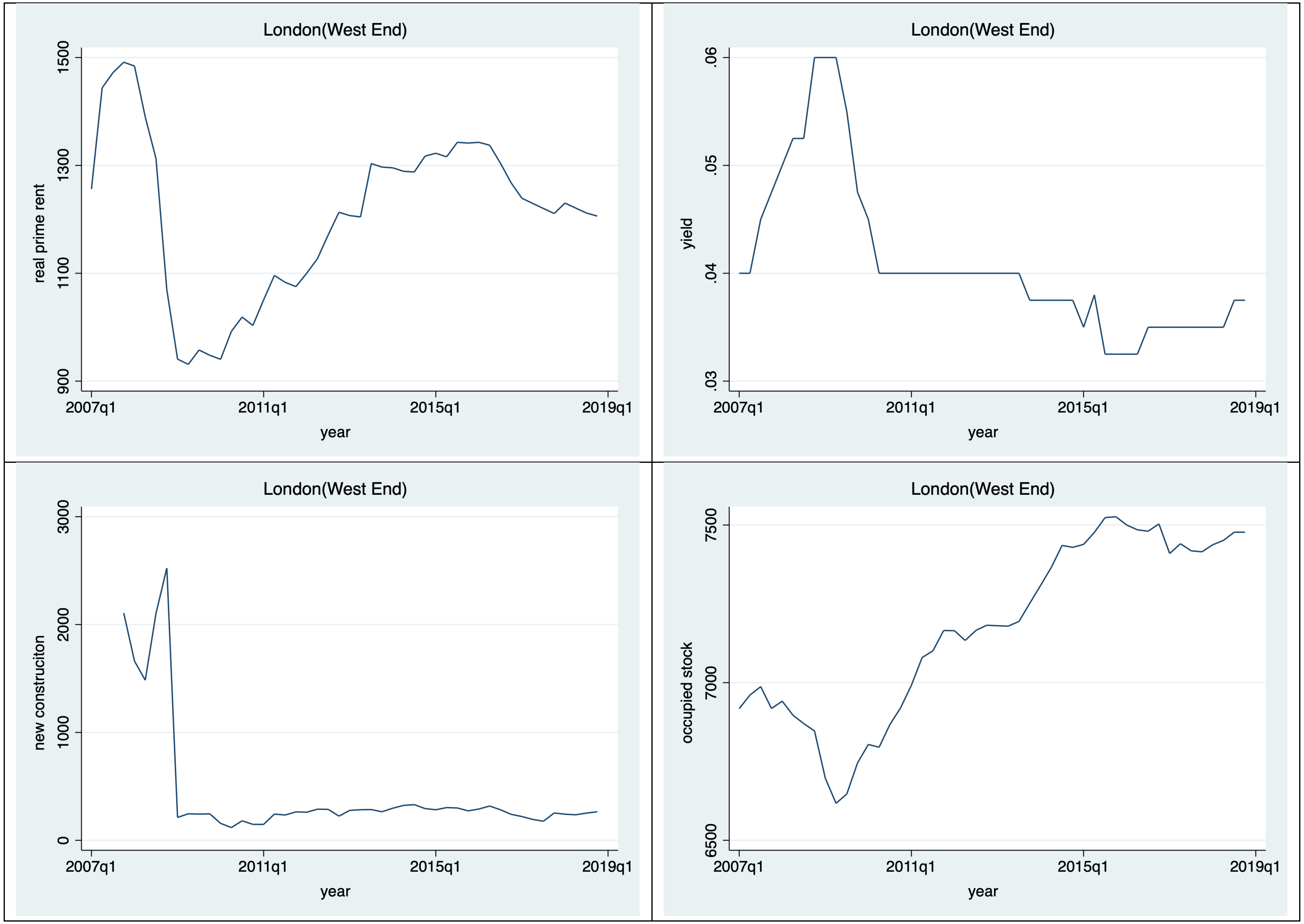

Figure 11.   Real prime rent, yield, new construction, and occupied stock of London, West End

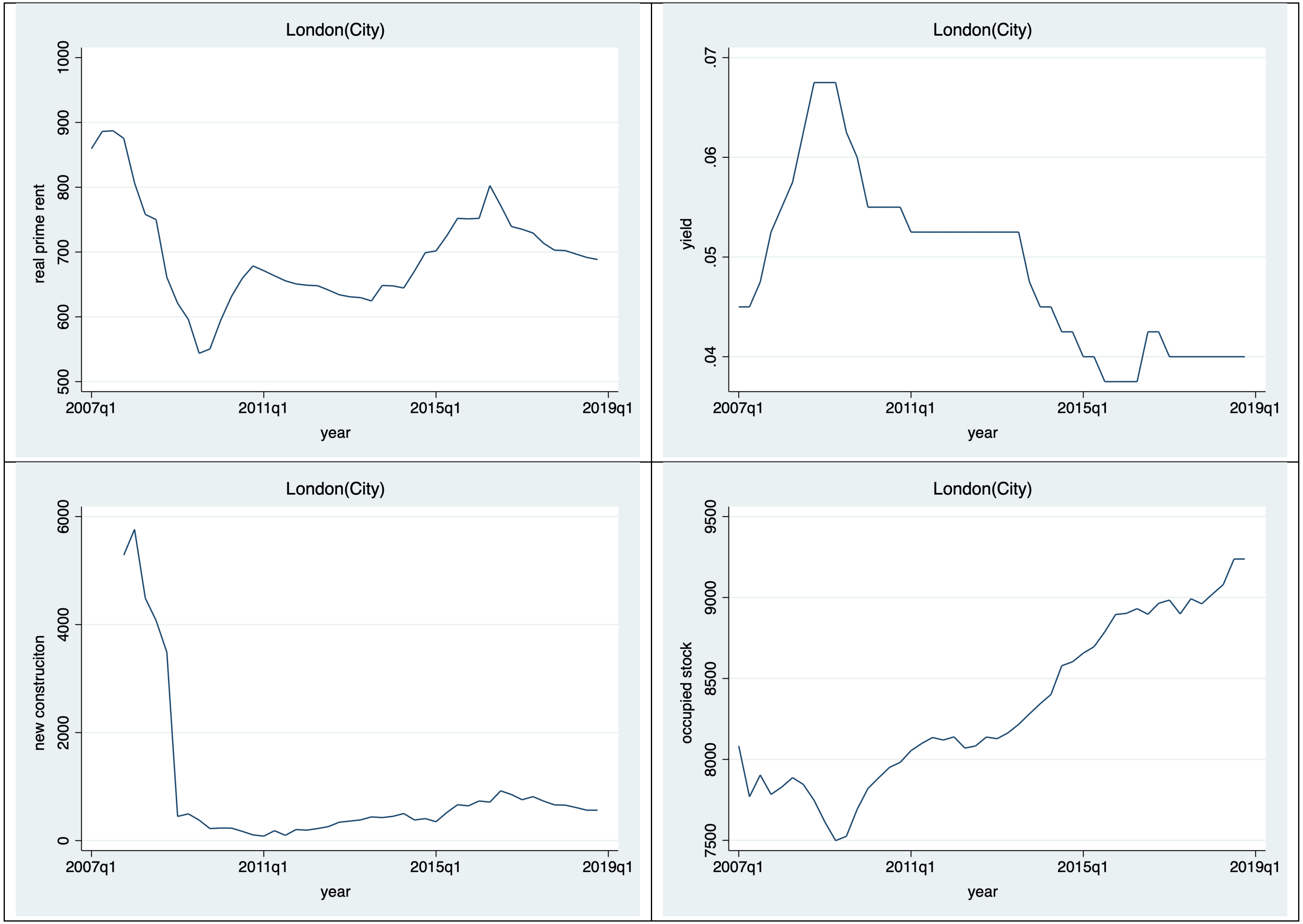

Figure 12. Real prime rent, yield, new construction, and occupied stock of London, City

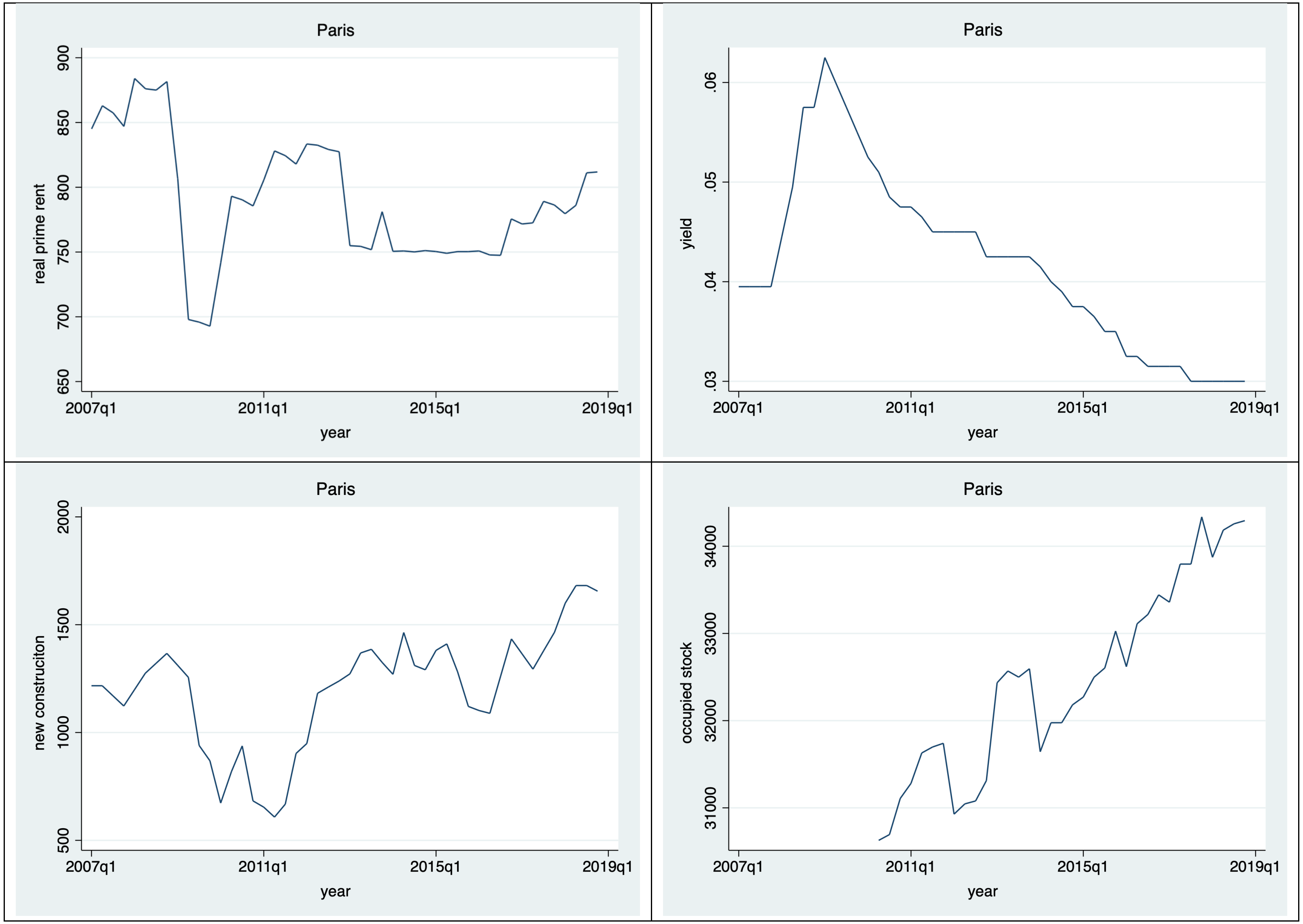

Figure 13. Real prime rent, yield, new construction, and occupied stock of Paris

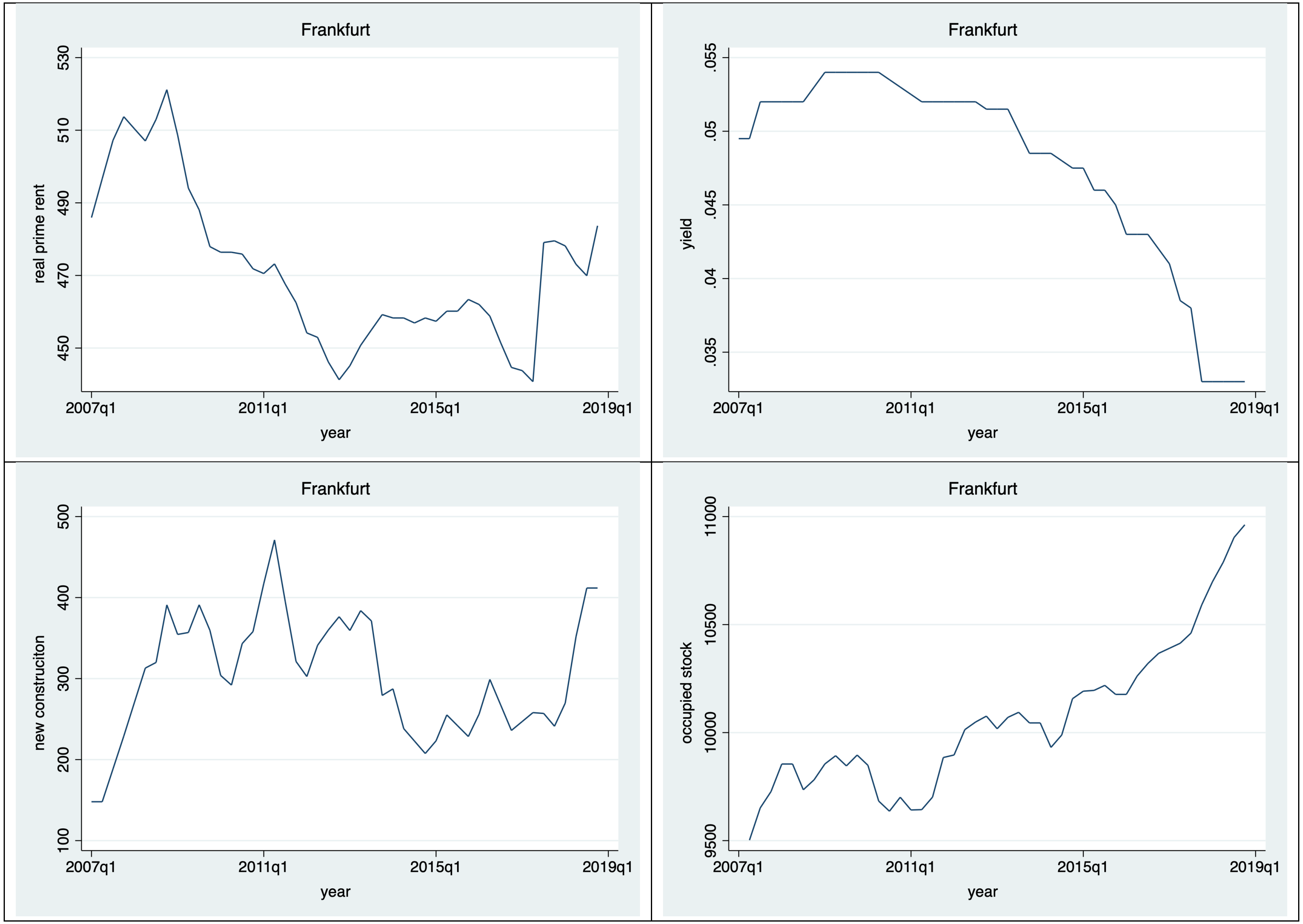

Figure 14. Real prime rent, yield, new construction, and occupied stock of Frankfurt

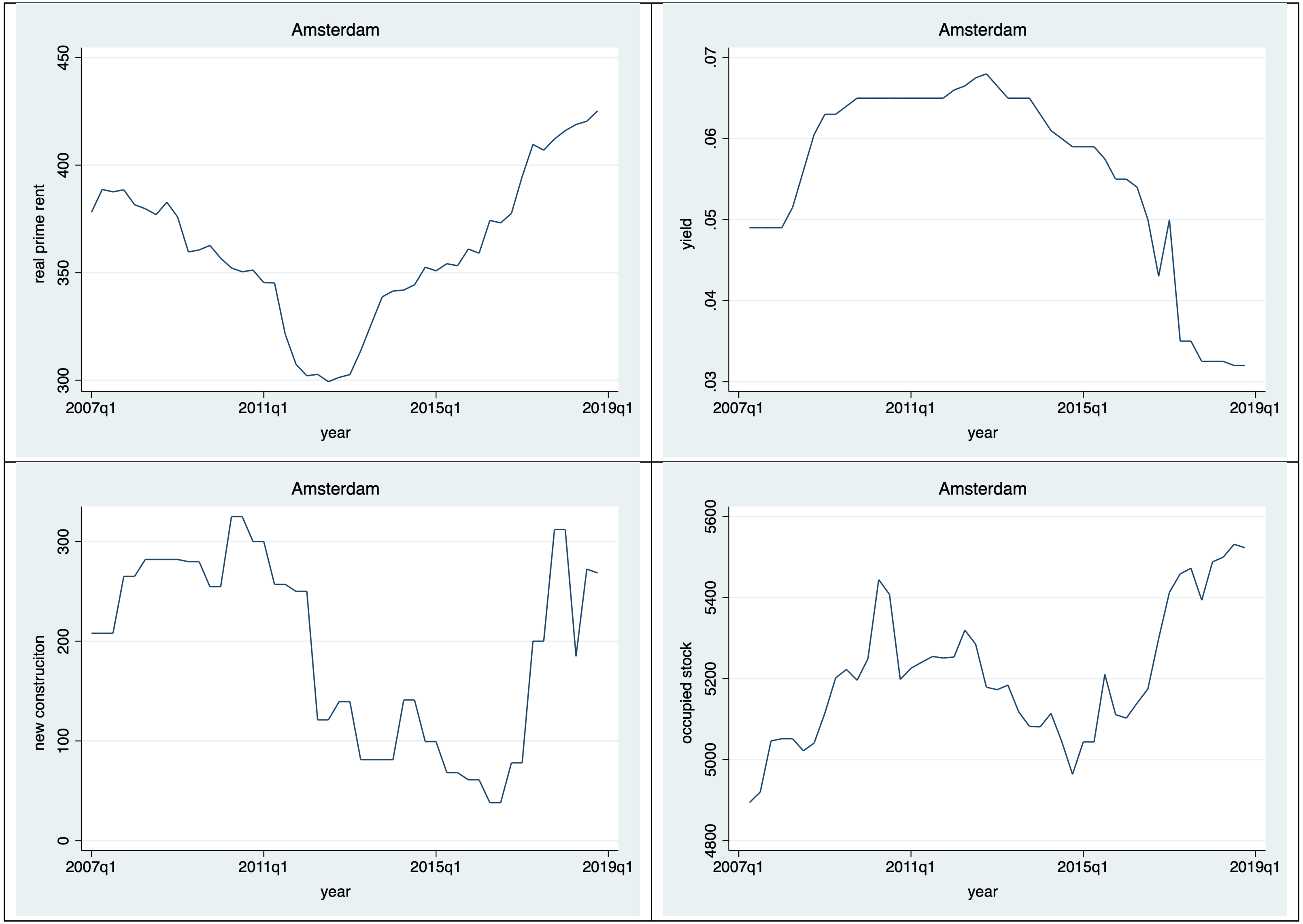

Figure 15. Real prime rent, yield, new construction, and occupied stock of Amsterdam

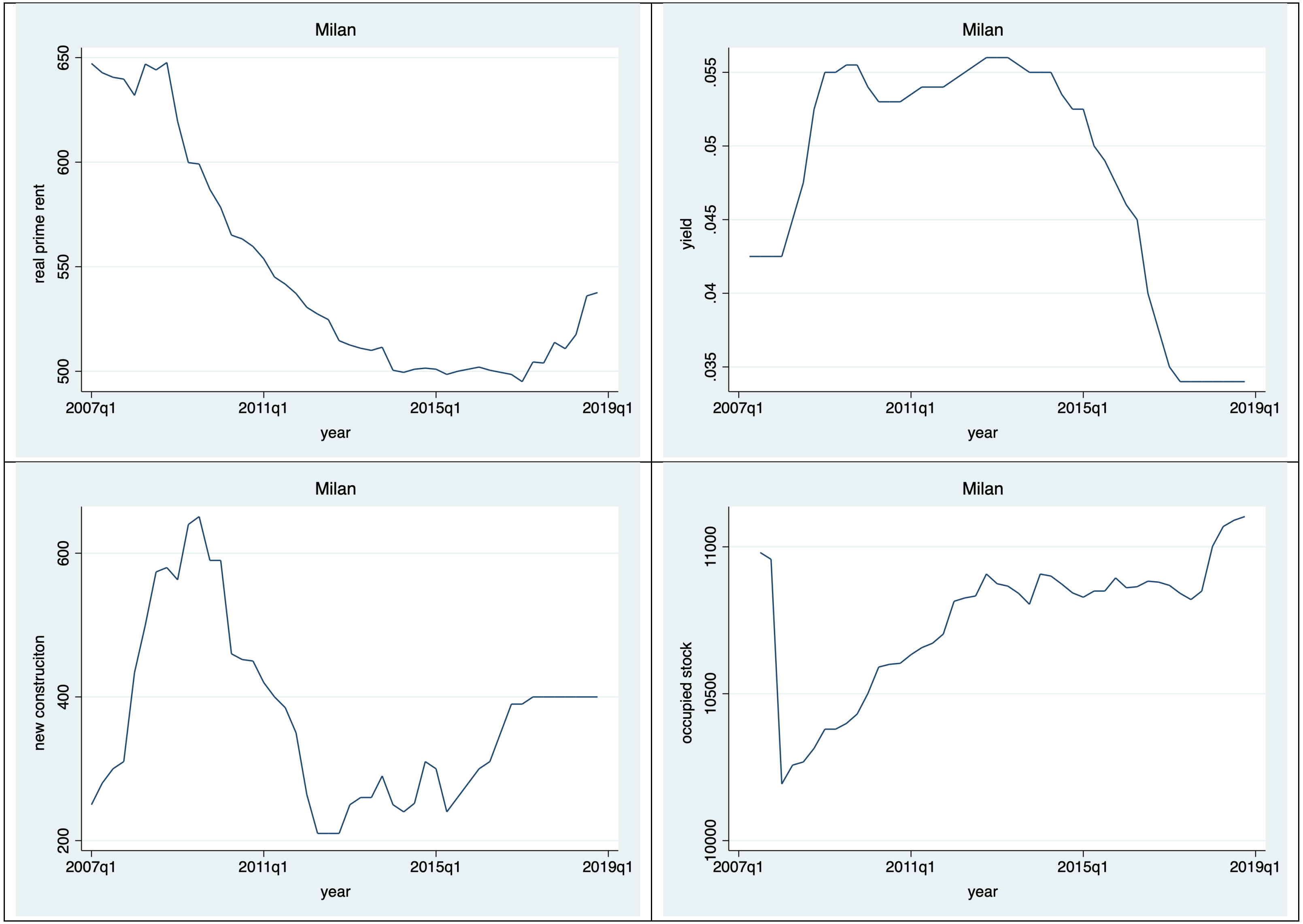

Figure 16. Real prime rent, yield, new construction, and occupied stock of Milan

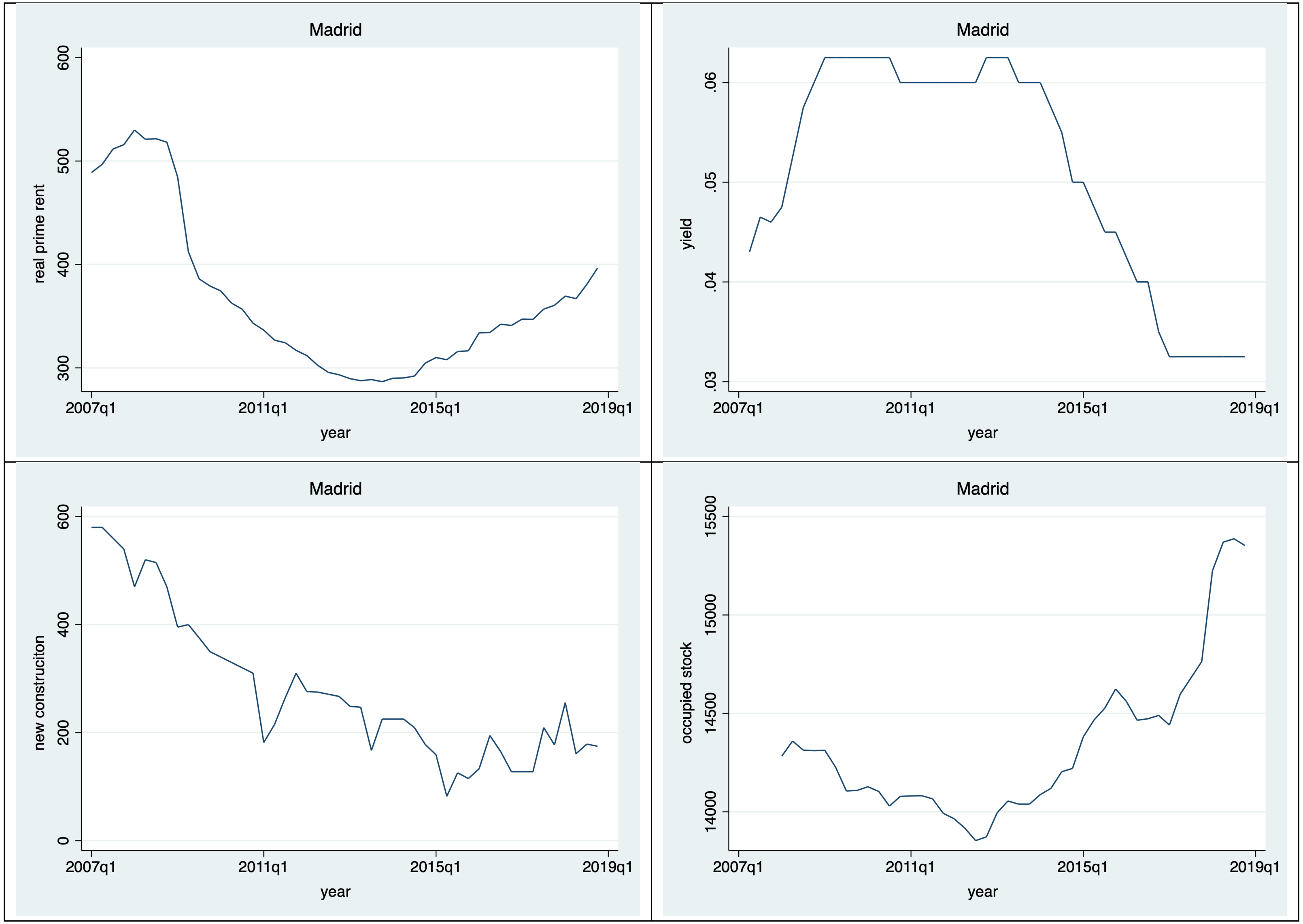

Figure 17. Real prime rent, yield, new construction, and occupied stock of Madrid

Figures 11 to 17 present the real rent, changes in real rent, yield, new construction and occupied stock within the sample time series for each city.

Important macroeconomic events historically have had a close relationship with the real estate market, and a series of studies applying business cycle theory to the real estate market support this view (Leitner, 1994; McGough and Tsolcaos, 1999; Meen, 2000; Barras, 2005). The real estate market cycles through periods of expansion, prosperity, recession and downturn, influenced by macroeconomic conditions.

It seems that common shock was caused by the global financial crisis (GFC) after 2009 for all cities, but the impact was stronger in London's West End, London City and Paris. For other markets, two periods of recession were observed in Frankfurt in 2012 and 2016, and both Milan and Madrid experienced a longer downturn period. Amsterdam was the only market that recovered from the shock and recorded higher real rent at the end of the time series (Q1 2019) than at the start (Q1 2017).

More specific details of the dependent variables by city are presented next: London, West End, and London, City, present similar patterns of rental movements in terms of business cycles. During the sampling periods, both areas' real rents fell to the lowest in 2009 and started to recover, until they reached a second peak in 2016, then slowly fell until the first quarter of 2019. After the Great Recession, real rents moved between the boundary of the previous peak in 2007 and the trough in 2009. In Figure 10, the change in rental level is described on the left-hand side (LHS), and the first-difference rental change on the right-hand side (RHS). The RHS presents the variable's extent of deviation from the average, and West End experienced a stronger shock than the City after the outbreak of the Great Recession, according to this observation.

Looking at other continental European cities, Paris exhibited a pattern most similar to that of London, with real rents hitting a record high in 2008 and then experiencing the greatest impact from the Great Recession in the entire time series. Frankfurt's real rents peaked in 2008, then tumbled in 2013 and 2017 due to the Great Recession, and then showed a relatively slow recovery until the first quarter of 2019. Amsterdam recorded a low in 2012, after the Great Recession, and real rents broke through the previous peak in 2016 and then continued to rise until the first quarter of 2019.

Milan's real rents peaked between 2007 and 2008, remained at their lowest point for a relatively long period from 2014 to 2016, and have since shown a modest recovery. The pattern of rent changes in Madrid is also similar, with real rents peaking in 2008 and then reaching their lowest point in 2014 after the Great Recession. In the case of Milan and Madrid, the shock caused by the Great Recession was reflected relatively slowly in real rent variables, and the effect also lasted longer than in London and Paris. London and Paris seem to have reached peaks and troughs faster in terms of business cycles than southern European cities, and the cycles were also faster. This implies that the rent adjustment process following the shock was more rapid in cities with more advanced office centres.

Global consulting firm, KPMG published reports on European real estate market for this period, using data from Cushman & Wakefield, CBRE, DTZ, Real Capital Analytics as their primary sources (KPMG, 2012, 2013, 2014, 2015, 2016, 2017). Below are more detailed highlights of each subsector by cities between 2012 and 2017 based on KPMG reports. Despite 6 years of short time-series availability, the summary highly synchronise with the movement of dependent variables presented from Figure 11 to Figure 17 for this period.

(1) London

London stands out from the 'secondary' domestic cities (or areas) known as the Big Six, namely, Birmingham, Manchester Metro, Edinburgh, Bristol, Glasgow and Leeds (KPMG, 2013). London's RGDP/GDP ratio ranges from 22.9% to 26.1% (Table 9).

The British economy experienced uncertainty in 2012, but the outlook became positive in 2013 and 2014, with growth starting from 2015 and continuing into 2016. However, signs of downside risks appeared in 2016. The unemployment rate was expected to decline in 2013, and inflation tended to decrease in 2014, with the Bank of England (BoE) targeting inflation rates of 2% within two years by 2015.

In 2012, rental growth in London remained flat, while it declined in the rest of the UK. However, with recovering employment, rental levels were anticipated to rise. The occupier market experienced a boom between 2014 and 2016, but rental levels came under pressure from 2017 onwards, influenced by Brexit. London dominated the British total transaction, accounting for the lion's share with 75% in 2012 and 50% in 2014. The occupier market faced uncertainty due to Brexit in 2017. Take-up continued to improve in 2012, but occupiers were hesitant to move into new spaces. In 2013, the office market in the UK outperformed other real estate sectors.

Vacancy rates reached an all-time low in 2015, driven by strong demand and rising rent. Vacancy rates in secondary cities such as Manchester and Leeds also decreased as occupiers sought lower-cost spaces in 2016. However, this trend slowed down or reversed due to Brexit's impact since 2017.

London's yield remained flat in 2012, while yields in other cities weakened. There was significant variation in yields across the country in 2013. London remained the top destination for investment activity in 2015, attracting domestic and foreign investors in both the West End and the City. This trend also influenced investment sentiment outside London, but this sentiment reversed since 2017 due to Brexit. The expected rise in interest rates in 2016 contributed to the stabilization of the property market. Capital values remained flat, and transaction volume decreased in 2012, but it reversed from the fall and grew in 2013. In 2014, there was yield compression due to the recovering economy, and office properties were perceived by investors as attractive assets, accounting for 55% of commercial real estate transactions in the first half of 2014.

From 2012 to 2014, new supply to the market was limited. With economic recovery, the lack of Grade A space was likely to drive speculative development in large cities. The development was generally lagging behind demand across the UK, and the conversion of office buildings to residential spaces worsened the situation. As a result, around 2016 there was potential risk of the office market experiencing oversupply in the upcoming two to three years.

(2) Paris

In terms of macroeconomics, the French economy remained relatively stagnant between 2012 and 2014 but saw a rapid recovery starting from 2016. During this period, unemployment sharply increased in 2013 and remained high in 2015. However, positive changes were observed in inflation, and the tax environment became more favourable in 2016. The RGDP/GDP ratio of Paris ranges from 31.2% to 34.1% (Table 9).

Prime rents in Paris experienced a decline since 2012, stabilizing in 2014 and 2015, and maintaining a positive trend until 2017. In 2017, the occupier market was backed by strong demand and this trend also made office properties attractive investment assets to investors. Among all the districts in Ile-de-France, Central Paris stood out as the most dynamic area, while other districts faced challenges. There was a notable disparity between inner-city districts and the rest within the Greater Paris area. The take-up of office buildings declined in 2012 and 2013 but witnessed a significant increase in 2017 due to robust demand.

Vacancy rates increased slightly in 2015 compared to 2014 but decreased in 2016. Significant disparities between different areas were observed in 2015.

In 2015, nearly 70% of total investments were concentrated in the Greater Paris area. However, total investment in the first half of 2015 experienced a 30% decrease compared to the first half of 2014, primarily due to a limited number of large deals. Nevertheless, investments in office properties exceeded 70% of the total investment in France. Yield compression was evident in both 2015 and 2017, affecting both the Greater Paris area and the entire country.

The supply of office space remained stable in 2012 and 2014. In 2015, the poor performance of the rental market in the Greater Paris area had an impact on the supply of office spaces. Outer areas accounted for nearly 30% of the supply, while Paris contributed only 20%.

(3) Frankfurt

Frankfurt is considered one of the top-tier cities domestically, alongside Berlin, Düsseldorf, Hamburg and Munich (KPMG, 2012). It serves as a prominent financial hub, boasting the highest prime rent, which accounts for between 6.8% and 7.3% of the RGDP/GDP ratio (Table 9).

From a macroeconomic perspective, Germany's economy faced a temporary decline in GDP in 2013, while the Eurozone experienced 1.5 years of economic contraction. This indicates Germany's economic strength and a stable job market, as stated by KPMG in 2013.

In terms of prime rent, there was an increase primarily driven by the focus on modern office spaces in 2012 and 2013. Frankfurt's rental level slightly surpassed that of 2009 in 2014 and remained stagnant in 2015. However, over the five years since 2016, it has experienced continuous growth, with a notable surge in demand leading to further increases in 2017. The take-up of office spaces also witnessed an upward trend in 2015, 2016, and 2017.

Due to the attractiveness of new spaces for occupiers, the availability of vacant spaces became limited in 2013, resulting in a decline in vacancy rates. Moreover, in 2016, the strong take-up of spaces contributed to a further decrease in vacancy rates.

Regarding yields, they returned to their 2007 level in 2012 and remained unchanged in 2014. However, there has been a tendency for prime yields to decrease due to low interest rates in 2014, with a subsequent decline in 2016 and 2017. Additionally, the investment volume saw an increase in 2013, and domestic investors shifted their focus to high-end properties in 2015. Initial signs of weakening demand can be observed, such as delays in tenants' decision-making and the postponement of letting transactions in 2013.

(4) Amsterdam

Amsterdam stands as one of the most popular cities domestically, particularly among the so-called G4 cities, consisting of Amsterdam, Rotterdam, The Hague and Utrecht. Amsterdam's RGDP/GDP ratio ranges from 21.4% to 23.4% (Table 9).

In terms of macroeconomics, the Dutch economy successfully recovered from the recession in 2012 and attracted overseas capital in 2013. Gross domestic product began to show growth in 2014, continuing its upward trajectory throughout the years 2015 to 2017. The inflation rate in 2012 reached a similar level as the average between 2000 and 2010 and experienced a drop in 2014, maintaining a relatively low level in 2016 and 2017. However, there was pressure from quantitative easing (QE) by the European Central Bank (ECB). The unemployment rate also experienced recovery in 2012, followed by a temporary increase in 2014, and consistently decreased thereafter.

In terms of prime rent, it remained stable for the five years after 2015, and began to show an upward trend in 2016. The efficient utilization of spaces was activated in 2012, and this trend continued in 2014, albeit with limited recovery. The total take-up of office spaces in 2013 was lower than in 2012, with space demand primarily concentrated in the Randstad area. The G4 cities accounted for 51% of the take-up in 2014, with Amsterdam experiencing particularly strong demand and witnessing further increases in 2015. Additionally, the price disparity between grade A and lower-grade office spaces widened in 2012, and this trend persisted in

2014. Despite increasing spatial demand, it was offset by the trend of efficient space utilization, resulting in stable vacancy rates in 2014 and a subsequent decrease from 2015.

Yields experienced a distinct contraction in 2015 compared to the previous year. Investments remained stable in 2012, rapidly recovered in 2013, and increased in 2014. In 2015, approximately 33% of investments were concentrated in Amsterdam (KPMG, 2015). Lowering yields in prime office spaces, particularly in the South-Axis area of Amsterdam, prompted investors to seek subprime locations. The government's policy of converting office spaces into refugee shelters, student residences and hotels stimulated investment demands in 2015.

Regarding supply, the total office stock remained stable in 2012 due to a decrease in construction volume. Although there were no major new developments in 2012, the supply started to exceed demand in 2014.

(5) Milan

Milan boasts the largest domestic office market in Italy, with Rome being the other major office market. Its RGDP/GDP ratio ranges from approximately 23.0% to 24.2% (Table 9).

In terms of macroeconomics, there was ongoing macroeconomic uncertainty in 2012 and 2013, accompanied by weak momentum. However, signs of recovery began to emerge in 2013 and 2014, as evidenced by the narrowing gap between Italian and German government bonds. From 2015 onwards, Italy's economy started to emerge from the previous challenges. Inflation experienced a decrease in 2012 and remained low in 2017, supported by expansionary government fiscal policies and the QE measures of the ECB. The labour market remained weak until 2015.

Regarding prime rent, there was a decrease in 2013 due to weak space demand and an increase in supply. However, it turned positive afterward, aligning with the low cost of capital. In terms of take-up, the letting market was primarily driven by the public sector in 2016 but was less active in 2017. The vacancy rate sharply increased in 2012, with over 10% of total space remaining vacant.

Prime yield remained stable in 2017. There was limited investment activity in 2012, with transaction volume shrinking in 2012 and 2013. However, it significantly increased in 2014, 2015 and 2016. Milan's investment market, in particular, was highly active in 2016, although the lack of prime office space posed an obstacle for further investment. In terms of supply, there was little activity in the office market in 2012. However, office supply increased in 2014 and showed signs of recovery in 2016. Development activity slightly increased in 2017.

(6) Madrid

Madrid represents the largest domestic office market, alongside other major office markets such as Barcelona. Madrid's RGDP/GDP ratio ranges from 19.7% to 20.8% (Table 9).

In terms of macroeconomics, Spain faced challenges in 2012 and 2013 following the real estate bubble bursting in 2007. This led to high unemployment rates and the restructuring of the finance sector. However, signs of recovery emerged in 2013, and the actual recovery began in 2014. The demand for real estate started increasing from 2015, and by 2016 Spain had become one of the fastest-growing European economies. Inflation remained absent in 2014, stayed negative in 2016, and saw a gradual decline in prices in 2017. Employment prospects were expected to gradually improve from 2014 onwards, with notable growth in service and tourism employment in 2017.

In terms of prime rent, Madrid (and Barcelona) experienced weak demand due to the economic recession in 2012 and 2013. However, the market remained stable in 2014, and the upswing of recovery started to reflect in the space market from 2015 onwards. Nevertheless, positive trends were observed in the IT and professional service sectors in 2012, and there was high demand for prime office spaces in 2013, showing signs of recovery in 2014. The volume of take-up was significant in 2015, and the demand appeared to spread to second-tier markets. The vacancy rate in Madrid increased in 2012 due to weak demand and new space supply, resulting in large buildings remaining vacant in 2013.

Regarding yields, there was an activation of investment in 2014, and investment opportunities in core assets became more competitive. In terms of supply, several key development projects were completed in 2012. However, due to the pessimistic macroeconomic situation in 2013, new construction was unlikely to start. Consequently, the supply level remained steady in 2014 and 2015.

5.3 Estimated Regression Results

5.3.1 OLS Estimation

(1) OLS Estimation Results (Non-Lag)

1) User Sector, OLS (Non-Lag)

In this model, there are five degrees of freedom for the model and 270 degrees of freedom for the residual. The R-squared value shows the coefficient of determination, which is a measure of how much variance in the dependent variable is explained by the independent variables in the model. The R-squared value is 0.8195, which means that approximately 82% of the variance in the dependent variable is explained by the independent variables in the model. The adjusted R-squared value takes account of the number of independent variables; the value is 0.8161, indicating that the explanatory power for the real rent equation is 81.6%. The F-statistic tests the null hypothesis that all the regression coefficients are equal to zero. In this case, the

F-statistic is 245.10 with a p-value of 0.0000, indicating that the regression model is statistically significant.

Table 10. OLS estimation results (non-lag)

variable \ equation	(1) real rent		(2) yield		(3) new construction		(4) occupied stock	
	expected	actual	expected	actual	expected	actual	expected	actual
real rent					(+)	0.427***	(-)	-0.276***
real GDP	(+)	0.612***						
employment	(+)	0.198***			(+)	0.314*		
interest rate			(+)	0.139***	(-)	0.600	(-)	-0.004
take-up	(+)	0.087***						
new construction	(-)	0.070***					(+)	0.191***
development permit					(+)	0.223***	(+)	0.136***
occupied stock	(-)	-0.419***						
constant		-0.321		-2.519***		-0.670		9.349***
Adjusted R^2		0.816		0.239		0.227		0.319
F-statistic		245.10***		104.76***		13.68***		21.45***
Number of samples		276		332		174		176

$$\ln rr_{it} = \underset{(-0.89)}{-0.321} + \underset{(22.24)}{0.612} \ln rGDP_{it} + \underset{(7.29)}{0.198} \ln emp_{it}$$
$$+\underset{(3.80)}{0.087} \ln tkp_{it} - \underset{(-13.27)}{0.419} \ln os_{it} + \underset{(3.84)}{0.070} \ln cons_{it}$$

The coefficient of real GDP is 0.612, indicating that the explanatory variables is key determinants of space demand with high elasticity for real rent. The employment and take-up ratio coefficients are 0.198 and 0.087, respectively, which are also positive but not as elastic as the previous variable. In terms of the hypothesis, occupied stock and new construction are expected to have negative signs, and the actual coefficients are -0.419 and 0.070, respectively.

2) Investment Sector, OLS (Non-Lag)

The sum of squares (SS) for the model represents the variation in the dependent variable (ly) that is explained by the independent variable (li). The mean squares (MS) for the model are simply the SS divided by the degrees of freedom (1). The residual value shows the sum of squares, the degrees of freedom and the mean squares for the residuals only. The SS for the residuals represents the variation in the dependent variable that is not explained by the independent variable (i.e., error or noise in the data). The MS for the residuals is simply the SS divided by the degrees of freedom (331). The R-squared is 0.2410, which means that about 24.1% of the variation in yield is explained by the interest rate. The adjusted R-squared value shows the adjusted R-squared, which takes account of the number of independent variables and the sample size. In this case, the adjusted R-squared is slightly lower than the R-squared, at 0.2387.

$$\ln y_{it} = \underset{(-46.35)}{-2.519} + \underset{(10.24)}{0.139} \ln int_{it}$$

Yield is correctly shown to be positively affected by the interest rate, with a coefficient of 0.139.

3) Flow of Development Sector, OLS (Non-Lag)

$$\ln cons_{it} = -0.670 + 0.427 \ln rr_{it} + 0.314 \ln emp_{it} + 0.600 \ln int_{it} + 0.223 \ln dev_{it}$$
$$(-0.46) \quad (2.92) \qquad (1.78) \qquad (0.82) \qquad (4.83)$$

The coefficients of each independent variable for new construction are positive: rent 0.427, employment 0.314, and development permit 0.223, which are all consistent with the hypothesis. On the other hand, the interest rate coefficient has a positive value of 0.600, which is inconsistent with the hypothesis that the interest rate has a negative effect on new construction. Real rent and development permit variables are statistically significant at the 0.05 level, as their p-values are less than 0.05.

4) Stock of Development Sector, OLS (Non-Lag)

The adjusted R-squared value is 0.319, suggesting that some of the independent variables may not be useful in explaining the dependent variable. The Prob > F-value of 0.0000 indicates that at least one of the independent variables is significantly related to the dependent variable.

$$\ln os_{it} = 9.349 - 0.276 \ln rr_{it} + 0.191 \ln cons_{it} - 0.004 \ln int_{it} + 0.136 \ln dev_{it}$$
$$(19.87) \quad (-3.99) \qquad (4.82) \qquad (-0.09) \qquad (5.21)$$

The coefficients of each independent variable for occupied stock are -0.276 for rent, 0.191 for new construction, -0.004 for interest rate and 0.136 for development permission 12 quarters (three years) ago. These results are all consistent with the hypotheses.

(2) OLS Estimation Results (Lag)

Table 11. OLS estimation results (lag)

equation / variable	(1) real rent		(2) yield		(3) new construction		(4) occupied stock	
	expected	actual	expected	actual	expected	actual	expected	actual
real rent					(+)	0.275*	(-)	-0.210**
real GDP	(+)	0.649***						
employment	(+)	0.199***			(+)	0.545***		
interest rate			(+)	0.139***	(-)	-0.143	(-)	-0.002
take-up	(+)	0.092***						
take-up (-1)	(+)	0.081***						
new construction (-12)	(-)	0.028*					(+)	0.128***
development permit (-12)					(+)	0.116**	(+)	0.148***
occupied stock	(-)	-0.464***						
constant		-0.572		-2.519***		-2.683		9.273***
Adjusted R^2		0.859		0.239		0.190		0.267
F-statistic		223.48***		104.76***		8.16***		11.55***
Number of samples		221		332		123		117

1) User Sector, OLS (Lag)

This output is from a linear regression model with the dependent variable real rent (lrr) and six independent variables: real GDP (lrgdp), employment (le), take-up (ltkpr and L.ltkpr), lagged new construction (L12.lcons) and occupied stock (los). The output provides information on the estimated coefficients, the estimated covariances and the estimated autocorrelations. It also reports the number of observations, the number of groups and the number of observations per group. The Wald chi-squared test was used to test the overall significance of the regression. The p-value is reported as significant at the 0.01 level, indicating that at least one of the independent variables is significantly related to the dependent variable. The R-squared value of 0.859 indicates that about 85.9% of the variation in real rent (lrr) is explained by the six independent variables in the model. The F-test has a p-value of 0.0000, which means that the model is statistically significant.

$$\begin{aligned}\ln rr_{it} = {} & -0.572 + 0.649 \ln rGDP_{it} + 0.199 \ln emp_{it} \\ & (-4.78) \quad (23.97) \qquad\qquad (7.33) \\ & +0.922 \ln tkp_{it} + 0.820 \ln tkp_{i(t-1)} - 0.464 \ln os_{it} - 0.571 \ln cons_{i(t-12)} \\ & (3.59) \qquad\qquad (3.04) \qquad\qquad (-13.75) \qquad (1.66)\end{aligned}$$

The coefficient of real GDP for rent is 0.649, and the current and previous take-up ratios are 0.922 and 0.820, respectively. The employment coefficient is 0.199, which has the expected positive sign but is not highly elastic for rent. Negative determinants in the hypothesis, the occupied stock and the new construction coefficient, show values of -0.571 and -0.464, respectively.

2) Flow of Development Sector, OLS (Lag)

This regression output is for a regression model with the dependent variable new construction (lcons) and four independent variables, real rent (lrr), employment (le), interest rate (li) and lagged development (L12.ldev). The R-squared value of 0.2168 indicates that the independent variables explain about 21.68% of the variation in the dependent variable. The adjusted R-squared value of 0.1902 is slightly lower, suggesting that some of the independent variables may not be sufficient to explain the dependent variable. The F-statistic is 8.16 with a p-value of 0.0000, which indicates that the regression model is statistically significant. The Root MSE is the square root of the mean squared error of the regression model. It measures the average distance between the observed values and the predicted values of the dependent variable. In this case, the Root MSE is 0.16109.

$$\begin{aligned}\ln cons_{it} = {} & -2.683 + 0.275 \ln rr_{it} + 0.545 \ln emp_{it} \\ & (-1.55) \quad (1.70) \qquad\qquad (2.67) \\ & -0.144 \ln int_{it} - 0.116 \ln dev_{i(t-12)} \\ & (-1.35) \qquad\qquad (2.01)\end{aligned}$$

The coefficients of each independent variable for new construction are as follows: rent 0.275, employment 0.545, interest rate -0.144, and development permission 12 quarters (3 years) ago -0.116. While coefficient development permit has opposite sign from the expected plus, others show satisfactory result in terms of signs and fit with the hypothesis. Employment (le), lagged development permit (L12.ldev), and real rent (lrr) have significant positive coefficients, indicating that increases in these variables are associated with increases in new construction (lcons). The coefficient for interest rate (li) is negative but not significant, suggesting that its impact on new construction (lcons) is uncertain.

3) Stock of Development Sector, OLS (Lag)

The R-squared value is 0.2920, so that independent variables explain about 29.20% of the model. The adjusted R-squared value of 0.267 is slightly lower than the R-squared. The p-value of the F-statistic is less than 0.05, indicating that at least one of the coefficients is significantly different from zero, and hence the model is statistically significant.

$$\begin{aligned} \ln os_{it} = {} & \underset{(13.86)}{9.273} - \underset{(-2.49)}{0.210} \ln rr_{it} + \underset{(2.86)}{0.128} \ln cons_{i(t-12)} \\ & + \underset{(0.03)}{0.002} \ln int_{it} + \underset{(3.96)}{0.148} \ln dev_{i(t-12)} \end{aligned}$$

The coefficients of each independent variable for occupied stock were -0.210 for rent, 0.128 for new construction (t-12), 0.002 for interest rate and 0.148 for development permission 12 periods (three years) ago. While new construction (t-12) and development permits are consistent with the hypothesis, real rent and interest rate are inconsistent.

The coefficient for real rent (lrr) is not statistically significant at the 5% level, since its p-value is greater than 0.05. A 1% increase in real rent (lrr) is associated with a 1.82% increase in occupied stock (los). The coefficient for interest rate (li) is not statistically significant at the 10% level, since its p-value is greater than 0.10. A 1% increase in interest rate (li) is associated with a 1.82% unit decrease in occupied stock (los). The coefficient for lagged new construction (L12.lcons) is not statistically significant at the 1% level, since its p-value is less than 0.01. A 1% increase in lagged new construction (L12.lcons) is associated with a 0.128% increase in occupied stock (los). The coefficient for lagged development permits (L12.ldev) is not statistically significant at the 1% level, since its p-value is greater than 0.01. A 1% increase in development permits (L12.ldev) is associated with a 0.148% increase in occupied stock (los).

5.3.2 GLS Estimation

(1) GLS Estimation Results (Non-Lag)

Table 12. GLS estimation results (non-lag)

variable \ equation	(1) real rent		(2) yield		(3) new construction		(4) occupied stock	
	expected	actual	expected	actual	expected	actual	expected	actual
real rent					(+)	0.483***	(-)	-0.403***
real GDP	(+)	0.543***						
employment	(+)	0.169***			(+)	0.319**		
interest rate			(+)	0.135***	(-)	0.090	(-)	-0.013*
take-up	(+)	0.085***						
new construction	(-)	0.111***					(+)	0.056
development permit					(+)	0.114***	(+)	0.015
occupied stock	(-)	-0.374***						
constant		0.196		-2.532***		-0.605		11.323***
Wald Chi^2		1751.2***		137.28***		55.72***		25.79***
Number of samples		276		332		174		123

1) User Sector, GLS (Non-Lag)

For each independent variable, the output shows the estimated coefficient (Coef.), its standard error (Std. Err.), the z-statistic, the associated p-value (P > |z|) and the 95% confidence interval for the coefficient.

$$\begin{aligned} \ln rr_{it} &= 0.196 + 0.543 \ln rGDP_{it} + 0.169 \ln emp_{it} \\ &\quad (0.87) \quad (22.60) \qquad\qquad (11.39) \\ &\quad +0.085 \ln tkp_{it} - 0.374 \ln os_{it} + 0.111 \ln cons_{it} \\ &\quad (5.71) \qquad\quad (-12.51) \qquad (7.32) \end{aligned}$$

The coefficients of real GDP, take-up ratio and employment are 0.543, 0.085 and 0.169, respectively. The occupied stock and the new construction coefficients indicated values of -0.374 and 0.111, respectively.

2) Investment Sector, GLS (Non-Lag)

In the second equation, there are 332 observations and seven groups. The Wald chi-square test shows that the joint significance of these variables is statistically significant at the 0.01 level.

$$\begin{aligned} \ln y_{it} &= -2.532 + 0.135 \ln int_{it} \\ &\quad (-54.29) \quad (11.72) \end{aligned}$$

Yield is correctly shown to be positively affected by the interest rate, with a coefficient of 0.135.

3) Flow of Development Sector, GLS (Non-Lag)

The Wald chi-squared statistic tests the overall significance of the model, which in this case is highly significant with a p-value of 0.0000. Therefore, at least one of the independent variables is significantly associated with the dependent variable.

$$\ln cons_{it} = -0.605 + 0.483 \ln rr_{it} + 0.319 \ln emp_{it} + 0.090 \ln int_{it} + 0.114 \ln dev_{it}$$
$$(-0.51) \quad (3.93) \quad (2.17) \quad (1.62) \quad (2.88)$$

The coefficients for each independent variable for new construction volume are all positive, with rent 0.483, employment 0.319, development permit 0.114 and interest rate 0.090. Since interest rate is expected to be negative, its result is inconsistent with the hypothesis, while all the other results are consistent.

4) Stock of Development Sector, GLS (Non-Lag)

The Wald chi-squared statistic indicates the significance of the overall regression, with a chi-squared value of 25.79 and a p-value of 0.0000. This suggests that at least one of the predictor variables is significantly related to the outcome variable.

$$\ln os_{it} = 11.332 - 0.403 \ln rr_{it} + 0.056 \ln cons_{it} - 0.013 \ln int_{it} + 0.015 \ln dev_{it}$$
$$(32.84) \quad (-9.31) \quad (1.92) \quad (-0.47) \quad (0.82)$$

(2) GLS Estimation Results (Lag)

Table 13. GLS estimation results (lag)

variable \ equation	(1) real rent		(2) yield		(3) new construction		(4) occupied stock	
	expected	actual	expected	actual	expected	actual	expected	actual
real rent					(+)	-0.105	(-)	-0.399***
real GDP	(+)	0.618***						
employment	(+)	0.199***			(+)	0.843***		
interest rate			(+)	0.139***	(-)	-0.062	(-)	-0.006
take-up	(+)	0.105***						
take-up (-1)	(+)	0.061***						
new construction (-12)	(-)	0.028*					(+)	-0.013
development permit (-12)					(+)	-0.061	(+)	0.006
occupied stock	(-)	-0.478***						
constant		-0.358		-2.532***		-2.387		11.767***
Wald Chi^2		2436.6***		137.3***		25.79***		63.14***
Number of samples		221		332		123		117

1) User Sector, GLS (Lag)

The dependent variable is real rent (lrr), and there are six independent variables: real GDP (lgdpr), employment (le), take-up (ltkp), lagged take-up (L1.ltkp), occupied stock (los) and lagged new construction (L12.lcons). The Wald $chi^2(6)$ statistic is 2436.61, indicating that at least one of the coefficients is statistically significant and the overall model is statistically significant.

$$\ln rr_{it} = -3.580 + 0.618 \ln rGDP_{it} + 0.199 \ln emp_{it}$$
$$(-1.55)\ (27.11)\qquad (12.62)$$
$$+1.051 \ln tkp_{it} + 0.091 \ln tkp_{i(t-1)} - 0.478 \ln os_{it} + 0.060 \ln cons_{i(t-12)}$$
$$(6.81)\qquad (5.62)\qquad (-17.04)\qquad (3.86)$$

The output reports that the model has estimated six coefficients. The coefficient for the independent variable real GDP (lgdpr) is 0.618, with a standard error of 0.023. The associated z-statistic is 27.11, and the p-value is less than 0.001, indicating that this variable is statistically significant. The coefficient of employment is 0.199, and the current and previous take-up ratios are 1.051 and 0.091, respectively. The coefficients of occupied space and new construction are -0.478 and 0.060, respectively. This output suggests that the variables real GDP (lgdpr), employment (le), take-up (ltkp), lagged take-up (L1.ltkp) and occupied stock (los) are statistically significant predictors of real rent (lrr) at the 0.01 level, and lagged construction (L12.lcons) at the 0.10 level.

2) Flow of Development Sector, GLS (Lag)

There are seven panels in the model, and the Wald chi-squared test indicates that at least one of the independent variables is statistically significant in explaining the variation in new construction (lcons). The p-value of the test is very small, suggesting that the model is a good fit for the data.

$$\ln cons_{it} = -2.387 - 0.105 \ln rr_{it} + 0.844 \ln emp_{it}$$
$$(-1.41)\ (-0.85)\qquad (3.75)$$
$$-0.062 \ln int_{it} - 0.061 \ln dev_{i(t-12)}$$
$$(-0.64)\qquad (-1.24)$$

The coefficients of each independent variable for the new construction volume are -0.105 for rent, 0.844 for employment and -0.062 for interest rate, which is consistent with the hypothesis. However, the impact of development permits 12 quarters (three years) ago on current new construction is -0.061, which is inconsistent with the hypothesis that development permits have a positive (+) effect on new construction.

The coefficients suggest that real rent (lrr), employment (le) and development permit (ldev) have positive and statistically significant effects on new construction (lcons), while interest rate (li) is not statistically significant. The lagged value of development permit (ldev) also has a positive and statistically significant effect on new construction (lcons).

The coefficient estimate for employment (le) is 0.844, and the standard error of the coefficient for employment (le) is 0.225. The t-statistics and associated p-values are presented in the 'z' and 'P>|z|', respectively. The t-statistic for employment (le) is 3.75, and the associated p-value is 0.000, indicating that the coefficient for le is statistically significant at conventional levels.

The '95% Conf. Interval' provides the 95% confidence intervals for the coefficient estimates. The 95% confidence interval for the coefficient for employment (le) is (0.4029493, 1.284329).

Overall, the output suggests that only the coefficient for employment (le) is statistically significant, with a positive value indicating that an increase in le is associated with an increase in new construction (lcons). The other variables, real rent (lrr), interest rate (li) and lagged development permit (L12.ldev), do not appear to have a statistically significant relationship with new construction (lcons), based on their p-values.

3) Stock of Development Sector, GLS (Lag)

This output refers to the dependent variable occupied stock (los) and four independent variables: real rent (lrr), new construction (L12.lcons), interest rate (li) and development permit (L12.ldev). The model used lag of new construction and development permit. The number of observations is 117, and the p-value of the Wald test is less than 0.05, indicating that at least one independent variable has a statistically significant effect on the dependent variable.

$$\begin{aligned} \ln os_{it} = {} & \underset{(25.03)}{11.768} - \underset{(-7.45)}{0.399} \ln rr_{it} - \underset{(-0.39)}{0.012} \ln cons_{i(t-12)} \\ & - \underset{(-0.12)}{0.005} \ln int_{it} + \underset{(0.25)}{0.007} \ln dev_{i(t-12)} \end{aligned}$$

The regression includes four independent variables. The coefficients of each independent variable for occupied space are -0.399 for rent, -0.012 for lagged new construction, -0.005 for interest rate and 0.148 for development permit 12 periods (three years) ago. The coefficients show the estimated change in the dependent variable associated with a one-unit increase in the corresponding independent variable.

In this model, real rent (lrr) has a negative coefficient of -0.399, indicating that a 1% increase in real rent (lrr) is associated with a decrease of approximately 0.4% in occupied stock (los). New construction (L12.lcons), interest rate (li) and development permit (L12.ldev) have no statistically significant effect on occupied stock (los) at a 5% significance level, as the p-value is higher than 0.05. The intercept is statistically significant at a 1% significance level, indicating that occupied stock (los) has an expected value of approximately 11.77 when all independent variables are zero.

5.3.3 Panel Fixed Effects Estimation

(1) Panel Estimation, Fixed Effects (non-lag)

1) User Sector, Panel Fixed Effects (Non-Lag)

Table 14. Estimation results - panel, fixed effects (non-lag)

variable \ equation	(1) real rent		(2) yield		(3) new construction		(4) occupied stock	
	expected	actual	expected	actual	expected	actual	expected	actual
real rent					(+)	2.969***	(-)	0.165***
real GDP	(+)	0.209***						
employment	(+)	2.188***			(+)	-0.818		
interest rate			(+)	0.187***	(-)	0.169	(-)	-0.044***
take-up	(+)	-0.003						
new construction	(-)	0.049***					(+)	-0.006*
development permit					(+)	0.013	(+)	0.004*
occupied stock	(-)	-1.148***						
constant		-7.929***		-2.330***		-4.375		7.989***
R^2 (overall)		0.328		0.241		0.076		0.018
F-statistic		46.68***		243.39***		8.01***		57.90***
Number of samples		276		332		174		176

The regression is estimated using fixed effects (within) method, which means that the analysis controls for unobserved time-invariant heterogeneity among the groups by removing group-specific fixed effects from both the dependent and independent variables. The model was estimated using a panel data set of seven groups with an average of 39.4 observations per group and a total of 276 observations.

The R-squared value is reported in three forms: within R-squared, between R-squared and overall R-squared. Within R-squared measures the variation in the dependent variable that is explained by the independent variables after controlling for the effects of time-invariant heterogeneity. Between R-squared measures the variation in the dependent variable that is explained by the independent variables at the group level. Overall R-squared measures the variation in the dependent variable that is explained by the independent variables in the entire sample.

The variance components of the model, including the within-group R-squared, measures the proportion of the variation in the dependent variable that is explained by the independent variables within each group. The corr (u_i, X_b) measures the correlation between the group-specific error term and the fitted values from the regression. A value close to -1 or 1 would suggest that the model is misspecified and may not be appropriate.

The F-test in the last row tests the null hypothesis that all group-specific intercepts are equal to zero, which would suggest that there is no unobserved heterogeneity across groups. The F-statistic is 46.68 and the p-value is 0.0000, indicating that the null hypothesis is rejected, and the fixed effects model is preferred over a pooled OLS regression. The explanatory power of the independent variable for real rent is 32.8%.

$$\ln rr_{it} = -0.792 + 0.209 \ln rGDP_{it} + 2.188 \ln emp_{it}$$
$$(-4.00) \quad (2.26) \qquad\qquad (10.06)$$
$$-0.003 \ln tkp_{it} - 1.1480 \ln os_{it} + 0.049 \ln cons_{it}$$
$$(-0.21) \qquad\qquad (-4.57) \qquad (5.46)$$

In the real rent equation, the coefficients of employment and occupied stock are 2.188 and -1.148. As determinants of space demand, they are found to be the main variables with high elasticity for rent. The coefficients of real GDP and new construction are 0.209, -0.003 and 0.049, which are positive values but not less elastic than employment and occupied stock. The coefficient of the take-up ratio is negative at -0.003, and it is different from the expected sign.

2) Investment Sector, Panel Fixed Effects (Non-Lag)

The number of observations is 332 and the number of groups is seven. R-squared values are also shown in the output. The within R-squared value of 0.4290 indicates that the model explains 42.90% of the within-entity variation of the dependent variable. The between R-squared value of 0.0183 indicates that the model explains 1.83% of the between-entity variation of the dependent variable. The overall R-squared value of 0.2410 indicates that the model explains 24.10% of the total variation of the dependent variable.

The F-test that all group-specific effects are zero has an F-statistic of 35.91 and a p-value of less than 0.05, indicating that the fixed effects model is statistically significant at the 5% level. The corr (u_i, X_b) value of -0.2942 shows the correlation between the error term and the estimated fixed effects. This value indicates that there is a negative correlation between the two, which is expected in fixed effects estimation.

$$\ln y_{it} = -2.330 + 0.187 \ln int_{it}$$
$$(-48.79) \quad (15.60)$$

In the yield equation, yield is correctly shown to be positively affected by the interest rate, and the coefficient is 0.187.

3) Flow of Development Sector, Panel Fixed Effects (Non-Lag)

The F-test of the null hypothesis that all individual-specific effects are zero has a p-value of 0.0000, indicating that the fixed effects regression model is statistically significant overall.

$$\ln cons_{it} = -4.375 + 2.969 \ln rr_{it} - 0.818 \ln emp_{it} + 0.169 \ln int_{it} + 0.013 \ln dev_{it}$$
$$(-0.23) \quad (4.93) \qquad\quad (-0.40) \qquad\quad (1.62) \qquad\quad (0.26)$$

4) Stock of Development Sector, Panel Fixed Effects (Non-Lag)

The number of observations is 176, and there are seven groups in the data. The within R-squared of 0.5840 represents the proportion of the total variation in the dependent variable that is explained by the independent variables after controlling for individual-specific fixed effects. The between R-squared of 0.0062 represents the proportion of the total variation in the dependent variable that is explained by the independent variables at the group level (i.e., across individuals). The overall R-squared of 0.0176 represents the proportion of the total variation in the dependent variable that is explained by the independent variables without controlling for individual-specific fixed effects. The overall R-squared indicates that independent variables explain only a very small proportion of the model. However, the within R-squared is 0.584 so that a larger proportion is explained by the model within each group.

The F-statistic of 57.90 tests the joint significance of all the independent variables in the model, and the associated p-value of 0.0000 indicates that the model is statistically significant. The correlation between the group fixed effects and the regressors is negative and close to -1, indicating that the fixed effects model is a good choice for controlling unobserved heterogeneity in the data.

$$\underset{}{\ln os_{it}} = \underset{(50.16)}{7.989} + \underset{(6.18)}{0.165}\ln rr_{it} - \underset{(-1.83)}{0.006}\ln cons_{it} - \underset{(-10.97)}{0.044}\ln int_{it} + \underset{(1.72)}{0.004}\ln dev_{it}$$

(2) Panel Estimation, Fixed Effects (Lag)

Table 15. Estimation results - panel, fixed effects (lag)

equation / variable	(1) real rent		(2) yield		(3) new construction		(4) occupied stock	
	expected	actual	expected	actual	expected	actual	expected	actual
real rent					(+)	0.093	(-)	0.223***
real GDP	(+)	0.164*						
employment	(+)	1.767***			(+)	5.989***		
interest rate			(+)	0.187***	(-)	0.019	(-)	-0.034***
take-up	(+)	-0.010						
take-up (-1)		-0.004						
new construction (-12)	(-)	-0.007***					(+)	-0.005*
development permit (-12)					(+)	-0.127***	(+)	-0.019
occupied stock	(-)	-0.801***						
constant		-5.945***		-2.330***		-55.283***		7.659***
R^2 (overall)		0.289		0.241		0.141		0.047
F-statistic		21.92***		243.4***		13.12***		43.35***
Number of samples		221		332		123		117

1) User Sector, Panel Fixed Effects (Lag)

The number of observations is 221, and the number of groups is seven. The dependent variable is real rent (lrr), and the independent variables are real GDP (lgdpr), employment (le), take-up (ltkp), lagged take-up (L.ltkp), occupied stock (los) and lagged new construction (L12.lcons). The R-squared values indicate that 38.74% of the variation in the dependent variable is explained by the independent variables within each individual unit, 36% of the variation is explained by the independent variables between individual units and the overall R-squared is

28.85%. The F-test shows whether the overall regression is significant or not. Here, the F-statistic is 21.92 with a probability value of 0.0000, indicating that the regression is significant. The correlation between the error term and the fitted values (X_b) is -0.8520, indicating that there is a high degree of serial correlation (or autocorrelation) in the errors, which violates one of the assumptions of the model.

$$\begin{aligned}\ln rr_{it} = &-5.945 + 0.164 \ln rGDP_{it} + 1.767 \ln emp_{it} \\ &(-3.42) \quad (1.76) \qquad\qquad (6.81) \\ &-0.010 \ln tkp_{it} - 0.004 \ln tkp_{i(t-1)} - 0.801 \ln os_{it} - 0.007 \ln cons_{i(t-12)} \\ &(-0.86) \qquad\qquad (-0.36) \qquad\qquad (-3.66) \qquad (-0.90)\end{aligned}$$

2) Flow of Development Sector, Panel Fixed Effects (Lag)

The regression output also reports the R-squared values for the model. The within R-squared is 0.3191, which means that 31.91% of the total variation in the dependent variable is explained by the independent variables after controlling for fixed effects. The between R-squared is 0.2932, which indicates that 29.32% of the variation in the dependent variable is due to differences between the groups. Finally, the overall R-squared is 0.1407, which represents the proportion of variation in the dependent variable explained by all the independent variables, including both fixed and time-invariant factors. The F-test for the joint significance of all the group fixed effects is statistically significant (F = 13.12, p = 0.000), indicating that there are significant differences in the intercepts of the groups.

$$\begin{aligned}\ln cons_{it} = &-55.283 + 0.093 \ln rr_{it} + 5.989 \ln emp_{it} \\ &(-3.91) \quad (0.16) \qquad\qquad (3.63) \\ &+0.019 \ln int_{it} - 0.127 \ln dev_{i(t-12)} \\ &(0.18) \qquad\qquad (-3.14)\end{aligned}$$

The coefficient estimate of real rent (lrr) is 0.0929 with a standard error of 0.5805, and the corresponding t-statistic is 0.16, which indicates that the coefficient is not significantly different from zero at the 5% level of significance. The coefficient estimate of employment (le) is 5.9888 with a standard error of 1.6489, and the corresponding t-statistic is 3.63, which indicates that the coefficient is significantly different from zero at the 5% level of significance.

The coefficient estimate of interest rate (li) is 0.0193 with a standard error of 0.1080, and the corresponding t-statistic is 0.18, which indicates that the coefficient is not significantly different from zero at the 5% level of significance. The coefficient estimate of lagged development permit (L12.ldev) is -0.1267 with a standard error of 0.0403, and the corresponding t-statistic is -3.14, which indicates that the coefficient is significantly different from zero at the 5% level of significance. The regression output indicates that the coefficient for employment (le) is positive and significant at the 1% level. On the other hand, the coefficient for development permit (L12.ldev) is statistically significant but the sign is negative, different from the expectation.

The F-test for the joint significance of all group fixed effects is reported at the bottom of the output. The null hypothesis is that all the group fixed effects are zero. The F-statistic is 44.88 with a p-value of 0.0000, which indicates that the null hypothesis is rejected at the 5% level of significance. The R-squared values are reported in the output, indicating that 16.43% of the variation in new construction (lcons) is explained by the independent variables after controlling for time-invariant, individual-specific effects.

3) Stock of Development Sector, Panel Fixed Effects (Lag)

$$\begin{aligned} \ln os_{it} = {} & \underset{(41.77)}{7.659} + \underset{(7.96)}{0.223} \ln rr_{it} - \underset{(-1.92)}{0.005} \ln cons_{i(t-12)} \\ & - \underset{(-6.33)}{0.034} \ln int_{it} - \underset{(-0.79)}{0.019} \ln dev_{i(t-12)} \end{aligned}$$

The coefficients for the independent variables can be interpreted as follows: A 1% increase in real rent (lrr) is associated with a 0.22% increase in occupied stock (los). A 1% increase in new construction (lcons) is associated with a -0.005% decrease in occupied stock (los). The p-value for this coefficient is 0.058, indicating that this result is statistically significant at the 10% level. A 1% increase in interest rate (li) is associated with a -0.034% decrease in occupied stock (los). A 1% increase in new development (ldev) is associated with a -0.019% decrease in occupied stock (los). However, the p-value for this coefficient is 0.429, greater than the 10% significance level, so this result is not statistically significant.

The σ_u and σ_e values are the standard deviations of the random effects and the residuals, respectively. The rho value is the fraction of the total variance in the dependent variable that is explained by the random effects. The F-test at the bottom of the output tests the null hypothesis that all of the random effects are equal to zero. In this case, the F-statistic is 6603.99 and the p-value is less than 0.0001, indicating that the null hypothesis can be rejected and indicating that at least one of the random effects is not zero. This confirms that the fixed effects model is a better fit for the data than a model with only a constant term.

5.3.4 Panel Random Effects Estimation

(1) Panel Estimation, Random Effects (Non-Lag)

1) User Sector – Panel, Random Effects (Non-Lag)

The standard error measures the precision of the estimates. The z-statistics are calculated by dividing the coefficient estimate by its standard error. A larger absolute value of the z-statistic indicates stronger evidence against the null hypothesis that the true coefficient is zero. The P>|z| presents the probabilities of observing a z-statistic as extreme or more extreme than the observed one if the null hypothesis were true. A p-value less than 0.05 is usually considered statistically significant. The '95% Conf. Interval' indicates the 95% confidence intervals for each coefficient estimate. These intervals give a range of plausible values for the true coefficient, based on the sample data.

Table 16. Estimation results - panel, random effects (non-lag)

variable \ equation	(1) real rent		(2) yield		(3) new construction		(4) occupied stock	
	expected	actual	expected	actual	expected	actual	expected	actual
real rent					(+)	1.310***	(-)	0.164***
real GDP	(+)	0.231***						
employment	(+)	1.580***			(+)	0.032		
interest rate			(+)	0.185***	(-)	0.082	(-)	-0.044***
take-up	(+)	0.002						
new construction	(-)	0.056***					(+)	-0.006*
development permit					(+)	0.069	(+)	0.004*
occupied stock	(-)	-0.759***						
constant		-5.742***		-2.339***		-2.721		8.081***
R^2 (overall)		0.392		0.241		0.136		0.016
Wald test		197.30***		238.42***		26.03***		187.32***
Number of samples		276		332		174		176

The number of observations is 276, and they are divided into seven groups. The output provides information on the goodness of fit of the model and the statistical significance of the estimated coefficients. The within-group R-squared is 0.4558, meaning that the independent variables explain about 45.58% of the variation in the dependent variable within each group. The between-group R-squared is 0.4216, indicating that there is significant variation between the groups that is not explained by the independent variables. The overall R-squared is 0.3921, which is the weighted average of the within- and between-group R-squared. The Wald chi-squared test statistic for the joint significance of the independent variables is 197.30, with a probability of 0.0000, indicating that at least one of the independent variables is statistically significant in explaining the variation in the dependent variable.

$$\begin{aligned}\ln rr_{it} = &-5.742 + 0.231 \ln rGDP_{it} + 1.580 \ln emp_{it} \\ &(-3.41)\ \ (2.78) \qquad\qquad\quad (8.40) \\ &+0.002 \ln tkp_{it} - 0.759 \ln os_{it} + 0.056 \ln cons_{it} \\ &\ \ (0.15) \qquad\qquad (-3.90) \qquad\quad (6.10)\end{aligned}$$

The employment coefficient for rent is 1.580, indicating that it is a main determinant of space demand with high elasticity. On the other hand, the coefficients of the real GDP and take-up ratio are 0.231 and 0.002, respectively, which shows a lower level of elasticity than other estimation methods. As negative determinants of rent in the hypothesis, the occupied stock coefficient is -0.759 and that of new construction is 0.056, indicating opposite results in the case of the new construction variable.

2) Investment Sector – Panel, Random Effects (Non-Lag)

The number of observations is 332. The R-squared values indicate that 42.9% of the variation in the dependent variable is explained by the within-group variation, and 1.83% is explained by the between-group variation. The overall R-squared, the explanatory power of the independent variable, is 24.1%. The Wald chi-square test tests the null hypothesis that all the random effects are zero. In this case, the test statistic is 238.42 and the p-value is 0.000, which provides strong evidence against the null hypothesis. This suggests that a random effects model is appropriate for these data, and that the random effects contribute significantly to the variation in the outcome variable.

$$\underset{}{\ln y_{it}} = \underset{(-36.43)}{-2.339} + \underset{(15.44)}{0.185} \ln int_{it}$$

Yield is correctly shown to be positively affected by the interest rate. The coefficient is 0.185, meaning yield increases by 0.185% when the interest rate increases by 1%. The result is significant at the 1% level and matches the expected sign.

3) Flow of Development Sector – Panel, Random Effects (Non-Lag)

In the development flow equation, R-squared indicates that about 13.6% of the total variation in new construction (lcons) is explained by the model, with 13.5% of the variation being within-group and 42.8% being between-group.

$$\ln cons_{it} = \underset{(-0.90)}{-2.721} + \underset{(3.99)}{1.310} \ln rr_{it} + \underset{(0.09)}{0.032} \ln emp_{it} + \underset{(1.05)}{0.082} \ln int_{it} + \underset{(1.40)}{0.069} \ln dev_{it}$$

The coefficients for each independent variable for new construction are all positive: rent 1.310, employment 0.032, interest rate 0.082 and development permit 0.069. While employment and development permit are less elastic than other estimation methods, real rent is highly elastic to the new construction. Interest rate was originally expected to be negative so the result is inconsistent with the hypothesis.

4) Stock of Development Sector – Panel, Random Effects (Non-Lag)

The number of observations is 176, and they are grouped into seven groups. The R-squared statistics indicate that most of the variation in the dependent variable is due to within-group differences rather than between-group differences. Specifically, the within-group R-squared is 0.5839, which means that about 58% of the variation in occupied stock (los) is due to differences within each group. The between-group R-squared is 0.0070, which means that only 0.7% of the variation in occupied stock (los) is due to differences between groups. The overall R-squared is 0.0163, which means that the independent variables explain only about 1.6% of the variation in occupied stock (los). The Wald chi-squared test indicates that at least one of the independent variables is statistically significant in explaining occupied stock (los).

$$\ln os_{it} = \underset{(41.90)}{8.081} + \underset{(5.56)}{0.164} \ln rr_{it} - \underset{(-1.54)}{0.006} \ln cons_{it} - \underset{(-9.91)}{0.044} \ln int_{it} + \underset{(1.65)}{0.004} \ln dev_{it}$$

The coefficients of each independent variable for occupied space were 0.164 for rent, -0.006 for new construction, -0.044 for interest rate and 0.004 for development permission 12 periods (three years) ago. Of these variables, it is inconsistent with the hypothesis that rent has a negative (-) and new construction a positive (+) effect on occupied space.

(2) Panel, Random Effects (Lag)

Table 17. Estimation results - panel, random effects (lag)

variable \ equation	(1) real rent		(2) yield		(3) new construction		(4) occupied stock	
	expected	actual	expected	actual	expected	actual	expected	actual
real rent					(+)	0.788**	(-)	0.222***
real GDP	(+)	0.649***						
employment	(+)	0.199***			(+)	0.703**		
interest rate			(+)	0.185***	(-)	-0.237***	(-)	-0.035***
take-up	(+)	0.092***						
take-up (-1)	(+)	0.082***						
new construction (-12)	(-)	0.027*					(+)	-0.005
development permit (-12)					(+)	-0.086*	(+)	-0.002
occupied stock	(-)	-0.464***						
constant		-0.572		-2.339***		-7.091**		7.768***
R^2 (overall)		0.862		0.241		0.124		0.005
Wald test		1340.9***		238.42***		37.66***		132.59***
Number of samples		221		332		123		117

1) User Sector – Panel, Random Effects (Lag)

The panel random effects model was estimated with 221 observations and seven groups. The dependent variable was denoted by real rent (lrr) and the independent variables included real GDP (lgdpr), employment (le), take-up (ltkp), last quarter's take-up (L.ltkp), occupied stock (los) and new construction of 12 quarters (three years) ago (L12.lcons).

The R-squared value indicates that the model explains 16.68% of the variation in the dependent variable within each group, 87.51% of the variation between groups, and 86.24% of the overall variation. The overall R-squared value of 0.8624 indicates that the model explains a substantial portion of the variation in the dependent variable. The Wald chi-squared test evaluates the overall statistical significance of the model, and the p-value of 0.0000 suggests that the model is statistically significant. The output also reports the estimated correlation between the error term and the independent variables, which is assumed to be zero in this case.

$$\ln rr_{it} = -0.572 + 0.649 \ln rGDP_{it} + 0.199 \ln emp_{it}$$
$$(-1.59) \quad (23.97) \qquad (7.33)$$
$$+0.092 \ln tkp_{it} + 0.082 \ln tkp_{i(t-1)} - 0.463 \ln os_{it} + 0.028 \ln cons_{i(t-12)}$$
$$(3.59) \qquad (3.04) \qquad (-13.75) \qquad (1.66)$$

The real GDP coefficient for rent has a high coefficient of 0.649, indicating that it is a main determinant of rent. On the other hand, the coefficient of employment is 0.199 and those of the take-up ratio (t and t-1) are 0.092 and 0.082, respectively, which is less elastic than other estimation methods. Regarding negative determinants in the hypothesis, the occupied space coefficient is -0.463, and new construction is 0.028. The coefficient estimates suggest that all variables except for lagged new construction (L12.lcons) and the constant term are statistically significant at the 5% level, based on their p-values.

2) Flow of Development Sector – Panel, Random Effects (Lag)

The dependent variable is new construction (lcons), and the independent variables are real rent (lrr), employment (le), interest rate (li) and development permit of 12 quarters (three years) ago (L12.ldev). In this model, within R-squared is 0.135, between R-squared is 0.428 and the overall R-squared is 0.137.

$$\begin{aligned} \ln cons_{it} = {} & -7.091 + 0.788 \ln rr_{it} + 0.703 \ln emp_{it} \\ & (-2.47) \quad (2.54) \qquad\qquad (2.06) \\ & -0.237 \ln int_{it} - 0.086 \ln dev_{i(t-12)} \\ & (-2.66) \qquad\quad (-1.95) \end{aligned}$$

The coefficients of each independent variable for new construction are 0.788 for rent, 0.703 for employment, -0.237 for interest rate and -0.086 for development permits of 12 quarters (three years) ago. Among these, interest rate and development permits do not match the hypothesis. At the same time, real rent and employment are strong drivers of new construction in the random effects estimation.

3) Stock of Development Sector – Panel, Random Effects (Lag)

The dependent variable is occupied stock (los), and the independent variables are real rent (lrr), new construction (lcons), interest rate (li), lagged development permit (L12.ldev) and lagged new construction (L12.lcons).

In a random effects model, there are three types of R-squared: within, between, and overall. The within R-squared (0.6206) measures the proportion of the total variation in the dependent variable that is explained by the independent variables. The between R-squared (0.0047) measures the proportion of the variation in the group means that is explained by the independent variables. The overall R-squared (0.0465) measures the proportion of the total variation in the dependent variable that is explained by both the independent variables and the group-level intercepts (i.e., the random effects).

$$\begin{aligned} \ln os_{it} = {} & 7.768 + 0.222 \ln rr_{it} - 0.005 \ln cons_{i(t-12)} \\ & (34.54) \quad (7.01) \qquad\qquad (-1.63) \\ & - 0.035 \ln int_{it} - 0.002 \ln dev_{i(t-12)} \\ & (-5.58) \qquad\quad (-0.62) \end{aligned}$$

The coefficients represent the expected change in the dependent variable for a one-unit increase in the corresponding independent variable. The coefficients of each independent variable for occupied space are 0.222 for rent, -0.005 for new construction, -0.035 for interest rate and -0.002 for development permission 12 quarters (three years) ago. Among these, interest rate and development permits are determinants consistent with the hypothesis. The p-values of real rent and interest rate for occupied stock are less than 0.05, which means that the coefficient is statistically significant at the 5% level.

5.3.5 GMM Estimation

(1) GMM Estimation (Non-Lag)

Table 18. GMM estimation results (non-lag)

variable \ equation	(1) real rent		(2) yield		(3) new construction		(4) occupied stock	
	expected	actual	expected	actual	expected	actual	expected	actual
real rent					(+)	0.203	(-)	0.011***
real GDP	(+)	0.056***						
employment	(+)	0.025			(+)	-0.020		
interest rate			(+)	0.030***	(-)	-0.044	(-)	-0.003**
take-up	(+)	0.021***						
new construction	(-)	-0.018***					(+)	-0.004***
development permit					(+)	-0.053*	(+)	0.001
occupied stock	(-)	0.006						
real rent (-1)	(+)	0.918***						
yield (-1)			(+)	0.936***				
new construction (-1)					(+)	0.900***		
occupied stock (-1)							(+)	1.002***
constant		-0.484***		-0.082**		-0.541		-0.076***
Wald Chi^2		11082***		8925.8***		502.70***		197948***
Number of samples		276		324		174		176

1) User Sector, GMM (Non-Lag)

The GMM relies on a set of instrumental variables to identify the parameters of the model. These instruments are chosen so that they are correlated with the explanatory variables but not correlated with the error term of the model. The specific instruments used depend on the lag structure of the model and the number of exogenous variables.

The estimation was conducted on a dataset with 276 observations and seven groups, with an average of 39.43 observations per group. The model includes 315 instruments, and the Wald chi-squared test has a value of 11,082.38 with six degrees of freedom, indicating strong evidence against the null hypothesis that all the coefficients are zero. The p-value associated with the Wald chi-squared test is zero, which indicates that the model has statistically significant explanatory power.

The 'one-step results' indicate the estimated coefficients and standard errors of each independent variable. The coefficient of real rent (lrr) on its first lag (L1) is 0.918, which is statistically significant at a very high level ($p < 0.001$). This suggests that there is a strong autocorrelation between real rent (lrr) and its lagged values.

The coefficients of the other independent variables (lgdpr, le, ltkp, los and lcons) indicate the effect of each variable on the dependent variable while controlling for the other variables. Among these, real GDP (lgdpr), take-up (ltkp) and occupied stock (los) are statistically significant at a high level ($p < 0.001$, $p = 0.03$, $p = 0.038$, respectively), while employment (le) and new construction (lcons) are not statistically significant at the conventional 5% level ($p = 0.228$, $p = 0.674$, respectively).

$$\begin{aligned}\ln rr_{it} = &-0.484 + 0.918 \ln rr_{i(t-1)} + 0.056 \ln rGDP_{it} + 0.025 \ln emp_{it} \\ &(-2.70)\quad (51.83) \qquad\qquad (3.66) \qquad\qquad (1.21) \\ &+0.185 \ln tkp_{it} + 0.006 \ln os_{it} - 0.018 \ln cons_{it} \\ &\ (3.87) \qquad\qquad (0.37) \qquad\qquad (-4.79)\end{aligned}$$

The coefficient of previous rent for the current rent is high at 0.918 for the previous rent. Real GDP has a coefficient of 0.056, employment of 0.025, and take-up ratio space of 0.185, which are consistent with the hypothesis but lower than other estimation methods. The occupied stock coefficient has a value of 0.017, and the new construction has a value of -0.018, thus the occupied stock variable indicates the opposite result to the hypothesis. In addition, this is an opposite result in GMM compared to other estimation methods, where occupied stock has a negative and new construction a positive coefficient.

2) Investment Sector, GMM (Non-Lag)

The number of observations is 324, divided into seven groups, and the average number of observations per group is around 46. The number of instruments used in the estimation is 342, and the Wald chi-squared test with two degrees of freedom was used to test the overall significance of the two variables in the model. The p-value of the test was reported to be less than 0.001, indicating that the model is statistically significant.

The Wald chi-squared test with two degrees of freedom tests the joint hypothesis that all coefficients are equal to zero. The test indicates that at least one of the coefficients is significantly different from zero, with a p-value of less than 0.05, suggesting that the model fits the data well.

$$\begin{aligned}\ln y_{it} = &-0.082 + 0.936 \ln y_{i(t-1)} + 0.030 \ln int_{it} \\ &(-2.38)\quad (68.68) \qquad\qquad (7.87)\end{aligned}$$

Yield of the previous period was found to have a coefficient of 0.936, and the interest rate has a coefficient of 0.030, which is consistent with the expected sign of the hypothesis.

3) Flow of Development Sector, GMM (Non-Lag)

The number of observations is 174, the average number of observations per group is 24.86, and the number of instruments used in the estimation is 157. The Wald chi-squared test of overidentifying restrictions is 502.70, and the associated p-value is 0.0000, which suggests that the model is a good fit for the data and that the instruments are valid.

$$\ln cons_{it} = -0.541 + 0.900 \ln cons_{i(t-1)} + 0.203 \ln rr_{it} - 0.020 \ln emp_{it}$$
$$(-0.27) \quad (20.83) \qquad (1.26) \qquad (-0.08)$$
$$-0.044 \ln int_{it} - 0.053 \ln dev_{it}$$
$$(-0.71) \qquad (-1.73)$$

The coefficient of the previous new construction is highly elastic to the current new construction with a value of 0.900. Coefficients of real rent (0.203) and interest rate (-0.044) are not as highly elastic as previous new construction, but consistent with the hypothesis. On the other hand, the employment coefficient and the development permit coefficient have negative values of -0.020 and -0.0530, respectively, which is not consistent with the hypothesis. These coefficients were originally expected to have a positive (+) effect on the new construction volume.

4) Stock of Development Sector, GMM (Non-Lag)

In the fourth equation, there are 176 observations in the sample, divided into seven groups. The minimum number of observations per group is 13, the average is 25.14, and the maximum is 44. The model has 161 instruments, and the Wald chi-squared test of overidentifying restrictions has a statistic of 197,947.62 with a probability value of 0.0000, indicating that the instruments are valid. The Wald chi^2 statistic tests the null hypothesis that all of the coefficients are zero. The p-value associated with this test is very small (0.0000), indicating that at least one of the coefficients is significantly different from zero.

$$\ln os_{it} = -0.076 + 1.002 \ln os_{i(t-1)} + 0.011 \ln rr_{it} - 0.004 \ln cons_{it}$$
$$(-2.62) \quad (389.27) \qquad (3.98) \qquad (-6.02)$$
$$-0.003 \ln int_{it} + 0.001 \ln dev_{it}$$
$$(-2.17) \qquad (1.63)$$

Coefficients of each independent variable for occupied space are 1.002 for the previous occupied space, 0.011 for rent, -0.004 for new construction, -0.003 for interest rate and 0.001 for development permission 12 quarters (three years) ago. The hypothesis that rent has a negative (-) effect on the occupied space and that new construction will have a positive (+) effect does not match with this result.

(2) GMM Estimation (Lag)

Table 19. GMM estimation results (lag)

variable \ equation	(1) real rent		(2) yield		(3) new construction		(4) occupied stock	
	expected	actual	expected	actual	expected	actual	expected	actual
real rent					(+)	-0.068	(-)	0.006**
real GDP	(+)	0.081***						
employment	(+)	0.028			(+)	0.272		
interest rate			(+)	0.030***	(-)	-0.0003	(-)	-0.0003
take-up	(+)	0.013**						
take-up (-1)	(+)	0.008						
new construction (-12)	(-)	-0.002					(+)	0.0005
development permit (-12)					(+)	-0.005	(+)	-0.0002
occupied stock	(-)	-0.035**						
real rent (-1)	(+)	0.884***						
yield (-1)			(+)	0.936***				
new construction (-1)					(+)	0.821***		
occupied stock (-1)							(+)	1.003***
constant		-0.334*		-0.082**		-1.281		-0.069**
Wald Chi^2		11082***		8925.8***		502.70***		215301***
Number of samples		276		324		123		117

1) User Sector, GMM (Lag)

The GMM estimates the effects of the independent variables (lgdpr, le, ltkp, los and lcons) on the dependent variable (lrr) using panel data. The analysis was conducted on a dataset with 276 observations. The analysis used 251 instruments and resulted in a Wald chi^2 test statistic of 11082 with a p-value of 0.0000, indicating that the model is statistically significant.

The ‘one-step results’ indicate the estimated coefficients and standard errors of each independent variable. The coefficient of real rent on its first lag (L.lrr) is 0.884, which is statistically significant at a very high level ($p < 0.001$). This suggests that there is a strong autocorrelation between real rent (lrr) and its lagged values.

$$\ln rr_{it} = -0.334 + 0.884 \ln rr_{i(t-1)} + 0.081 \ln rGDP_{it} + 0.028 \ln emp_{it}$$
$$(-1.76)\ (36.25)\qquad (3.55)\qquad (1.21)$$
$$+0.135 \ln tkp_{it} + 0.008 \ln tkp_{i(t-1)} - 0.035 \ln os_{it} - 0.002 \ln cons_{i(t-12)}$$
$$(2.17)\qquad (1.16)\qquad (-2.07)\qquad (-0.42)$$

In the user sector equation, the coefficient of previous rent for current rent is highly elastic at 0.884. Real GDP has a coefficient of 0.081, employment of 0.028 and take-up ratio of 0.135, which are consistent with the hypothesis but lower than other estimation methods. Regarding the negative determinants in the hypothesis, occupied stock coefficient indicates values of -0.035 and new construction of -0.002, so the sign direction of both independent variables is consistent with the hypothesis.

The coefficients of the independent variables indicate the effect of each variable on the dependent variable while controlling for the other variables. Among these, real GDP (lgdpr), take-up (ltkp), occupied stock (los) and lagged real rent (L.lrr) are statistically significant, while lagged take-up (L.ltkp), employment (le) and new construction (lcons) are not statistically significant.

Instruments in GMM address the endogeneity issue in the model, which occurs when the independent variables are correlated with the error term. The GMM type shows the lag structure of the instruments, and the standard shows the variables used as instruments.

2) Flow of Development Sector, GMM (Lag)

The model includes five independent variables: new construction (lcons), real rent (lrr), employment (le), interest rate (li) and development permit of 12 quarters (three years) ago (L12.ldev). The model uses data from 123 observations and seven groups, with an average of 17.57 observations per group.

The Wald chi^2 and Prob > chi^2 sections provide information about the overall goodness of fit of the model. The Wald chi^2 statistic tests the null hypothesis that all of the coefficients are zero. In this case, the test statistic is 272.26 with a p-value of 0.0000, indicating that the model is statistically significant.

$$\begin{aligned}\ln cons_{it} = &-1.281 + 0.821 \ln cons_{i(t-1)} - 0.068 \ln rr_{it} + 0.273 \ln emp_{it} \\ &(-0.49)\ (15.76) \qquad\qquad (-0.49) \qquad\quad (0.84) \\ &-0.003 \ln int_{it} - 0.005 \ln dev_{i(t-12)} \\ &(-0.00) \qquad\quad (-0.17)\end{aligned}$$

In the flow equation of the development sector, the coefficients of each independent variable for new construction have the following values: 0.821 for the previous quarter's new construction, -0.068 for rent, 0.273 for employment, -0.003 for interest rate and -0.005 for development permission before the 12th quarter (three years). Previous new construction, employment and interest rates are consistent with the hypothesis.

3) Stock of Development Sector, GMM (Lag)

The dependent variable is occupied stock (los), and the independent variables are real rent (lrr), new construction of 12 quarters (three years) ago (L12.lcons), interest rate (li) and development permit of 12 quarters (three years) ago (L12.ldev).

The Wald chi^2 test was used to test the overall significance of the model. The test result indicates a Wald chi^2 statistic of 215301.54 with a p-value of 0.0000, indicating that the model is statistically significant.

$$\ln os_{it} = -0.069 + 1.003 \ln os_{i(t-1)} + 0.006 \ln rr_{it} - 0.0005 \ln cons_{i(t-12)}$$
$$(-2.46) \quad (402.56) \qquad (2.50) \qquad (0.93)$$
$$- 0.0003 \ln int_{it} - 0.0002 \ln dev_{i(t-12)}$$
$$(-0.19) \qquad (-0.26)$$

In stock equation of the development sector, coefficients of each independent variable for occupied space are 1.003 for previous occupied space, 0.006 for rent, -0.0005 for new construction, -0.0003 for interest rate and -0.0002 for development permission 12 quarters (three years) ago. Among these, it is inconsistent with the hypothesis that rent has a negative (-) effect on occupied space, and that new construction and development permits have a positive (+) effect.

5.3.6 3SLS (SUR) Estimation

(1) SUR (3SLS) Estimation Results (Non-Lag)

Table 20. SUR (3SLS) estimation results (non-lag)

variable \ equation	(1) real rent		(2) yield		(3) new construction		(4) occupied stock	
	expected	actual	expected	actual	expected	actual	expected	actual
real rent					(+)	0.707***	(-)	-0.552***
real GDP	(+)	0.640***						
employment	(+)	0.187***			(+)	0.254		
interest rate			(+)	0.154***	(-)	0.066	(-)	-0.022
take-up	(+)	0.072**						
new construction	(-)	0.080***					(+)	0.239***
development permit					(+)	0.239***	(+)	0.145***
occupied stock	(-)	-0.436***						
constant		-0.411		-2.482***		-1.900		10.772***
R^2		0.793		0.277		0.266		0.333
Chi^2		612.87***		58.10***		71.19***		176.44***
Number of samples		154		154		154		154

The following describes the analysis results of each of the four equations in the 3SLS model that do not consider the time lag effect.

1) User Sector, SUR (Non-Lag)

The first equation estimates the impact of gross domestic product (lgdpr), employment (le), take-up (ltkp), new construction (lcons) and occupied stock (los) on real rent (lrr). The equation has 154 observations and five parameters. The root mean squared error (RMSE) is 0.2044, and the R-squared, the explanatory power of independent variables, is 0.7930 (79.3%). The chi-squared test indicates that the overall model is significant at the 0.05 level of significance.

$$\ln rr_{it} = -0.411 \; + \; 0.640 \ln rGDP_{it} \; + \; 0.187 \ln emp_{it}$$
$$(-0.63) \quad (15.16) \qquad\qquad (3.71)$$
$$+0.072 \ln tkp_{it} - 0.436 \ln os_{it} + 0.080 \ln cons_{it}$$
$$(2.06) \qquad\quad (-9.82) \qquad (3.36)$$

In the first equation, the coefficient of real GDP for rent and that of employment are both high at 0.644 and 0.187, respectively. On the other hand, the take-up ratio coefficient is 0.072 and the new construction coefficient is 0.080, indicating a different result from the hypothesis.

2) Investment Sector, SUR (Non-Lag)

$$\ln y_{it} = -2.482 \;\; + \;\; 0.154 \ln int_{it}$$
$$(-30.32) \;\; (7.62)$$

The second equation estimates the impact of interest rate on yield. The equation has 154 observations and one parameter. The RMSE is 0.1904, and the R-squared is 0.2766. Therefore, the explanatory power of the independent variable for the rate of return is 27.7%. The chi-squared test indicates that the overall model is significant at the 0.05 level of significance.

Interest rate has a coefficient of 0.154, which indicates that yield increases by 0.154% when the interest rate increases by 1%. The result is significant at the 1% level, and correctly signed according to the hypothesis.

3) Flow of Development Sector, SUR (Non-Lag)

The third equation estimates the impact of real rent (lcons), employment (le), interest rate (li) and development permit (ldev) on new construction (lcons). The equation has 154 observations and four parameters. The RMSE is 0.7189 and the R-squared, the explanatory power of independent variables, is 0.2659 (26.6%). The chi-squared test indicates that the overall model is significant at the 0.05 level of significance.

$$\ln cons_{it} = -1.900 \; + \; 0.707 \ln rr_{it} + 0.254 \ln emp_{it} + 0.066 \ln int_{it} + 0.239 \ln dev_{it}$$
$$(-1.16) \;\; (4.58) \qquad\quad (1.29) \qquad\qquad (0.84) \qquad\qquad (5.00)$$

In the third equation, the coefficients of each independent variable for new construction volume are 0.707 for rent, 0.254 for employment, 0.066 for interest rate and 0.239 for development permit. Interest rate is the only determinant which is inconsistent with the hypothesis.

4) Stock of Development Sector, SUR (Non-Lag)

The fourth equation estimates the impact of real rent (lrr), new construction (lcons), interest rate (li) and development permit (ldev) on occupied stock (los). The equation has 154 observations and four parameters. The RMSE is 0.3947 and the R-squared is 0.3326. The explanatory power of the independent variable for occupied inventory is 33.3%. The chi-squared test indicates that the overall model is significant at the 0.05 level of significance.

$$\ln os_{it} = \underset{(25.37)}{10.772} - \underset{(-8.71)}{0.552} \ln rr_{it} + \underset{(6.63)}{0.239} \ln cons_{it} - \underset{(-0.53)}{0.022} \ln int_{it} + \underset{(6.21)}{0.145} \ln dev_{it}$$

In the fourth equation, the coefficient of each independent variable for occupied stock are -0.552 for rent, -0.022 for interest rate, 0.239 for new construction and 0.145 for new development. These are all consistent with the hypotheses.

(2) SUR (3SLS) Estimation Results (Lag)

Table 21. SUR (3SLS) estimation results (lag)

variable \ equation	(1) real rent		(2) yield		(3) new construction		(4) occupied stock	
	expected	actual	expected	actual	expected	actual	expected	actual
real rent					(+)	0.496***	(-)	-0.391***
real GDP	(+)	0.723***						
employment	(+)	0.145**			(+)	0.321**		
interest rate			(+)	0.062**	(-)	-0.122	(-)	-0.001
take-up	(+)	0.099**						
take-up (-1)	(+)	-0.002						
new construction (-12)	(-)	0.022					(+)	0.122***
development permit (-12)					(+)	0.147***	(+)	0.137***
occupied stock		-0.468***						
constant		-0.557		-2.891***		-1.840		10.533***
R^2		0.809		0.066		0.629		0.417
Chi^2		479.40***		4.74**		38.83***		78.31***
Number of samples		99		99		99		99

This is the output of the seemingly unrelated regression (SUR) model with four equations estimated simultaneously. The independent variables are different across the equations, but some of them are shared. Table 21 reports the estimated coefficients, expected and actual signs, the associated p-values, and R^2. The coefficients represent the expected change in the dependent variable for a one-unit change in the corresponding independent variable.

1) User Sector, SUR (Lag)

For real rent equation, there are five independent variables: real GDP (lgdpr), employment (le), take-up (ltkp), occupied stock (los) and new construction of 12 quarters (three years) ago (L12.lcons). The coefficients of real GDP and occupied stock are statistically significant at the 5% level ($p < 0.05$), indicating that they have a significant effect on the dependent variable real rent (lrr). The R-squared value for this equation is 0.8093, which suggests that the model explains a large proportion of the variation in real rent (lrr1). The coefficients also suggest positive impacts of real GDP (lgdpr), employment (le) and take-up (ltkp) on real rent (lrr), while the impact of occupied stock (los) on real rent (lrr) is negative.

2) Investment Sector, SUR (Lag)

For yield equation, there are only two variables, interest rate (li) and a constant term. Only the coefficient of interest rate (li) is statistically significant at the 5% level. The coefficient suggests that a one-unit increase in li is associated with a 0.062 increase in yield (ly). The R-squared value for this equation is quite low (0.066), indicating that the model explains very little of the variation in yield (ly).

3) Flow of Development Sector, SUR (Lag)

For new construction equation, there are four independent variables: real rent (lrr), employment (le), interest rate (li) and development permits of 12 quarters (three years) ago (L12.ldev). The coefficients of real rent (lrr), employment (le) and development permits of 12 quarters (three years) ago (L12.ldev) are statistically significant, while that of interest rate (li) is not. The coefficients suggest that higher values of real rent (lrr), employment (le) and development permits (ldev) are associated with higher values of new construction (lcons), while higher values of interest rate (li) are associated with lower values of new construction (lcons). The R-squared value for this equation is 0.629, indicating that the model explains a moderate proportion of the variation in new construction (lcons).

4) Stock of Development Sector, SUR (Lag)

For occupied stock equation, there are four independent variables: real rent (lrr), new construction of 12 quarters (three years) ago (L12.lcons), interest rate (li) and new development of 12 quarters (three years) ago (L12.ldev). The coefficients of real rent (lrr) and new construction (L12.lcons) are statistically significant, while the coefficients of interest rate (li) and development permit (L12.ldev) are not. The R-squared value for this equation is 0.417, indicating that the model explains a moderate proportion of the variation in occupied stock (los).

Three independent variables are statistically significant. The coefficient for real rent (lrr) suggests that higher values of real rent (lrr) are associated with lower values of occupied stock (los), while the coefficients for development permit (ldev) and new construction (lcons) suggest that higher values of the variables are associated with higher values of occupied stock (los). The results suggest that the relationships between the dependent variables and the independent variables intersect across the equations, which justifies the use of the SUR model to estimate them simultaneously.

(3) Scenario Analysis

Scenario analysis enables the obtaining of values of the dependent variables that are altered according to unexpected events by modifying the input conditions based on the established model (Brooks and Tsolacos, 2009). Given that the model assumes that the investment subsector connects the user and developer subsectors, the changes in the investment subsector and their impacts on other subsectors are examined. If the yield decreases, it will result in an increase in capital value due to the reduction in the capitalisation rate as well as a stimulating effect on the construction sentiment. Therefore, this case is called a positive scenario, and the opposite situation is referred to as a negative scenario. Tables 22 and 23 present the positive and negative scenario analyses and assume that the yield and interest rate decreased and increased by 0.005 (0.5%), respectively.

Table 22. SUR (3SLS) estimation results (non-lag, positive scenario)

variable \ equation	(1) real rent		(2) yield		(3) new construction		(4) occupied stock	
	expected	actual	expected	actual	expected	actual	expected	actual
real rent					(+)	0.802***	(-)	-0.552***
real GDP	(+)	0.626***						
employment	(+)	0.219***			(+)	0.032		
interest rate			(+)	0.119***	(-)	0.025	(-)	-0.045
take-up	(+)	0.069*						
new construction	(-)	0.087***					(+)	0.229***
development permit					(+)	0.249***	(+)	0.144***
occupied stock	(-)	-0.431***						
constant		-0.629		-2.701***		-0.443		10.737***
R^2		0.785		0.212		0.236		0.333
Chi^2		559.41***		37.71***		63.72***		163.85***
Number of samples		145		145		145		145

$$\ln y_{it} = -2.701 + 0.119 \ln int_{it}$$
$$(-32.27)\quad(6.14)$$

Under the positive scenario (Table 22) when the interest rate decreases by 0.5%, the correlation coefficient of the interest rate to the yield in the yield equation decreases from 0.154 in Table 20 to 0.119, and the explanatory power of the yield equation also decreases from 27.7% to 21.2%. Additionally, the impact on other subsectors, particularly the development subsector (flow), is observed as the elasticity of real rent to new construction in the third equation and increases from 0.707 to 0.802.

$$\ln y_{it} = -2.224 + 0.207 \ln int_{it}$$
$$(-23.92)\quad(8.30)$$

Conversely, when the interest rate increases by 0.5% in the negative scenario (Table 23), the correlation coefficient of the interest rate to the yield in the yield equation increases from 0.154 in Table 19 to 0.207, and the explanatory power of the yield equation increases from 27.7% to 31.2%.

Table 23. SUR (3SLS) estimation results (non-lag, negative scenario)

variable \ equation	(1) real rent		(2) yield		(3) new construction		(4) occupied stock	
	expected	actual	expected	actual	expected	actual	expected	actual
real rent					(+)	0.716***	(-)	-0.552***
real GDP	(+)	0.641***						
employment	(+)	0.185***			(+)	0.247		
interest rate			(+)	0.207***	(-)	0.097	(-)	-0.043
take-up	(+)	0.074***						
new construction	(-)	0.080***					(+)	0.238***
development permit					(+)	0.241***	(+)	0.147***
occupied stock	(-)	-0.438***						
constant		-0.395		-2.224***		-1.794		10.698***
R^2		0.793		0.312		0.266		0.333
Chi^2		614.01***		68.89***		71.54***		180.65***
Number of samples		154		154		154		154

(4) Extension of Investment Subsector

1) FTSE 100 Index

The expansion of yield equation can be considered as another attempt to enhance understanding of the investment subsector, and stock prices are additionally included in the system here as an indicator of the macroeconomic sentiment. The Financial Times Stock Exchange 100 Index (FTSE 100) is selected as a proxy of stock prices, as the indicator comprises the 100 largest UK companies in terms of total market value listed on the London Stock Exchange. Since stock prices and required rate of return have an inverse relationship, the expected sign between the FTSE 100 index and yield is negative.

Table 24. SUR (3SLS) estimation results (non-lag, FTSE 100 included)

variable \ equation	(1) real rent		(2) yield		(3) new construction		(4) occupied stock	
	expected	actual	expected	actual	expected	actual	expected	actual
real rent					(+)	0.690***	(-)	-0.538***
real GDP	(+)	0.615***						
employment	(+)	0.159***			(+)	0.231		
interest rate			(+)	0.081***	(-)	0.067	(-)	-0.024
FTSE 100	(+)		(-)	-0.744***				
take-up	(+)	0.065**						
new construction	(-)	0.080***					(+)	0.236***
development permit					(+)	0.244***	(+)	0.140***
occupied stock	(-)	-0.418***						
constant		0.740***		3.734***		-1.578		10.706***
R^2		0.787		0.448		0.267		0.338
Chi^2		591.55***		125.38***		69.52***		143.25***
Number of samples		154		154		154		154

$$\ln y_{it} = 3.734 + 0.081 \ln int_{it} - 0.744 \ln FTSE_{it}$$
$$(4.06) \quad (4.01) \quad (-6.77)$$

In the previous scenario analysis, a positive scenario involved a decrease in interest rates, which boosts the real economy. Hence, a decrease in interest rates reflects economic expansion here as well.

2) Network Connectivity

In the earlier theoretical review (subsection 2.3.5) and the modelling of the office market (subsection 3.2.5), the geographical factor was considered one of the external factors. This study introduced network connectivity to reflect the geographical impact within the real estate market framework (Figure 10).

This variable was initially set as a positive determinant of rent in the derivation of the structural equation (section 3.4), specifically, in equation (22.1). However, during the model adjustment stage in subsection 4.3.2, when the rent equation was revised to equation (9.1), network connectivity was excluded as an independent variable to achieve statistically significant results and to satisfy the principles of parsimony and the identification conditions. As a result, while the key independent variables of the subsectors within the office market were included in the model, the influence of external factors, except for GDP, was not reflected.

Therefore, to further explore the omitted geographical influence between cities, Table 25 re-estimates the simultaneous equations model, replacing the new construction variable—which is insignificant in the 3SLS estimation results in Table 20—with the network connectivity variable.

Table 25. SUR (3SLS) estimation results (non-lag, network connectivity included in the user subsector)

	(1) real rent		(2) yield		(3) new construction		(4) occupied stock	
	expected	actual	expected	actual	expected	actual	expected	actual
real rent					(+)	0.669***	(-)	-0.545***
real GDP	(+)	0.610***						
employment	(+)	0.126**			(+)	0.284		
interest rate			(+)	0.157***	(-)	0.080	(-)	-0.025
take-up	(+)	0.039						
new construction							(+)	0.238***
development permit					(+)	0.239***	(+)	0.149***
occupied stock	(-)	-0.255***						
network connectivity	(+)	0.789***						
constant		-5.631***		-2.471***		-1.903		10.720***
R^2		0.804		0.277		0.269		0.394
Chi^2		616.00***		60.27***		68.95***		175.61***
Number of samples		154		154		154		154

The rent equation estimation results show that a 1% increase in network connectivity leads to a 0.789% increase in rent, aligning with the assumption in equation (22.1) on the impact of network connectivity on rent.

$$\ln rr_{it} = -5.631 + 0.610 \ln rGDP_{it} + 0.126 \ln emp_{it}$$
$$(-2.87) \quad (11.93) \qquad\qquad (2.04)$$
$$+0.039 \ln tkp_{it} - 0.255 \ln os_{it} + 0.789 \ln nc_{it}$$
$$(0.99) \qquad (-3.34) \qquad (2.38)$$

In Table 26, network connectivity is included in the user subsector, and both network connectivity and the FTSE 100 Index are included in the investment subsector. This alternative model is based on the assumptions from equation (22.1) that network connectivity is a positive determinant of rent and from Table 24 in this subsection that a higher FTSE 100 Index, as a proxy for stock prices, implies a lower required rate of return; and from an additional assumption that cities with closer connections to other cities will be more competitive in the investment subsector.

Table 26. SUR (3SLS) estimation results (non-lag, FTSE 100 and network connectivity included)

variable \ equation	(1) real rent		(2) yield		(3) new construction		(4) occupied stock	
	expected	actual	expected	actual	expected	actual	expected	actual
real rent					(+)	0.667***	(-)	-0.429***
real GDP	(+)	0.582***						
employment	(+)	0.077			(+)	0.251		
interest rate			(+)	0.058***	(-)	0.080	(-)	-0.037
FTSE 100			(-)	-0.955***				
take-up	(+)	0.024						
new construction							(+)	0.236***
development permit					(+)	0.244***	(+)	0.137***
occupied stock	(-)	-0.209***						
network connectivity	(+)	1.145***	(-)	-0.785***				
constant		-7.485***		10.618***		-1.569		9.981***
R^2		0.801		0.508		0.268		0.368
Chi^2		636.92***		216.61***		68.64***		141.73***
Number of samples		154		154		154		154

In the rent equation, network connectivity is identified as a strong positive determinant of rent, with an elasticity coefficient of 1.145.

$$\ln rr_{it} = -7.485 + 0.582 \ln rGDP_{it} + 0.077 \ln emp_{it}$$
$$(-3.99) \quad (11.97) \qquad\qquad (1.32)$$
$$+0.024 \ln tkp_{it} - 0.209 \ln os_{it} + 1.145 \ln nc_{it}$$
$$(0.65) \qquad (-2.92) \qquad (3.61)$$

In the yield equation, the yield decreases by 0.955% with a 1% increase in the FTSE 100 Index and by 0.785% with an increase in network connectivity, indicating that both these independent variables have negative elasticity with respect to yield. Additionally, the r-squared of the yield equation is 50.8%, showing a significant increase in the explanatory power of the investment subsector compared to Table 20.

$$\ln y_{it} = 10.618 + 0.058 \ln int_{it} - 0.955 \ln FTSE_{it} - 0.785 \ln nc_{it}$$
$$(8.58) \quad (3.11) \quad (-9.89) \quad (9.58)$$

5.3.7 Panel Fixed Effects Estimation - London West End and the City

(1) London, West End

Table 27. Estimation results - panel, fixed effects (non-lag) of London, West End

variable \ equation	(1) real rent		(2) yield		(3) new construction		(4) occupied stock	
	expected	actual	expected	actual	expected	actual	expected	actual
real rent					(+)	4.282 ***	(-)	0.179 ***
real GDP	(+)	0.006						
employment	(+)	0.833 ***			(+)	-3.539		
interest rate			(+)	0.259***	(-)	0.733*	(-)	-0.052***
take-up	(+)	0.047						
new construction	(-)	0.097 ***					(+)	-0.018***
development permit					(+)	-0.119	(+)	0.001
occupied stock	(-)	2.001***						
constant		-20.124**		-2.225***		15.140		7.507***
R^2 (overall)		0.834		0.502		0.431		0.916
F-statistic		30.24***		45.50***		7.19***		106.26***
Number of samples		36		47		43		44

1) User Sector, Fixed Effects (Non-Lag)

The fixed-effects (within) regression results indicate that the model has a high overall R-squared value of 0.8344, which means that 83.44% of the variation in the dependent variable (lrr1) can be explained by the independent variables included in the model. The F-test of overall significance with F (5,30) = 30.24 and Prob > F = 0.0000 indicates that the regression model is statistically significant at the 5% level, which means that at least one of the independent variables in the model is statistically significant in explaining the variation in the dependent variable.

Based on the output, it can be seen that none of the independent variables are statistically significant at conventional levels (i.e., $p < 0.05$), except for occupied stock (los) and new construction (lcons). The coefficient estimate for occupied stock (los) is 2.001 with a standard error of 0.9435, indicating that a one-unit increase in occupied stock (los) is associated with a 2.001 unit increase in real rent (lrr) after controlling for the other variables in the model. The coefficient estimate for new construction (lcons) is 0.0970 with a standard error of 0.0152, indicating that a one-unit increase in new construction (lcons) is associated with a 0.0970 unit increase in real rent (lrr) after controlling for the other variables in the model.

2) Investment Sector, SUR (Non-Lag)

The R-squared value for the model is 0.5022, which means that about 50% of the variation in the dependent variable is explained by the independent variable. The F (1,45) value of 45.40 is the result of an F-test of the joint hypothesis that the coefficients of all the independent variables, except for the constant, are equal to zero. The p-value associated with this F-test is 0.0000, which means that the null hypothesis (no relationship between the independent variable and the dependent variable) is rejected.

There are 47 observations in the panel data, and R-squared indicates the goodness of fit of the model, indicating that 50.22% of the variation in yield (ly) is explained by the variation in the interest rate (li). The F statistic tests the overall significance of the regression, which is significant at the 1% level.

The regression output shows that the coefficient of the interest rate (li) is positive and statistically significant at the 1% level. This suggests that interest rate (li) has a positive effect on yield (ly) after controlling for time-invariant heterogeneity. The σ_u and σ_e estimates are not reported, since the model does not use a random effects estimator. Finally, the F-test of the null hypothesis that all fixed effects are equal to zero is rejected at the 1% level, indicating that the fixed effects model is preferred to the pooled OLS model.

3) Flow of Development Sector, SUR (Non-Lag)

The F-test in the last line tests the null hypothesis that all the individual-specific effects are equal to zero. The low p-value (0.0002) suggests that the null hypothesis can be rejected, meaning that there are individual-specific effects that are not accounted for by the independent variables included in the model. The R-squared value of 0.4310 indicates that the independent variables explain 43.10% of the variation in the dependent variable within each group.

The coefficient for real rent (lrr1) is 4.282, which is statistically significant at the 1% level, indicating that a one-unit increase in real rent (lrr) is associated with a 4.282 unit increase in new construction (lcons). The coefficient for employment (le) is -3.539, which is not statistically significant at the 10% level, indicating that there is no evidence of a relationship between employment (le) and new construction (lcons). The coefficient for li is 0.733, which is marginally statistically significant at the 10% level, indicating that there might be a relationship between interest rate (li) and new construction (lcons). The coefficient for development permit (ldev) is -0.119, which is not statistically significant at the 10% level, indicating that there is no evidence of a relationship between development permit (ldev) and new construction (lcons). The σ_e value of 0.514 indicates that there is a substantial amount of unexplained variation in the model, which might be due to omitted variables, measurement error, or other factors. The F-test for the joint significance of the fixed effects is statistically significant at the 1% level, indicating that the fixed effects are important for the model.

4) Stock of Development Sector, SUR (Non-Lag)

The number of observations (cross-sectional units) is 44, and the number of groups (individuals or entities) is one. This suggests that the panel data are composed of observations on a single entity over multiple time periods. The within R-squared is 0.9160, indicating that 91.6% of the variation in occupied stock (los) is explained by the independent variables after controlling for individual-specific fixed effects. The F-test for overall significance of the regression is highly significant with a p-value of 0.0000, indicating that at least one of the independent variables is statistically significant in explaining the variation in occupied stock (los). The F-test for the null hypothesis that all individual-specific effects are zero is highly significant with a p-value of 0.0000, indicating that individual-specific effects are present and the fixed effects regression is appropriate.

The coefficient of real rent (lrr) is 0.1794, which is statistically significant at the 1% level. This means that a one-unit increase in real rent (lrr) is associated with a 0.1794 unit increase in occupied stock (los). The coefficient of new construction (lcons) is -0.01795, which is statistically significant at the 1% level. This means that a one-unit increase in new construction (lcons) is associated with a -0.01795unit decrease in occupied stock (los). The coefficient of interest rate (li) is -0.0516, which is statistically significant at the 1% level. This means that a one-unit increase in li is associated with a -0.0516 unit decrease in occupied stock (los). The coefficient of development permit (ldev) is 0.0014, which is not statistically significant at the 10% level. This means that the relationship between development permit (ldev) and occupied stock (los) is not statistically significant. The F-test with a null hypothesis that all group-specific intercepts are zero has a p-value of zero, which indicates that the fixed-effects model is a better fit than the pooled OLS model.

(2) London, the City

Table 28. Estimation results - panel, fixed effects (non-lag) of London, the City

equation / variable	(1) real rent		(2) yield		(3) new construction		(4) occupied stock	
	expected	actual	expected	actual	expected	actual	expected	actual
real rent					(+)	6.957***	(-)	0.122**
real GDP	(+)	-0.317**						
employment	(+)	-3.057***			(+)	9.831		
interest rate			(+)	0.275***	(-)	1.462***	(-)	-0.119***
take-up	(+)	-0.021						
new construction	(-)	0.076***					(+)	-0.006
development permit					(+)	0.094	(+)	0.004
occupied stock	(-)	3.747***						
constant		8.025		-1.983***		-135.303**		7.792***
R^2 (overall)		0.778		0.513		0.439		0.847
F-statistic		21.05***		48.39***		6.86***		49.66***
Number of samples		36		48		40		41

1) User Sector, SUR (Non-Lag)

The results show that the model has an R-squared value of 0.7782, which indicates that the model explains a significant portion of the variation in the dependent variable. The F-statistic has a value of 21.05 with a corresponding p-value of 0.0000, indicating that at least one of the independent variables is significantly related to the dependent variable.

The overall fit of the model is assessed by the R-squared value, which indicates that 77.82% of the variation in lrr1 is explained by the independent variables in the model. The within-group R-squared value is used to evaluate the fit of the fixed effects model, which measures the proportion of variation in real rent (lrr) that is due to within-group variation. In this case, the within-group R-squared value is also 77.82%.

The output also shows the variance components of the model, which are estimated using the method of moments. The variance of the random effects (σ_u) cannot be estimated in this case, as there is only one group. The residual variance (σ_e) is estimated to be 0.0486. Finally, the output displays a test of the null hypothesis that all group-specific effects are zero. Since there is only one group, the F-test is not applicable, and the p-value is missing.

2) Investment Sector, SUR (Non-Lag)

The output indicates that there are 48 observations in total, all of which belong to the same group. The R-squared value for the within variation is 0.5127, indicating that the independent variable interest rate (li) explains about 51% of the variation in the dependent variable yield (ly) within the group. The F-statistic for the regression is 48.39, with a corresponding p-value of 0.0000, indicating that the coefficient for the independent variable (li) is statistically significant at conventional levels.

The coefficient for the independent variable, interest rate (li), is 0.275 with a standard error of 0.039. This indicates that, on average, a one-unit increase in interest rate (li) is associated with a 0.275 unit increase in yield (ly). The F-test for the joint significance of all the fixed effects (u_i) is not reported because there is only one group in the panel data. The value of rho is missing because there is no variation in the group-level variable. The within R-squared value is 0.5127, indicating that the model explains 51.27% of the variation in the dependent variable within each group.

3) Flow of Development Sector, SUR (Non-Lag)

The R-squared row shows three different measures of the goodness of fit of the model: the within R-squared, the between R-squared and the overall R-squared. The within R-squared measures the proportion of the total variation in the dependent variable that is explained by the independent variables, after controlling for time-invariant unobserved heterogeneity (i.e., fixed effects). The between R-squared measures the proportion of the total variation in the dependent variable that is explained by the independent variables, ignoring time-invariant unobserved heterogeneity. The overall R-squared is the weighted average of the within R-squared and the between R-squared. In this case, the within R-squared is 0.4393, indicating that the model explains 43.93% of the within-group variation in new construction (lcons).

The F row shows the F-statistic and the corresponding p-value for the joint significance of all independent variables in the model. In this case, the F-statistic is 6.86 and the p-value is 0.0003, indicating that at least one of the independent variables is jointly significant in explaining new construction (lcons). The F-test tests the hypothesis that all group-specific effects are zero. The null hypothesis is that there are no group-specific effects, and the alternative hypothesis is that at least one group-specific effect is not zero. The F-statistic of 0 indicates that the null hypothesis cannot be rejected, which suggests that there are no group-specific effects.

4) Stock of Development Sector, SUR (Non-Lag)

The R-squared values indicate the proportion of variance in the dependent variable explained by the independent variables. The within R-squared is 0.8466, which means that the independent variables explain 84.66% of the variation in occupied stock (los) after controlling for fixed effects. The F-test tests the overall statistical significance of the regression model. Here, the F-statistic is 49.66 with a p-value of 0.0000, which means that the model is statistically significant.

The coefficient for real rent (lrr) is positive, indicating that a one-unit increase in real rent (lrr) is associated with an increase in occupied stock (los). However, this coefficient is not statistically significant at the 5% level (p-value = 0.056). The coefficient for new construction (lcons) is negative but not statistically significant (p-value = 0.334). The coefficient for interest rate (li) is negative and statistically significant at the 5% level (p-value = 0.000), indicating that a one-unit increase in interest rate (li) is associated with a decrease in occupied stock (los). The coefficient for development permit (ldev) is positive but not statistically significant (p-value = 0.345). The F-test of the null hypothesis that all individual-specific effects are zero has a p-value of 0.0000, indicating that we can reject the null hypothesis and conclude that there are individual-specific effects.

5.3.8 SUR (3SLS) Estimation - London West End and the City

(1) London, West End

The R-squared indicates the proportion of variation in the dependent variable explained by the independent variables. For example, the model for the occupied stock (los) equation has an R-squared of 0.8973, indicating that the independent variables (real rent (lrr), new construction (lcons), interest rate (li) and development permit (ldev) explain about 89.73% of the variation in occupied stock (los).

The chi-square statistic tests the null hypothesis that all coefficients in the equation are zero. The p-value associated with the chi-square statistic indicates the probability of observing such a large statistic if the null hypothesis is true. In all equations, the p-value is less than 0.05, indicating that the null hypothesis can be rejected at a 5% significance level, and suggesting that the model fits the data well.

Table 29. SUR (3SLS) estimation results (non-lag) of London, West End

variable \ equation	(1) real rent		(2) yield		(3) new construction		(4) occupied stock	
	expected	actual	expected	actual	expected	actual	expected	actual
real rent					(+)	5.805***	(-)	0.219***
real GDP	(+)	0.048						
employment	(+)	0.375			(+)	-7.095***		
interest rate			(+)	0.377***	(-)	1.127***	(-)	-0.040***
take-up	(+)	0.007						
new construction	(-)	0.124***					(+)	-0.022***
development permit					(+)	-0.045	(+)	0.002
occupied stock	(-)	2.366***						
constant		-19.157***		-1.767***		42.256		7.298***
R^2		0.813		0.566		0.413		0.897
Chi^2		260.67***		51.64***		119.34***		413.64***
Number of samples		35		35		35		35

1) User Sector, SUR (Non-Lag)

In the real rent (lrr) equation, the variable occupied stock (los) has a statistically significant positive effect on real rent (lrr1) at the 5% significance level ($p < 0.001$), and new construction (lcons) has a statistically significant positive effect on real rent (lrr1) at the 5% significance level ($p < 0.001$). On the other hand, real GDP (lgdpr) and take-up (ltkp) have non-significant coefficients ($p > 0.05$).

2) Investment Sector, SUR (Non-Lag)

In the yield (ly) equation, the variable interest rate (li) has a statistically significant positive effect on yield (ly) at the 5% significance level ($p < 0.001$).

3) Flow of Development Sector, SUR (Non-Lag)

In the new construction (lcons) equation, the variable real rent (lrr) has a statistically significant positive effect on new construction (lcons) at the 5% significance level ($p < 0.001$), while employment (le) has a statistically significant negative effect on new construction (lcons) at the 5% significance level ($p < 0.05$). Other variables, such as development permit (ldev) and constant, are not statistically significant.

4) Stock of Development Sector, SUR (Non-Lag)

In the occupied stock (los) equation, real rent (lrr), new construction (lcons) and interest rate (li) have statistically significant coefficients at the 5% significance level ($p < 0.001$, $p < 0.001$, and $p < 0.001$, respectively), while development permit (ldev) is not statistically significant.

(2) London, the City

Table 30. SUR (3SLS) estimation results (non-lag) of London, the City

equation / variable	(1) real rent		(2) yield		(3) new construction		(4) occupied stock	
	expected	actual	expected	actual	expected	actual	expected	actual
real rent					(+)	10.245***	(-)	0.202***
real GDP	(+)	-0.259***						
employment	(+)	-1.844***			(+)	8.801		
interest rate			(+)	0.388***	(-)	2.134***	(-)	-0.093***
take-up	(+)	-0.042***						
new construction	(-)	0.074***					(+)	-0.011***
development permit					(+)	0.005	(+)	0.0009
occupied stock	(-)	2.942***						
constant		2.135		-1.539***		-143.285**		7.410***
R^2		0.759		0.648		0.391		0.790
Chi^2		158.08***		59.13***		62.24***		148.87***
Number of samples		32		32		32		32

For the City of London, the output shows that the real rent (lrr) equation has an RMSE of .0485154, an R-squared of 0.7592 and a chi-squared statistic of 158.08 with a p-value of 0.0000, indicating a goodness of fit and statistical significance. The yield (ly) equation has an RMSE of 0.1073, an R-squared of 0.6476 and a chi-squared statistic of 59.13 with a p-value of 0.0000, which also indicates goodness of fit and significance. The new construction (lcons) equation has an RMSE of 0.7916, an R-squared of 0.3913 and a chi-squared statistic of 62.24 with a p-value of 0.0000, suggesting a less satisfactory fit and a significant relationship. The occupied stock (los) equation has an RMSE of 0.0246, an R-squared of 0.7896 and a chi-squared statistic of 148.87 with a p-value of 0.0000, indicating a goodness of fit and a significant relationship between the predictor variables and the outcome variable.

1) User Sector, SUR (Non-Lag)

For the real rent equation, the dependent variable is real rent (lrr). The independent variables are real GDP (lgdpr), employment (le), take-up (ltkp), occupied stock (los) and new construction (lcons). The coefficients of the independent variables indicate the estimated change in the dependent variable for a one-unit change in the independent variable.

A one-unit increase in new construction (lcons) is associated with a 0.0740 unit increase in real rent (lrr). The coefficient for real GDP (lgdpr) is negative and statistically significant at the 5% level, indicating that a one-unit increase in real GDP (lgdpr) is associated with a 0.2593 unit decrease in real rent (lrr). The coefficient for occupied stock (los) is positive and statistically significant at the 1% level, indicating that a one-unit increase in occupied stock (los) is associated with a 2.9424 unit increase in real rent (lrr).

2) Investment Sector, SUR (Non-Lag)

For the yield equation, the coefficient for interest rate (li) is positive and statistically significant at the 1% level, indicating that a 1% increase in interest rate (li) is associated with a 0.39% increase in yield (ly).

3) Flow of Development Sector, SUR (Non-Lag)

For the new construction equation, the independent variables are real rent (lrr), employment (le), interest rate (li) and development permit (ldev). The coefficient for real rent (lrr) is positive and statistically significant at the 1% level, indicating that a 1% increase in real rent (lrr1) is associated with a 10.24% increase in new construction (lcons). The coefficient for employment (le) is positive but not statistically significant at the 5% level, indicating that the relationship between employment (le) and new construction (lcons) is uncertain. The coefficient for interest rate (li) is positive and statistically significant at the 1% level, indicating that a 1% increase in interest rate (li) is associated with a 2.13% increase in new construction (lcons). The coefficient for new development (ldev) is positive but not statistically significant at the 5% level, indicating that the relationship between new development (ldev) and new construction (lcons) is uncertain.

4) Stock of Development Sector, SUR (Non-Lag)

For the occupied stock equation, the dependent variable is occupied stock (los). The independent variables are real rent (lrr), interest rate (li), new construction (lcons), development permit (dev) and a constant term.

The coefficient for real rent (lrr) is positive and statistically significant at the 1% level, indicating that a 1% increase in real rent (lrr) is associated with a 0.20% increase in occupied stock (los). The coefficient for new construction (lcons) is negative and statistically significant at the 1% level, indicating that a 1% increase in new construction (lcons) is associated with a 0.01% decrease in occupied stock (los). The coefficient for interest rate (li) is negative and statistically significant at the 1% level, indicating that a 1% increase in interest rate (li) is associated with a 0.09% decrease in occupied stock (los).

5.4 Diagnostic tests

5.4.1 OLS and GLS Diagnostic Tests

(1) Multicollinearity

1) The Variance Inflation Factor (VIF) Test

The VIF test, which measures the existence of serial correlation, assumes that multicollinearity exists when the diagnostic test value exceeds 10. For this test, low VIF values between 1 and 1.95 were obtained in all submarkets, indicating that there are no series correlation. The collinearity test also showed good results between 1.32 and 3.12, and therefore no collinearity was found in any submarkets. However, the diagnostics for the collinearity test were unavailable when the model used the lags.

Table 31. Result of variance inflation factor (VIF) test

Variable	VIF	1/VIF
occupied stock (los)	2.33	0.429449
take-up (ltkp)	2.30	0.434806
GDP (lgdpr)	1.94	0.516402
new construction (lcons)	1.82	0.548372
employment (le)	1.35	0.738224
Mean VIF	1.95	

The output shows the results of a VIF analysis for a multiple regression model. The VIF test is a measure of collinearity among the predictor variables in a regression model, with values greater than 1 indicating a potential problem with collinearity. Table 31 displays the VIF and its reciprocal (1/VIF) for each predictor variable in the model. The mean VIF at the bottom of the table is the average VIF across all predictor variables.

In this case, all the VIFs are less than 5, which is a commonly used threshold for identifying problematic collinearity. This indicates that there is no significant collinearity among the predictor variables in the model. The mean VIF is 1.95, which is relatively low and further supports the conclusion that there is no significant collinearity.

Therefore, there is no significant multicollinearity issue among the predictor variables in the model based on the VIF analysis.

2) The Ramsey Regression Equation Specification Error Test (RESET)

The RESET test is a test for the presence of omitted variables in a regression model. It checks whether the regression model fits the data adequately by examining whether there is any nonlinearity in the relationship between the dependent variable and its predicted values. In this case, the test used powers of the fitted values of real rent (lrr) to check whether there are any omitted variables in the model.

The RESET test, which measures the functional form, shows that the functional form is good as the null hypothesis was adopted in the occupier subsector, but not in the investment, new construction market and occupied space subsectors.

Ramsey RESET test using powers of the fitted values of real rent (lrr)
H_0: model has no omitted variables
F (3, 267) = 2.10
Prob > F = 0.1006

The null hypothesis (H_0) in this test is that the model has no omitted variables. The test statistic is an F-test with 3 and 267 degrees of freedom. In this case, the test statistic is 2.10, and the p-value is 0.1006. Since the p-value is greater than the significance level of 0.05, we fail to reject the null hypothesis. This suggests that there is no evidence to suggest that the model has any omitted variables, and the model fits the data adequately.

(2) Normality

The Jarque-Bera test was conducted to test the normal distribution of the models. In the results, the Chi^2 values vary from 17.36 to 54.22 by subsectors and all the p-values are rejected at the 5% level, indicating that the normality assumption is violated.

The diagnostic was not available for the equations which include lagged variables, and these are omitted from Table 32.

Table 32. Skewness / kurtosis tests for normality

Variable	Obs.	Pr(Skewnes)	Pr(Kurtosis)	adj chi2(2)	Prob>chi2
real rent (lrr1)	336	0.0166	0.0001	17.36	0.0002

The output shows the results of the skewness/kurtosis tests for normality on the variable real rent (lrr) with 336 observations. The Pr (Skewness) and Pr (Kurtosis) columns show the p-values for the individual tests of skewness and kurtosis, respectively. The adj $chi^2(2)$ column shows the adjusted chi-squared statistic for the joint test of skewness and kurtosis, and the Prob>chi^2 column shows the p-value for the joint test.

Both the individual tests of skewness and kurtosis have p-values less than 0.05, indicating that the variable real rent (lrr) is significantly skewed and has excess kurtosis. The joint test of skewness and kurtosis also has a p-value less than 0.05, providing evidence that the variable real rent (lrr) departs significantly from a normal distribution.

(3) Heteroscedasticity

1) Breusch-Pagan / Cook-Weisberg test

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
Ho: Constant variance
Variables: fitted values of lrr1
chi2(1) = 74.09
Prob > chi2 = 0.0000

This test checks for the presence of heteroskedasticity in the regression model. The null hypothesis (H_0) is that the variance of the errors in the model is constant across all values of the independent variables. The test uses the fitted values of the dependent variable, real rent (lrr), to check for the presence of heteroskedasticity. The test statistic is chi-squared with one degree of freedom. In this case, the chi-squared statistic is 74.09 and the associated p-value is 0.0000, which is less than the typical significance level of 0.05. Thus, we reject the null hypothesis and conclude that there is evidence of heteroskedasticity in the model.

2) Cameron & Trivedi's IM-test

Table 33. Cameron & Trivedi's decomposition of IM-test

Source	chi2	df	p
Heteroskedasticity	177.81	20	0.0000
Skewness	9.45	5	0.0924
Kurtosis	2.24	1	0.1345
Total	189.51	26	0.0000

Table 33 shows the results of Cameron and Trivedi's decomposition of the IM-test. The test is used to detect departure from normality in a regression model. The table is divided into three sources of departures from normality: heteroskedasticity, skewness and kurtosis. The null hypothesis for each source of departure is that there is no departure from normality.

The table shows that the test statistic for heteroskedasticity is 177.81 with 20 degrees of freedom and the p-value is less than 0.05, which indicates strong evidence of heteroskedasticity. The test statistic for skewness is 9.45 with 5 degrees of freedom and the p-value is greater than 0.05, which suggests weak evidence of skewness. The test statistic for kurtosis is 2.24 with one degree of freedom and the p-value is greater than 0.05, which suggests weak evidence of kurtosis.

The total test statistic is 189.51 with 26 degrees of freedom and the p-value is less than 0.05, which indicates strong evidence of departure from normality. Therefore, we can reject the null hypothesis of normality and conclude that the regression model is not a good fit for the data.

Table 34. Summary of OLS and GLS diagnostic tests

Type of diagnostic test	Details of the test result						
	User market equation (non-lag) (1-1)	User market equation (lag) (1-2)	Investment market equation (2)	New construction equation (non-lag) (3-1)	New construction equation (lag) (3-2)	Occupied stock equation (non-lag) (4-1)	Occupied stock equation (lag) (4-2)
Serial correlation (VIF test) (collinearity test)	no serial correlation 1.62 (mean) 3.12 (mean)	no serial correlation 1.69 (mean) - (test unavailable)	no serial correlation 1.00 (mean) 1.32 (mean)	no serial correlation 1.20 (mean) 1.34 (mean)	no serial correlation 1.25 (mean) - (test unavailable)	no serial correlation 1.16 (mean) 1.33 (mean)	no serial correlation 1.25 (mean) - (test unavailable)
Functional form (RESET test)	no omitted variables F (3,267) = 2.15 p-value = 0.0940	no omitted variables F (3, 261) = 1.88 p-value = 0.1332	omitted variables F (3,327) = 5.22 p-value = 0.016	omitted variables F (3,166) = 4.45 p-value = 0.049	omitted variables F (3,115) = 4.62 p-value = 0.044	omitted variables F (3, 168) = 5.34 p-value = 0.0015	omitted variables F (3,109) = 3.51 p-value = 0.0179
Normality (Jarque-Bera test)	normality violation Chi2 (lrr1) = 17.37 p-value = 0.0002	- (test unavailable)	normality violation Chi2 (ly) = 54.22 p-value = 0.0000	normality violation Chi2 (lcons) = 18.51 p-value = 0.0001	- (test unavailable)	normality violation Chi2 (los) = 32.00 p-value = 0.0000	- (test unavailable)
Heteroscedasticity (Cameron & Trivedi test) (Breusch-Pagan test)	heteroscedasticity detected Chi2 = 190.46 p-value = 0.0000 Chi2 = 72.94 p-value = 0.0000	heteroscedasticity detected Chi2 = 195.74 p-value = 0.0000 Chi2 = 81.95 p-value = 0.0000	heteroscedasticity detected Chi2 = 67.30 p-value = 0.0000 Chi2 = 14.00 p-value = 0.0002	heteroscedasticity detected Chi2 = 35.22 p-value = 0.0131 Chi2 = 9,25 p-value = 0.0024	heteroscedasticity detected Chi2 = 113.87 p-value = 0.0000 Chi2 = 5.91 p-value = 0.0150	heteroscedasticity detected Chi2 = 156.04 p-value = 0.0000 Chi2 = 63.26 p-value = 0.0000	heteroscedasticity detected Chi2 = 144.17 p-value = 0.0000 Chi2 = 43.20 p-value = 0.0000

* Shaded cell indicates violation detected from diagnostics.
- violation of no serial correlation assumption: none
- violation of functional form assumption: equation (3-1), (3-2), (4-1), (4-2)
- violation of normality assumption: equation (1-1), (2), (3-1), (4-1)
- violation of no heteroscedasticity assumption: all of the equations

* Partial test
unavailability (in serial correlation and normality tests) are due to the inclusion of lagged variable(s) in the equations ((1-2), (3-2), (4-2)).

5.4.2 Panel (Fixed and Random Effects) Diagnostic Tests

(1) Lagrange Multiplier (Breusch-Pagan) test

Table 35. Panel FE, Breusch-Pagan test (xttest2)

	rent	yield	new construction	occupied stock
without lags	119.275 (0.0000)	282.128 (0.0000)	N/A	N/A
with lags	N/A	-	N/A	N/A

The null hypothesis of the Breusch–Pagan test is no heteroskedasticity in the model. The test result indicates that heteroskedasticity is found in rent (without lags) and yield equations.

Breusch–Pagan LM test of independence: $chi^2(21)$ = 119.275, Pr = 0.0000
Based on 27 complete observations

The Breusch–Pagan LM test is a statistical test used to check for heteroscedasticity in a regression model. Heteroscedasticity refers to the situation where the variance of the residuals in the model is not constant across all levels of the independent variables, which can affect the validity of statistical inference.

The output shows that the test statistic is chi-squared distributed with 21 degrees of freedom, and the calculated value of the test statistic is 119.275. The p-value associated with this test statistic is very small (Pr = 0.0000), which indicates strong evidence against the null hypothesis of homoscedasticity (i.e., the assumption that the variance of the residuals is constant across all levels of the independent variables).

Based on the sample size of 27 complete observations, the test results suggest that there is evidence of heteroscedasticity in the regression model being tested. This means that the variance of the residuals in the model is not constant across all levels of the independent variables, and therefore the standard errors, t-values and p-values obtained from the model may not be reliable. It may be necessary to use alternative methods to correct for heteroscedasticity, such as robust standard errors or weighted least squares regression.

(2) Wald test

Table 36. Panel FE, Wald test (xttest3)

	rent	yield	new construction	occupied stock
without lags	60.72 (0.0000)	46.17 (0.0000)	455.28 (0.0000)	796.11 (0.0000)
with lags	808.26 (0.0000)	-	155.91 (0.0000)	155.28 (0.0000)

The null hypothesis of the Wald test is no heteroskedasticity in the model. All test results indicate that the null hypothesis is rejected and therefore heteroskedasticity is found.

Modified Wald test for groupwise heteroskedasticity in fixed effect regression model
H0: $\sigma_i^2 = \sigma^2$ for all i
χ^2 (7) = 60.78
Prob > χ^2 = 0.0000

The modified Wald test is a statistical test used to detect groupwise heteroskedasticity in a fixed effects regression model. Groupwise heteroskedasticity refers to a situation where the variances of the error terms are not equal across groups in the data. The null hypothesis being tested is that the variance of the error term is the same for all groups ($\sigma_i^2 = \sigma^2$ for all i).

The output shows that the test statistic is chi-squared distributed with 7 degrees of freedom, and the calculated value of the test statistic is 60.78. The p-value associated with this test statistic is very small (Prob > χ^2 = 0.0000), which indicates strong evidence against the null hypothesis of equal variances across all groups.

Based on the test results, it can be concluded that there is groupwise heteroskedasticity in the fixed effects regression model being tested. This means that the variance of the error term is not the same across all groups, and therefore the standard errors, t-values and p-values obtained from the model may not be reliable. It may be necessary to use alternative methods to correct for groupwise heteroskedasticity, such as clustered standard errors or generalised least squares regression.

Table 37. Panel RE, Breusch-Pagan test (xttest0)

	rent	yield	new construction	occupied stock
without lags	2282.66 (0.0000)	968.81 (0.0000)	117.54 (0.0000)	636.17 (0.0000)
with lags	0.00 (1.0000)	-	157.57 (0.0000)	202.71 (0.0000)

LM test H_0: pooled OLS is more efficient than panel random effect model

In all test results, the null hypothesis is rejected, which indicates that the random effects model should be used.

Breusch–Pagan Lagrangian multiplier test for random effects
chibar2(01) = 2239.01
Prob > chibar2 = 0.0000

The Breusch–Pagan Lagrangian multiplier test for random effects is a statistical test used to detect the presence of heteroscedasticity in a random effects model. Heteroscedasticity refers to a situation where the variance of the error terms is not constant across all levels of the independent variables.

The output shows that the test statistic is distributed as a chi-squared distribution with one degree of freedom, and the calculated value of the test statistic is 2239.01. The p-value associated with this test statistic is very small (Prob > chibar2 = 0.0000), which indicates strong evidence against the null hypothesis of homoscedasticity (i.e., the assumption that the variance of the error term is constant across all levels of the independent variables).

Based on the test results, it can be concluded that there is heteroscedasticity in the random effects model being tested. This means that the variance of the error term is not constant across all levels of the independent variables, and therefore the standard errors, t-values and p-values obtained from the model may not be reliable. It may be necessary to use alternative methods to correct for heteroscedasticity, such as robust standard errors or weighted least squares regression.

Table 38. Panel RE, joint (LM) test (xttest1)

	rent	yield	new construction	occupied stock
without lags	2305.40 (0.0000)	1095.43 (0.0000)	137.16 (0.0000)	642.12 (0.0000)
with lags	N/A	-	N/A	N/A

The Command 'xttest1' is only available in a random effect and balanced dataset panel model, which tests for the existence of autocorrelation in the model. The null hypothesis is no evidence of autocorrelation. The test results reject the null hypothesis in all four tests and indicates that autocorrelations exist in all models without lags. For lag models, the test command was not available.

```
Tests for the error component model:
    Tests:
      Random Effects, Two Sided:
      ALM (Var(u) = 0)        = 2028.43 Pr > chi2(1) = 0.0000
      Random Effects, One Sided:
      ALM (Var(u) = 0)        =   45.04 Pr > N(0,1)  =  0.0000
      Serial Correlation:
      ALM (lambda = 0)        =   23.23 Pr > chi2(1) = 0.0000
      Joint Test:
      LM(Var(u)=0, lambda = 0) = 2305.40 Pr > chi2(2) = 0.0000
```

The output shows the results of several statistical tests for the error component model.

The first test is the random effects test for the two-sided alternative hypothesis, with the null hypothesis being that the variance of the random effects is equal to zero (ALM(Var(u)=0)). The calculated test statistic is 2028.43, and the p-value associated with the test is 0.0000, which indicates strong evidence against the null hypothesis of zero variance of the random effects.

The second test is also a random effects test, but for the one-sided alternative hypothesis that the variance of the random effects is greater than zero. The calculated test statistic is 45.04, and the p-value associated with the test is 0.0000, which indicates strong evidence against the null hypothesis of zero or negative variance of the random effects.

The third test is for serial correlation, with the null hypothesis being that there is no correlation between the error terms. The calculated test statistic is 23.23, and the p-value associated with the test is 0.0000, which indicates strong evidence against the null hypothesis of no correlation between the error terms.

The fourth test is a joint test, which combines the two random effects tests and the serial correlation test, with the null hypothesis being that all three null hypotheses are true. The calculated test statistic is 2305.40, and the p-value associated with the test is 0.0000, which indicates strong evidence against the null hypothesis of no variance of the random effects, no positive variance of the random effects and no correlation between the error terms.

In summary, based on the results of these statistical tests, it can be concluded that the error component model being tested has non-zero variance of the random effects, positive variance of the random effects, and correlation between the error terms. These results suggest that the assumptions of the model may not be met, and alternative models or methods may need to be considered.

(3) Hausman test

Hausman test: Chi2 (5) = $(b - B)'[(V_b - V_B)^{(-1)}](b - B)$ = 24.28 (0.0002)
coefficient b (b_0) = consistent under H0 and Ha; obtained from xtreg
coefficient B (b_1) = inconsistent under H_a, efficient under H_0; obtained from xtreg
null hypothesis: H_0 = difference in coefficients not systematic

Table 39. Hausman test

	rent	yield	new construction	occupied stock
without lags	30.48 (0.0000)	12.73 (0.0004)	18.18 (0.0011)	36.06 (0.0000)
with lags	0.78 (0.9926)	-	8.87 (0.0645)	29.33 (0.0000)

* Chi^2 / p-value (in parenthesis)

The Hausman test is the diagnostics which determines more efficient estimation between panel fixed effects (FE) and random effects (RE) models, and also makes a judgement on the heteroscedasticity issue.

The results of the Hausman test for the rent, yield and new construction equations indicates that fixed effects is preferred over random effects in panel model selection. By contrast, the random effects model is preferred for rent and new construction when lag is considered:

- rent equation without lags: FE preferred / rent equation with lags: RE preferred.
- yield equation without lags: FE preferred.
- new construction equation without lags: FE preferred / new construction equation without lags: FE preferred at 10 percent significance level.
- occupied stock equation without lags: FE preferred / occupied stock equation with lags: FE preferred.

Test: H_0: difference in coefficients not systematic

$$\text{chi2}(5) = (b - B)'[(V_b - V_B)^{(-1)}](b - B)$$
$$= 30.48$$
$$\text{Prob>chi2} = 0.0000$$
(V_b - V_B is not positive definite)

The output shows the results of the Hausman test, which is used to test the null hypothesis that the difference in coefficients between a fixed effects model and a random effects model is not systematic.

While the null hypothesis implies that the difference in coefficients is not systematic, it is rejected with $Chi^2 = 30.48$, indicating that the fixed effects model is preferred over the random effects model. The p-value associated with the test is 0.0000, which is less than the conventional significance level of 0.05. This means that there is strong evidence against the null hypothesis and that the difference in coefficients between the fixed effects and random effects models is systematic.

The output also indicates that the variance-covariance matrix of the difference between the two sets of coefficients, denoted as (V_b - V_B), is not positive definite. This suggests that there may be issues with the estimation of the variance-covariance matrix and that the results of the test may need to be interpreted with caution.

The results of the Hausman test suggest that the choice between fixed effects model and random effects model is important and that the difference in coefficients between the two models is systematic.

Table 40. Evaluation criteria of Hausman test

	H_0 is true	H_1 is true
b_1 (RE estimator)	consistent efficient	inconsistent
b_0 (FE estimator)	consistent inefficient	consistent

(4) Unit Root Tests

Stationarity is a crucial assumption because it ensures that the statistical properties of the series remain constant over time, and the diagnostic tests assess whether a time series is stationary or non-stationary. Table 41 presents the results of augmented Dickey-Fuller, Phillips-Perron, and Levin-Lin-Chi unit-root tests (Dickey and Fuller, 1979; Phillips and Perron, 1988; Levin et al., 2002).

Table 41. Augmented Dickey-Fuller, Phillips-Perron, and Levin-Lin-Chu unit-root tests

	real rent	yield	new construction	occupied stock
Augmented Dickey-Fuller test	2.3519 (0.0093)	-2.1886 (0.9857)	2.9994 (0.0014)	-1.8354 (0.9668)
Phillips-Perron test	0.2312 (0.4086)	-2.3854 (0.9915)	1.8540 (0.0319)	-1.8569 (0.9683)
Levin-Lin-Chi unit-root test	-2.6859 (0.0036)	-	-	-

1) Fisher-type unit root test based on augmented Dickey-Fuller tests:
H_0: All panels contain unit roots / H_a: At least one panel is stationary
Modified inv. chi-squared Pm, p-value in parentheses

2) Fisher-type unit root test based on Phillips-Perron tests:
H_0: All panels contain unit roots / H_a: At least one panel is stationary
Modified inv. chi-squared Pm, , p-value in parentheses

3) Levin-Lin-Chu unit-root test:
H_0: Panels contain unit roots / H_a: Panels are stationary
Adjusted t* statistics, p-value in parentheses

The augmented Dickey-Fuller (ADF) test assesses whether a unit root is present in a time series. The p-value of new real rent and new construction is very low (0.0093 and 0.0014), thereby suggesting strong evidence to reject the null hypothesis of a unit root and, therefore, indicating that the variables are stationary. In contrast, the p-value of yield and occupied stock are rather high (0.9857) and high (0.9668), respectively, indicating strong evidence against rejecting the null hypothesis of a unit root. Therefore, yield and occupied stock are not stationary. The Phillips-Perron test also checks for a unit root in a time series, thereby accounting for potential autocorrelation in the errors. The test statistics of real rent, yield, and occupied stock are 0.2312,

-2.3854 and -1.8569, with p-values of 0.4086, 0.9915, and 0.9683, respectively, which indicate no strong evidence against the null hypothesis of a unit root. New construction is the only variable which is stationary with a low p-value of 0.0319 in this test. The Levin-Lin-Chu test is only available for real rent, and the test statistic is -2.6859 with a p-value of 0.0036. Since the p-value is low (0.0036), real rent is stationary.

In summary, real rent is stationary based on ADF and Levin-Lin-Chu tests, and new construction is stationary according to ADF and Phillips-Perron tests. In contrast, neither the ADF nor Phillips-Perron tests provide evidence that yield and occupied stock are stationary.

(5) Cointegration Tests

The diagnostic tests are used to assess the presence of cointegration among variables. Cointegration implies a long-term relationship between non-stationary variables, which is important in time series analysis, particularly when dealing with multiple variables that may be integrated in different orders. Table 42 presents the result of three cointegration tests (Pediorni, 2004; Kao, 1999; Westerlund, 2005).

Table 42. Pedroni, Kao, and Westerlund cointegration tests

	Pedroni test	Kao test	Westerlund test
Augmented Dickey-Fuller test	-3.1083 (0.0009)	-4.4508 (0.0000)	-
Modified Phillips-Perron test	-1.7618 (0.0390)	-	-
Variance ratio	-	-	-1.6779 (0.0467)

1) Pedroni test - H_0: No cointegration / H_a: All panels are cointegrated
2) Kao test - H_0: No cointegration / H_a: All panels are cointegrated
3) Westerlund test - H_0: No cointegration / H_a: Some panels are cointegrated

The Pedroni test yields an ADF test statistic of -3.1083 and a p-value of 0.0009; the modified Phillips-Perron test statistic is -1.7618 and the p-value is 0.0390. Since both p-values are lower than the 5% significance level (0.05), there is significant evidence to reject the null hypothesis of no cointegration. Kao's test indicates a test statistic of -4.4508 with a p-value of 0.0000, which implies strong evidence to reject the null hypothesis of no cointegration. Another test for cointegration, the Westerlund test, yields a p-value of 0.0467, which also suggests evidence to reject the null hypothesis of no cointegration.

The selected variables for cointegration are real rent, employment, GDP, and network connectivity. Since all the three tests reject the null hypothesis, the Pedroni, Kao, and Westerlund tests support the presence of cointegration among the selected variables.

5.4.3 3SLS Diagnostic Tests

(1) Order Condition of Identification

Order condition of identification for the four subsector equations are as follows:
m = number of endogenous variables in the model
k = total number of variables excluded from the equation under consideration

If k = m - 1, the equation is exactly identified.
If k > m - 1, the equation is overidentified.
If k < m - 1, the equation is unidentified.
(Gujarati, 2004)

In a multi-equation model, the number of equations are M = 4 and thus M - 1 = 3. There are a total of nine variables in the system, and at least three variables should be omitted according to the condition for identification. The real rent equation is exactly identified and the three other equations are overidentified, as listed below, and therefore consistent estimation is available for this multi-equation model:

lrr = f (lgdpr, le, ltkpr, lcons, los): three variables are omitted
ly = f (li): seven variables are omitted
lcons = f (lrr, le, li, ldev): four variables are omitted
los = f (lrr, li, lcons, ldev): four variables are omitted

Therefore, the four equations satisfy the order identification condition.

(2) Breusch–Pagan Test

Breusch–Pagan test of independence: $\chi^2(6) =$ 55.835, Pr = 0.0000

The Breusch–Pagan test is a statistical test used to detect heteroskedasticity in a linear regression model. In this case, the test was used to test for independence in the errors of the model.

The Breusch–Pagan test is used to check for the existence of heteroscedasticity in 3SLS. The test statistic is chi-squared (χ^2) with 6 degrees of freedom and has a value of 55.835. The associated p-value is 0.0000, which is less than the significance level of 0.05, indicating that we reject the null hypothesis of independence in the errors of the model. This means that there is evidence of dependence or correlation between the errors, which violates one of the assumptions of a linear regression model.

(3) Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC)

Information criterion: AIC 265.3059; BIC 319.9711 (N = 154)

Table 43. Result of Akaike's information criterion and Bayesian information criterion

Model	N	ll(null)	ll(model)	df	AIC	BIC
	154	-	-114.653	18	265.3059	319.9711

The output shows the values for the Akaike information criterion (AIC) and the Bayesian information criterion (BIC) for a model with 154 observations and 18 estimated parameters. The AIC and the BIC are model selection criteria used to compare different models and select the one that best fits the data while penalising for model complexity.

Two information criteria were tested, the AIC and the BIC. The values of 265.31 for the AIC and 319.97 for the BIC were derived from the 3SLS estimation. The problem here is that the values need be compared with other AIC or BIC values from other estimations.

Lower AIC and BIC values indicate better fitting models with good trade-off between model fit and complexity. In this case, the AIC value is 265.3059 and the BIC value is 319.9711. The model with the lower AIC or BIC value would be preferred over other models being compared.

5.4.4 GMM Diagnostic Tests

(1) Sargan test

Table 44. GMM, Sargan test

	rent	yield	new construction	occupied stock
without lags	343.0983 (0.0822)	462.3178 (0.0000)	110.3297 (0.9946)	205.8308 (0.0039)
with lags	231.3408 (0.6777)	-	110.6731 (0. 5444)	114.1174 (0.2340)

The output shows the results of the Sargan test, which is used to test the validity of the instrumental variables used in a regression analysis.

Sargan test of overidentifying restrictions

H_0: overidentifying restrictions are valid

Chi^2 (308) = 343.0983

Prob > Chi^2 = 0.0822

The null hypothesis is that the overidentifying restrictions are valid, which means that the instrumental variables are not correlated with the error term in the regression equation. The test statistic is Chi^2 (308), which has a value of 343.0983. The p-value associated with the test is

0.0822, which is greater than the significance level of 0.05. This means that there is insufficient evidence to reject the null hypothesis, and that the overidentifying restrictions are valid.

In other words, the instrumental variables used in the regression analysis are not significantly correlated with the error term and are therefore valid for the purposes of the analysis. The Sargan test provides a way to assess the validity of the instrumental variables and can help to ensure that the results of the regression analysis are reliable.

5.5 Comparison and Evaluation

(1) OLS Estimation

1) Model performance: Looking at the OLS estimation results first, the adjusted R-squared is 0.816 (non-lag) and 0.859 for occupier, 0.239 for investment, 0.227 (non-lag) and 0.190 (lag) for supply flow, and 0.319 (non-lag) and 0.267 (lag) for supply stock subsectors. The level of goodness of fit is satisfactory for space demand-side, while it is not for the supply-side and intermediary (investment) subsector.

2) Consistency with expected signs: The actual sign versus the expected sign is found to be largely consistent, but the new construction in the rent equation (both when time lag was considered / not considered) and the interest rate in the occupied inventory equation (when time lag was not considered) are different from the expected signs.

3) Statistical properties: Violations of the basic assumptions are found in the test, confirming that there are econometric problems in the diagnostics. To be specific, assumptions of serial correlation are not violated (VIF test) but assumptions of normality and no heteroscedasticity are violated (normality: Jarque–Bera test, heteroscedasticity: Breusch–Pagan test / Cameron–Trivedi test). Also, omitted variables are found in consideration of functional form (RESET test). Therefore, the Gauss–Markov assumption is violated and OLS is not BLUE, which means that an estimation method other than OLS should be chosen for statistical robustness.

(2) GLS Estimation

1) Model performance: Although R-squared is not derived from GLS, the appropriateness of the equation model can be tested through the F statistical value. All four equations are found to be significant at the 1% level, indicating the validity of the four equations as an empirical model.

2) Consistency with expected signs: Looking at the coefficients of the independent variables, the signs are all the same with OLS in the model without lag. By contrast, there are several mismatches between expected and actual signs, which are also different from the direction of signs in the OLS estimation. These mismatches are found for the new construction variable in the rental equation, and the development permit and occupied stock variables in the new

construction equation. It can be said that robust GLS estimation generates different coefficient output in terms of the direction of signs, but the consistency of signs overall is not as good as that of OLS.

3) Statistical properties: efficiency of FGLS (feasible GLS) over OLS: When OLS is not an efficient estimate, feasible GLS (FGLS) is used as an alternative. Although FGLS is a more efficient estimate than OLS, results that violate Gauss–Markov assumptions in data structures such as normality and heteroscedasticity tests have been shown.

According to White (1980), consistency of econometric estimation can be secured by the covariance matrix estimation method. This method does not rely on the formal heteroscedastic structure, and test result is obtained from the comparison between component factor and general covariance estimation elements. The estimates are generally the same if there is no heteroscedasticity, but it diverges otherwise. Therefore, the test provides a valid explanation for the least squares method.

Since the homoscedasticity assumption was violated in the OLS diagnostic test, GLS was performed for robustness estimation. Under the condition, existence of heteroscedasticity is basically assumed in the model, but the statistical outcome is still reliable. General least squares is thus a more efficient estimation method than OLS under the violation of the Gauss-Markov assumption.

The OLS diagnostic test results show that the of was violated, so a robust estimation was performed under the assumption of heteroscedasticity. In this case, despite the presence of heteroscedasticity, the reliability of the statistical results is increased.

(3) Panel Fixed Effects (FE) and Random Effects (RE) Estimation

1) Model performance: In the panel model, there is a problem in that the overall R-squared is greatly reduced in the supply and demand equation. This is because the between R-squared offsets the within R-squared, and the overall R-squared is lowered. The panel RE model with time lag performs better than the FE model in comparison of their overall R-squared.

2) Consistency with expected signs: In both panel methods, the level of sign inconsistency is severe compared to other estimation methods.

In the fixed effects estimation, there is inconsistency between expected and actual signs for take-up and new construction (without lag) and for take-up (with lag) in the real rent equation; inconsistency for interest rate (without lag), development permit (with lag), rent and new construction (without lag) in the new construction equation; and inconsistency for rent, new construction and development permits (with the time lag) in the occupied stock equation.

In the random effects estimation, there is inconsistency between expected and actual signs for new construction (without lag) and new construction (with lag) in the real rent equation; inconsistency for the new construction equation and interest rate (without lag) and interest rate (with lag) in the new construction equation; and inconsistency for rent, new construction (without lag) / rent, new construction and development permits (with lag) in the occupied stock equation.

Overall, the consistency of actual signs compared to expectations is worse than with the other estimation methods.

3) Statistical properties: As a result of the Hausman test, when time lag was not considered, the fixed effect was selected in all equations, but when time lag was considered, the random effect was selected in the rent and new construction equations, and the fixed effect was selected in the yield and occupied stock equations, respectively.

Significantly different results were obtained compared to time series estimation when data were analysed in the panel structure (time series and cross-sections are combined). In the panel FE estimation, expected and actual signs matched in general. Adjusted R-squared is high in the demand side (user subsector). According to the Hausman test, fixed effects is preferred over random effects in the short term. (However, the supply flow equation sector cannot be estimated.)

Random effects is preferred in the Hausman test, and it presents a satisfactory level of goodness of fit (adjusted R-squared). According to the Hausman test, random effects is preferred over fixed effects in the long term.

The results estimated using the panel model revealed significantly different estimation values compared to other estimations, such as OLS, GLS, and 3SLS. This is because the values of the between-estimator influences the estimates in addition to the within-estimator, thereby indicating that the panel data structure has a substantial impact on the estimation compared to time-series estimation.

(4) GMM

1) Model performance: Although R-squared is not derived from the GMM estimation, the adequacy of the equation model can be tested through the Wald chi-squared value. All four equations are found to be significant at the 1% level, and the result indicates that the equational model setting is appropriate.

2) Consistency with expected signs: The outputs are overall different from other estimation methods because the GMM estimation is based on the maximum likelihood estimation and the method of moments, while all the other methods are based on the least squares assumption. It seems there is a disadvantage in the use of the method of moments instead of least squares because of severely low coefficient values in general. The result implies the relationship

between dependent and explanatory variables is quite weak in the four equations. When it comes to consistency with expected signs, many mismatches were found in the flow and stock development subsectors while the occupier and investment subsectors showed consistent results. Such inconsistencies were found for employment (model without lag) and development permits (models without and with lag) variables in the third (new construction) equation, and for real rent and new construction (model without lag) and development permits (model with lag) variables in the fourth (occupied stock) equation.

3) Statistical properties: In GMM, the estimation results can be trusted when the identification condition is met. According to the Sargan test, rent, yield and occupied stock equations are appropriately identified, indicating that the estimation is available in the equations.

(5) SUR (3SLS)

1) Model performance: The explanatory power of SUR (3SLS) is 0.793 (non-lag) and 0.810 (lag) for occupier, 0.277 (non-lag) and 0.066 (lag) for investor, 0.266 (non-lag) and 0.629 (lag) for development flow, and 0.333 (non-lag) and 0.417 (lag) for development stock subsectors. It should be noted that the level of goodness of fit for the supply side significantly increases while it is greatly decreases for the investment subsector when the time lag is considered in the model.

2) Consistency with expected signs: The expected and the actual signs were found to be generally consistent, and the direction of the signs are mostly similar to those of OLS. The actual signs of the new construction variable in the rental equation are not matched with expectation in both the non-lag and lag models, and the actual sign of the interest rate variable does not match with expectation in the new construction equation in the non-lag model.

3) Statistical properties and interpretation: According to order condition of identification, estimation is not available if the SUR (3SLS) model is not identified. The four equations in the model are either just-identified or over-identified, so that SUR (3SLS) estimation is available. However, heteroscedasticity was found according to Breusch–Pagan test. The AIC and the BIC are two general information criteria, and a model with lower value is determined as more efficient than one with higher value. The lag model appears to be more efficient than the non-lag model in consideration of the criteria.

Overall, there were no significant changes compared to the OLS and GLS estimates. This can be interpreted as a signal that the errors in the OLS estimates were not sufficiently significant to violate the assumptions of econometric data.

The four-quadrant model is a dynamic explanatory model in that it explains the process of achieving long-term equilibrium through interactions among the short-term occupancy, investment, and development sectors; this equilibirum converges to a new long-term equilibrium after an adjustment process over a certain period. This model differentiates itself from existing single equation models that have focused on static explanations of each subsector, particularly the occupancy sector centred around rents.

The ECM and the multi-equation model each appear to partially contribute to empirically applying the dynamic theoretical explanation of the four-quadrant model. The ECM has a strength in terms of explaining the process of achieving a new long-term equilibrium through short-term adjustments from the existing equilibrium by including an error correction equation. Meanwhile, the multi-equation model is more suitable for explaining the interaction process, where the subsectors are not operating independently but are interconnected; the model also explains how changes in one sector are linked to and influence other sectors.

Further, it is assumed that simultaneity is inherent among the variables within the multi-equation structure. Econometrically, this can be resolved by using an estimation method that reflects the interactions among variables, provided there is no under-identification through the identification process. To achieve unbiased estimates, it is necessary to use an estimation method that considers endogeneity, where the dependent variable of one equation affects the independent variable of another equation, and there is a violation of the independence assumption that the independent variable of one equation is correlated with the error term of another equation within the multi-equation structure.

Thompson and Tsolacos (2000) established three multi-equation models for industrial real estate and estimated them using OLS and TSLS (2SLS). Theoretically, 2SLS—which reflects simultaneity—should provide improved estimation results compared to OLS. However, the analysis results reported no significant differences in terms of coefficients and significance.

In this study, a conceptual model was derived that can apply the theoretical explanations of the four-quadrant model to empirical analysis. First, a theoretical framework was constructed to explain the operational process of the office market. Then, according to the parsimonious principle, the model was restructured to one in which simultaneous estimation is possible, considering the importance in terms of explanatory power of the model, availability of variables observed during the data collection process, and appropriateness as proxy variables. In this stage, certain independent variables that were intended to be considered in the theoretical review stage were excluded.

The results of the 3SLS estimation were generally satisfactory. Among the independent variables that explained the supply stock subsector, GDP, employment, take-up, new construction, and occupied stock, most variables performed well; however, the sign and significance of new construction with respect to rent did not align with expectations. This result appears to reflect the difficulty in adequately deriving the relationship with rents because new construction is not consistent in each quarter of the year. The interest rate, an independent variable in the investment sector, performed well as expected, playing a role in connecting the occupancy and development sectors. However, the explanatory power of the equation was not high at it had only one independent variable.

With regard to the development sector (flow), among the independent variables such as rent, employment, interest rate, and development permits, the sign of the interest rate on new construction was unexpected and not statistically significant. Employment had a matching sign but was not significant, while rent and development permits had expected signs and were significant. However, the explanatory power of the new construction equation was not high. For the development sector (stock)—among the independent variables such as rent, interest rate, new construction, and construction permits—rent, new construction, and construction permits had matching signs and were significant, whereas the interest rate had a matching sign but was not significant. Moreover, the explanatory power of the occupied stock equation was not high.

With regard to the analysis results, it was confirmed that the theoretical explanation that the demand sector operates elastically even in the short term and responds efficiently to external changes was also observed in the rent equation. The relationship between yield and interest rates in the investment sector also operated normally. On the other hand, the inelasticity due to developers' myopic forecasts in the supply sector was reconfirmed and it was found that the more generous the development permits, the more positively they affected supply. These results can be interpreted positively as supporting the hypothesis that the interaction structure of the theoretical multi-equation model actually operates in the office market that targets major European cities.

However, in comparison with OLS, there is not much evidence that 3SLS significantly improved the sign, significance, and explanatory power of the model compared to OLS, which is similar to the results derived by comparing OLS and TSLS (2SLS) in Thompson and Tsolacos (2000). The possible explanation for this is that although 3SLS supports the hypothesis that a dynamic model considering interaction structures can operate in the European office market, the inefficiency of OLS is not sufficiently significant to noticeably improve the model's performance through OLS estimates.

One issue that arose in the construction of the multi-equation model is that of identification. In other words, the inherent advantage of the multi-equation model, which reflects the condition of simultaneity and differentiates it from single equation models, requires that the conditions of exact or over-identification be satisfied during the actual estimation process. This poses a problem. If there are too many variables included in the multi-equation model, under-identification occurs, thereby making it impossible to derive estimates. Thus, the constraints of over-identification or exact identification in the identification process actually limit the number of variables that the multi-equation can estimate. This acted as an obstacle in the process of moving from the conceptual framework to the empirical analysis during this study.

(6) Limitations and Difficulty of Individual City Estimations

In contrast to the estimation output for the entire sample, the estimations for individual cities did not present satisfactory market explanation.

1) Panel FE: As a result of panel fixed effects regression analysis for each city, the estimated results of the four equations for each city for the office market subsectors are presented in Chapter 5. Compared to the estimation for the entire sample, the estimation results for each city are not satisfactory in terms of the direction and significance of the signs. Moreover, except for London's West End and City areas, estimation by panel analysis in the flow and development sectors is statistically unreliable, as the number of samples is less than 30, which is too few.

2) SUR: When the SUR estimation was used, the number of samples was over 30 only in London's West End and City areas, and a statistically reliable estimate could not be obtained in the other areas.

As a result, it is difficult to analyse individual cities with the multi-equation model due to the limited observations. Previous researchers have mentioned data limitation as a key reason for the difficulty in adopting the multi-equation model, and a similar problem occurs here when the level of analysis goes to the individual city level.

London's West End and the City are two areas where panel fixed effects and SUR estimations are available, but actual signs did not appear to be satisfactory (compared to the expected signs), and independent variables are not significant overall. Although R-squared appeared high in SUR, it is still difficult to evaluate the model effectively due to the inaccuracy of the signs. From the results, it was found that longer (at least more than 30 observations per city for all subsectors) time-series data are required for more reliable estimation results using the multi-equation model at individual city level. Unless these conditions are met, it is highly likely that combining several cities in a cross-section is a much more reliable way to analyse data. This can also be a reason why the European office market is analysed in a combined panel, since to date few cities have been able to meet this condition.

(7) Estimation Results in Terms of Variables

Table 45 summarises the estimation results of the main model (Table 20) for all determinant variables in the system.

1) Real rent: The real rent in the new construction equation was significant, except in the GMM, and matched the expected sign in all estimation methods. In the inventory occupancy equation, real rent was significant in all estimation methods but matched the expected sign (-) only in the OLS, GLS, and 3SLS estimation methods.

2) GDP: The real GDP in the real rent equation was significant in all estimation methods and matched the expected sign (+).

Table 45 Summary of estimation in terms of variables

variables / sign		OLS	GLS	Panel FE	Panel RE	GMM	3SLS
real rent	eq. 3 (+) eq. 4 (-)	0.327*** -0.276***	0.483*** -0.403***	2.969*** 0.165***	1.310*** 0.164***	0.203 0.011***	0.707*** -0.552***
GDP	eq. 1 (+)	0.612***	0.543***	0.209***	0.231***	0.056***	0.640***
employment	eq. 1 (+) eq. 3 (+)	0.198*** 0.314*	0.169*** 0.319**	2.188*** -0.818	1.580*** 0.032	0.025 -0.020	0.187*** 0.254
interest rate	eq. 2 (+) eq. 3 (-) eq. 4 (-)	0.139*** 0.600 -0.004	0.135*** 0.090 -0.013*	0.187*** 0.169 -0.044***	0.185*** 0.082 -0.044***	0.030*** -0.044 -0.003***	0.154*** 0.066 -0.022
take-up	eq. 1 (+)	0.087***	0.085**	0.002	0.021***	0.021***	0.072**
new construction	eq. 1 (-) eq. 4 (+)	0.070*** 0.191***	0.111*** 0.056	0.049*** 0.006*	0.056*** 0.006*	-0.018*** 0.004***	0.080*** 0.239***
development permit	eq. 3 (+) eq. 4 (+)	0.223*** 0.136***	0.114*** 0.015	0.013 0.004*	0.069 0.004*	-0.053* 0.001	0.239*** 0.145***
occupied stock	eq. 1 (-)	-0.419***	-0.374***	-1.148***	-0.759***	1.002***	-0.436***

3) Employment: Employment in the real rent equation was significant, except in the GMM, and matched the expected sign in all estimation methods. In the new construction equation, employment was significant at the 10% level in OLS and at the 5% level in GLS, and it matched the expected sign in all estimation methods, except in the GMM.

4) Interest rate: The interest rate in the return equation was significant in all estimation methods and matched the expected sign. In the new construction equation, the interest rate was not significant in all estimation methods and matched the expected sign (-) only in the GMM. In the inventory occupancy equation, the interest rate was significant at the 10% level in GLS, at the 1% level in panel FE and panel RE, and at the 5% level in the GMM, thereby matching the expected sign (-) in all estimation methods.

5) Take-up: The take-up in the real rent equation was significant at the 5% level in the OLS, GLS, and 3SLS, and at the 1% level in GMM, with the sign matching the expected sign (+) in all equations except for panel FE.

6) New construction: New construction in the real rent equation was significant in all equations but did not match the expected sign (-), except in the GMM. In the inventory occupancy equation, new construction was significant at the 1% level in OLS, GMM, and 3SLS as well as at the 10% level in panel FE and panel RE, thereby matching the expected sign (+) only in OLS, GLS, and 3SLS.

7) Development permit: The development permits in the new construction equation were significant at the 1% level in OLS, GLS, and 3SLS, as well as at the 10% level in the GMM, thereby matching the expected sign (+), except in the GMM. In the inventory occupancy equation, building permits were significant at the 1% level in OLS and 3SLS, and at the 10% level in panel FE and panel RE, matching the expected sign (+) in all estimation methods.

8) Occupied stock: The occupied stock in the real rent equation was significant in all equations and matched the expected sign (-), except in the GMM.

5.6 Summary and Commentary

The overall high R-squared of the user subsector support the short-run efficiency and high explanatory power in traditional notion and previous empirical results (for instance, Shilling et al., 1987; Wheaton, 1987; Gardiner and Henneberry, 1991; Wheaton, Torto and Evans, 1997). Although R-squared is low in the investment subsector, it should be considered that only interest rate was adopted as determinant of yield, and actual sign matches with expected sign in all estimation methods. On the other hand, the performance of the development subsectors (i.e. new construction and occupied stock equation) are not satisfactory with low R-squared, despite of adopting four (five in case of GMM) independent variables. This result is in accordance with relatively low elasticity of the supply side in the office market, compared to housing or industrial markets (Fraser, 1986; Nanthakumran, Watkins and Orr, 2000). The lag models did not make much improvement from non-lag models, and only a few exceptions are found in new construction equation of OLS and 3SLS.

The existence of dependence between error terms implies that one assumption of OLS is violated and therefore it is no longer BLUE. In this case, GLS is more efficient estimation method in terms of econometrics but matches between actual and expected signs goes worse under the GLS. The result raises question to the reliability of previous empirical studies using OLS, particularly when R-squared is too high (over 90 percent), it may be because of multicollinearity or heteroscedasticity. Panel FE assumes the existence of city-specific effects under the panel data structure and preferred over Panel RE as the result of Hausman test. Panel FE is therefore a proper method for panel data structure (combined by time-series and cross-section) in the result, but it should be noted that matches between actual and expected signs are dissatisfactory. Although there is no diagnostic violation found, the coefficients of GMM presents too low values and sign matches are also not satisfactory. 3SLS is the most suitable method in reflection of multi-equation structure since it considers endogeneity and simultaneity, and it presents satisfactory model performance and sign consistency.

Panel FE and 3SLS estimation of London, West and the City poorly performs both in model performance and sign consistency and the result backs up the assumption that estimation using pooled data has advantage over that of individual city.

6 Conclusion and Implication

6.1 Introduction

This thesis has sought to make a contribution to the real estate modelling literature by developing a series of applied models of the European office market, in pursuit of the overall aim of exploring the determinants and dynamics of commercial real estate within the European context. The study has estimated models using panel data from six cities and tested a variety of model specifications (from simple to more complex) using a range of methods of estimation. The model results are considered in relation to their theoretical consistency, model performance (e.g., in relation to the ability to predict key outcomes/variables), and statistical properties. The study reveals that there is no single best approach and that often researchers need to trade off theoretical consistency and different aspects of empirical performance. Modelling strategies are also often constrained by data limitations.

This chapter offers reflections on the motivation for the study and its key findings. It also provides some thoughts on the broader implications of the study in terms of what lessons it offers for conceptual thinking, for future research, and for both practitioners who model real estate markets (modellers) and their approaches and for practitioners whose work requires that they are able to understand the market and predict future trends (model users).

6.2 Motivation and Aims of Study

Mainstream economics theoretically assumes an efficient market, where demand and supply are in balance and the equilibrium is automatically achieved under perfect information. In consideration of the general economic theory, the classical school puts emphasis on the supply side, while the Keynesian school focuses more on the demand side. A theoretical framework of neoclassical synthesis was established in comprehensive consideration of the two sides, and a more balanced approach was achieved as a result. However, the gap between theory and practice has not been completely removed despite the theoretical advances in economics (Harrod, 1973). This background provides a reason for the imperfect market operation in the real world, and the problem is more severely experienced in the real estate market.

Although rigidity and inefficiency of the supply side are not features only found in the real estate market, such characteristics are more pronounced than in other markets due to factors such as: 1) the non-productivity of land, 2) administrative factors, for example, development permission from the public authority, and 3) the long period of time necessary for a new construction. Since the factors significantly worsen the uncertainty of the supply side, empirical results quite often deviate from the explainable boundary of mainstream economics (Ball, 1998). On top of this, cyclicality provides another reason for the difficulty in analysing the real estate market. Ups and downs, and booms and busts in the macroeconomy play an important role in the market as external factors (Barras, 2005).

An equilibrium may be achieved in the long term, but the property market basically suffers, by its nature, from inelasticity and imbalance, particularly from the supply side. In the short term, the property market deviates from the optimal point where price (P) and quantity (Q) match both demand and supply, due to the lack of information and the myopic expectations of market participants. Specifically, the supplier (i.e., the space provider) is considered more responsible for the imbalanced state because of the inelasticity of the short-term adjustment process. For this reason, it has been emphasised that the supply side should be considered as a key factor in real estate analysis (Leitner, 1994).

Under the condition that supply is rigid, it is unable to respond to excess demand quickly enough and, as a result, the market cannot reach an equilibrium condition, at least temporarily. The benefit of the holistic approach presented by Keogh (1994) and DiPasquale and Wheaton (1992) is that they brought this concern into real estate study and presented the working process with interactive multi-equation and visualized graphs. This approach enables researchers to describe a temporary disequilibrium and the adjustment process between subsectors, that is, the user, investment and development markets.

To reflect the aforementioned neoclassical concerns in a quantitative office market study requires a couple of considerations. First, using lag for supply-side variables enables the model to prevent regression errors possibly caused by cyclicality and a temporal difference between variables. Second, the estimation method should consider simultaneous interactions between sectors, since there are adjustment processes between submarkets because of temporary disequilibrium caused by excess demand and lack of supply.

(1) Lack of Previous Studies in Structural Equation Modelling

The error correction model (ECM) has often been adopted as a quantitative approach in a series of recent empirical studies (Hendershott, MacGregor and White, 2002; Mouzakis and Richards, 2007; Brooks and Tsolacos, 2008; De Francesco, 2008; Ke and White, 2009, 2013; Adams and Füss, 2012; McCartney, 2012; Bruneau and Cherfouh, 2015).

While the studies are based on the theoretical backgrounds of early 1980s (Rosen, 1984; Hekman, 1985; Wheaton, 1987) and more developed 1990s models (Wheaton, Torto and Evans, 1997; Hendershott, Lizieri and Matysiak, 1997), they tend to be interested in short- and long-term adjustment processes rather than the model structure itself.

Although not used as much as the ECM, the autoregressive integrated moving average (ARIMA) model is also consistently utilised in office market research as it has an advantage in time-series and forecasting analysis (McGough and Tsolacos, 1995; Thomson and Tsolacos, 2000; Stevenson and McGarth, 2003; Stevenson, 2007).

In consideration of such research trends, it seems that the existing three-equation models of Wheaton, Torto and Evans (1997) and Hendershott, Lizieri and Matysiak (1997) are currently accepted as the standard, while applications of more technical approaches, for example ECM and ARIMA, have also been attempted. However, research which examines the structural aspects of the multi-equation models and proposes alternatives to existing models is still conducted as well (Henneberry et al., 2005, for instance) although relatively rare.

(2) Lack of Panel Analysis

Although the use of panel data is more frequently utilised than before, the number of empirical cases is still significantly limited in terms of European office studies (Hendershott, MacGregor and White, 2002; Hollies, 2007; Mouzakis and Richards, 2007).

(3) Lack of Econometric Estimation Other than OLS

The majority of empirical studies have used OLS estimation, which does not consider violation of basic econometric assumptions.

Discussions addressing endogeneity and exogeneity in relation to the real estate market are also scarce, but Dunes, Jones, White, Trevillion and Wang (2007) have undertaken relevant research regarding yield.

Furthermore, the low explanatory power of supply-side equation models due to the rigidity in the real estate market's supply is pointed out, as this acts as a complicating factor for empirical analysis.

Considering these limitations, this study aimed to systematically explain the function of the overall office market by developing a multi-equation model that starts from the four-quadrant model and connects each subsector, taking into account various explanatory variables for the dependent variables in each sector. While these explanatory variables were theoretically considered, they were either rarely used in empirical analysis or overlooked in the overall market despite being discussed in individual subsectors.

In addition, macroeconomic factors and investment sectors in the operational process of the office market system, which had been overlooked in the existing three-equation system (Wheaton, Torto and Evans, 1997; Hendershott, Lizieri and Matysiak, 1999) were incorporated into the empirical model. This study also aimed to elucidate the impact of these factors on the office market.

However, it should be noted that in the modelling process, variables for each sector, particularly macroeconomic factors and development sector variables, were collected in annual data form, leading to a lack of observations and preventing their inclusion in regression models. As a result, the initial model (discussed in section 3.3) could not be practically used in empirical analysis and remained at the stage of model derivation. If data availability expands in the future, empirical analysis using this model could become feasible.

6.3 Key Findings

The research aims, objectives, and research questions have been previously established in Chapter 1. Since the empirical results are derived in Chapter 5, this section provides answers to the three research questions based on the analysis results in Chapter 5.

(1) What are the determinants of office rents in the selected European markets?

In the user subsector, GDP, employment, occupied stock, and take-up are found to be significant determinants (Table 20) of European office rent. GDP represents national economic activity, and employment indicates corporate demand for office space. Therefore, the high elasticity of GDP with respect to rent (0.640) suggests that rents are highly responsive to economic activity. Similarly, the elasticity of employment (0.187) indicates that the corporate demand for office space drives up rents. Take-up, which measures the actual increase in corporate space demand, revealed a positive coefficient consistent with the expectation that an increase in market space consumption would increase rents, although its effect was relatively modest (0.072). Occupied stock, a supply factor, revealed a negative elasticity (-0.436) with respect to rent, which is consistent with the expectation that an increase in market space supply would lead to a decrease in rents.

The findings that GDP and employment are determinants that drive up rents are consistent with results widely depicted in existing single and multi-equation models in Tables 5 and 6. The empirical result further confirms these relationships for major European office centres.

The determinants of occupied stock include rent, new construction, and development permits, which function as indirect determinants of rent. This is further discussed in the response to the third question.

(2) To what extent do office rents vary across space and time (spatial and temporal variation)?

The information derived from descriptive statistics, cointegration tests, and panel estimation provides clues of spatial and temporal changes in office rents.

First, temporal changes in the office rents in individual cities can be found in the descriptive statistics in Table 9 and in Figures 11–17. As presented in Table 9, office rents in London's West End average approximately 1200 euros (per square foot), which is significantly higher than that in other central areas. Next, Paris and the City of London have rents between 700 euros and 800 euros, Milan and Frankfurt between the mid-400 euros and 500 euros, and Amsterdam and Madrid around mid-300 euros. Higher rents are generally associated with larger standard deviations; however, Paris (48.69) showed relatively low volatility despite high rent levels, whereas Madrid (76.78) and Milan (52.78) exhibited high volatility despite having lower rent levels.

In spite of these differences in rental levels, a decline in rents and an increase in yields due to the impact of the global financial crisis in 2008 were commonly observed across the seven central areas. The time required for rent recovery varies by city, but the rents in all cities did not return to the level of 2007, except that in Amsterdam. In terms of the real estate cycle, it appears that rents have been moving through the phases of peaking, recession, troughing, and expansion over the 12-year observation period.

In the development subsector, it is difficult to find commonalities among cities, and initial observation values are missing for Paris, Milan, and Madrid. Observing the occupied stock variable, the effect of supply reduction due to falling rents and decreased new supply in 2008–2009 was evident in London West End, City of London, and Milan, but there were no significant changes in the other cities. Nonetheless, the supply of space revealed a steady increase in all cities except Amsterdam after 2010. Amsterdam also witnessed an increase in supply beginning in 2015, reaching the highest levels at the end of 2018. Although the changes in supply patterns are much less pronounced among cities compared to the user subsector, these changes in supply trends indicate the recovery of the European office market, which is similar to the expansion phase of office rent.

Second, the cointegration test—which indicates the time-series correlation—can be used to understand the temporal relationships between rent and other selective variables. According to the Pedroni, Kao, and Westerlund cointegration tests in Table 42, there is a strong cointegration among real rent, employment, GDP, and network connectivity. This serves as evidence that office rent, corporate demand of space, national economic activity, and the connectivity among cities are temporally correlated in each city. In addition, GDP and employment were found to be significant determinants in the rent equation in the answer to the first question, and the existence of a strong cointegration relationship supports the validity of causal relationships.

Third, the between-effects in the spatial integration of selected European cities can be observed from the random effects model in the panel estimations. However, since the random effects model was rejected in the Hausman test in Table 39, the between-effects is considered to be insignificant. In other words, the impact of spatial interactions between cities is not substantial.

In addition, the advantage of fixed effects (FE) is that they can completely control for entity-specific characteristics that do not change over time, thus eliminating omitted variable bias. Consequently, the FE estimators become consistent. FE choose statistically consistent estimators over random effects (RE), considering that the inconsistency caused by RE is a more serious problem than the inefficiency caused by fixed effects. Therefore, the adoption of the FE model indicates that consistency is more important than inefficiency in the panel structure of European cities.

(3) What are the interactions (or dynamics) among the submarkets?

To understand how interactions occur among subsectors, it is necessary to 1) examine the role of individual variables within a system of simultaneous equations, and 2) investigate the functioning of the investment subsector, which functions as an intermediary between the user and the development subsector.

Interest rates is a determinant of yields in the investment subsector, and a 1% increase in interest rates increases yields by 0.154%, as presented in Table 20. From the identity of rent/yield = capital value, interest rate impacts capital value as a determinant of yields.

Further, rent and development permits are determinants of new construction. An increase in rent boosts profit and promotes new construction, which is confirmed by the high positive elasticity (0.707). The importance of the planning variable was proposed by Henneberry et al. (2005), and generous development permits from the planning authorities also stimulates new construction, with a coefficient of 0.239. Although it was expected that the resulting new construction would drive down rents, it actually showed a positive value (0.08). However, the impact of construction on rent in the user subsector is uncertain because new construction is not a significant determinant of rent in the first equation.

Rent, development permits, and new construction are determinants of occupied stock. An increase in rent is expected to reduce space demand, thereby decreasing occupied stock, which shows a negative elasticity (-0.552). If planning authorities are lenient with development permits or if new construction is active, the supply of space will increase and lead to an expected rise in supply and occupied stock. The analysis in Table 20 confirms that new construction (0.239) and development permits (0.145) have positive coefficients. This determined occupied stock, being an endogenous variable, is expected to act as a determinant in the user subsector to reduce rent again. This is confirmed by the negative coefficient (-0.436) in the rent equation.

Next, the role of the investment subsector is examined. This study's multi-equation model is similar to the theoretical approaches of the three-equation models given by Wheaton et al. (1997) and Hendershott et al. (1999). The reason for the similarity is that the foundation of the model's structure is based on DiPasquale and Wheaton's (1992) four-quadrant theory. Among these, Hendershott et al. (1999) claim that their model is differentiated from that of Wheaton et al. (1997) because it considers the endogeneity of the investment subsector. Ball et al. (1999) also introduce these two models as examples of multi-equation models and acknowledge the advantages of Hendershott et al.'s (1999) model in the process of modelling the investment subsector.

Considering these aspects, the investment subsector is separated in the yield equation and the 3SLS estimation demonstrates that interest rates are a significant determinant of yield in this subsector. Although the R-squared is low at 27.7% (Table 20), including the FTSE index increases the R-squared to 44.8% (Table 24) and including both the FTSE 100 index and network connectivity further increases it to 50.8% (Table 26). The FTSE 100 index and network connectivity function as strong negative determinants of yield, thereby aligning with the expected signs. These results highlight the importance of the investment subsector as an intermediary which links the user and the development subsectors. These findings suggest the need for further research on the investment subsector in terms of the subsectors' interaction process.

6.4 Implication for Research

6.4.1 Implication for Research in Terms of Data Collection

Real estate studies in the UK are often conducted at the national level rather than the regional level due to data limitations. By contrast, the US has been relatively free from these limitations on data collection compared to the UK and Europe. This study prepared a framework for analysing the European real estate market as an integrated market by expanding the cross-sectional scope of data collection to major European cities and combining cross-sectional and time-series data in the form of panels. Data corresponding to the dependent and independent variables of the four equations were collected for seven office markets in Europe and structured in a balanced panel (i.e., quarterly with regular intervals for all groups) with the aim of overcoming the previous data limitation. Although there are missing values for some variables (especially in the supply sector, where data collection is known to be difficult), the collected data are in the form of a balanced panel with a sufficient sample size. This enables a researcher to perform more complex quantitative analysis, such as panel analysis and 3SLS, other than OLS.

The empirical approach of this study is divided into two parts: descriptive statistics and regression analysis. In the descriptive statistics analysis, basic statistical information such as the mean, maximum, minimum, and standard deviation of the dependent variables for each subsector and independent variables (annual basis) is presented.

The temporal changes of the dependent variables for each city are also illustrated through graphs. For the regression analysis, the structural equation has been developed from the initial five-equation model in section 3.2 to the final four-equation model in section 4.3. In the regression analysis, the structural equation model finalised in the section 4.3 is estimated separately for each subsector using various econometric techniques. Diagnostic tests are conducted for each analysis result to assess the reliability of the estimated outcomes.

6.4.2 Implications in Terms of Economics

Since the 1970s, rational expectations have become the dominant paradigm in macroeconomics, and one of the main reasons for this is the consistency between theory and results (Muth 1961; Sargent and Wallace, 1976). Economies rely on expectations based on economic structure, and if actors' subjective beliefs do not take economic structure into account, their predictions will consistently underperform; where the rational expectations hypothesis excels is in its insight that markets converge to an equilibrium through this self-adjustment process. Therefore, rational expectation comprises an essential part of the Walrasian equilibrium.

DiPasquale and Wheaton (1992)'s four-quadrant model is a pedagogical model which provides theoretical interpretation of the interaction process. To briefly recapitulate, the model starts by defining the functional relationships of user, investment, and flow and stock subsectors and provides links between them by formulating interaction relationships in the four-quadrant system. From a macroeconomic perspective, the four-quadrant model is an advantageous tool in terms of describing the process of achieving a Walrasian equilibrium in the real estate market, based on the implementation of the rational expectation hypothesis. The theoretical advantage of the four-quadrant model over the single equation model in this sense is that one of the basic assumptions of economics, long-term equilibrium, is applied to the real estate market by explaining the interaction of subsectors. These features enable the model to provide a solid theoretical explanation of the real estate market operation process, and it has greatly influenced the fundamental framework for empirical analysis in subsequent studies.

In this study, each of the four-quadrant models is expressed in the form of an individual equation (i.e., real rent, yield, new construction and occupied stock equations) in the modelling process, in reflection of the four-quadrant model. The modelling process contrasts with previous cases where single equation models were used to focus on a single subsector and multi-equation models were used to focus on two (supply and demand) or three (rental, new construction and occupied stock) functions. As the yield equation connects space demand and supply sides, it enables the model to describe the investor's intermediary role in the system, as the subsector has been missing in previous studies.

This research also focused on the more improved availability of office market data and practised its implementation in the model. Important factors of subsectors were set as independent variables referenced by the previous literatures, and relevant data were collected for the performance of regression analysis in consideration of data availability.

6.4.3 Implications in Terms of Econometric Estimation

In this study, estimations were conducted using various econometric techniques to empirically explore which estimation method is appropriate when using panel data for the quantitative analysis of the European office market.

In the regression analysis, the performance of lag model did not show significant difference from non-lag model. Therefore, impact of lagged supply variables as determinants is remaining uncertain. In terms of simultaneity, 3SLS method is used and basic estimation of OLS and GLS is also performed in the purpose of comparison. Panel random and fixed effects, GMM are estimated respectively due to the cross-sectionally combined data structure, and GMM is estimated in consideration of dynamic impact of lagged dependent variable as a determinant.

The violation of econometric assumptions is also checked, and the following is the findings of diagnostics by estimation methods:

In OLS and GLS, series correlation is not found, but partial violation of function form (in investment and development sectors), violation of normal distribution hypothesis and existence of heteroscedasticity are detected. Panel fixed effect is preferred between FE and RE methods. Heteroscedasticity is found, and there is a penalty in terms of equation parsimony (the number of variables) in 3SLS. Overidentification constraint is appropriate in GMM.

Regarding the quality of data, there are not much difference between estimation methods since the same sample has been used. There are only slight differences when dynamic model (such as GMM) takes lag of dependent variable and drops one-time period data as a consequence. Rather larger difference seems to be found between sectors, probably because of the gap between the original and proxy variables. It seems that the quality gap of the data is particularly more severe in development sector variables considering low explanatory powers of flow and stock development equations. User and investment sector variables presented better performance in the same standard.

However, it should be noted that alternative estimation methods solve some of the original problems of OLS. Three-stage least squares estimation takes account of the existing endogeneity issue with some of the dependent and independent variables, and panel random effects estimation enables interpretation of a time-series and cross-section combined panel structure rather than cross-section only (more detailed results of econometric estimations and comparisons were presented in Chapter 5). Therefore, it can be concluded that 3SLS fits well with the four-quadrant framework, as the performance measured by the significance of coefficients and matches with expected signs are good enough for the occupier, investment, flow and stock development equations.

In sum, single estimation method which both satisfies theoretical context and econometric standard in diagnostics have not found in this study. However, a potential conclusion by far is that 3SLS is the closest estimation which answers to theoretical interaction of submarkets and its empirical reflection in consideration of simultaneity, despite the detection of heteroscedasticity. It is found that 3SLS presents high level of suitability in terms of expected variable signs and explanatory power of R2 value (except occupied stock equation) in general. It does not mean that 3SLS is superior to the other estimation methods by nature, but still can be said that 3SLS more adequately fits to the research when its focus is holistic approach putting emphasis on submarket interactions. The concept of endogeneity and exogeneity is considered in the estimation and it enables to capture the impact of an explanatory variable in one submarket on other sectors, for instance, real rent's impact on investment or development subsectors.

A diagnostic test was performed as part of the regression analysis, and one important purpose of the test was to determine whether estimation using OLS, generally considered a default option, is appropriate. If not, it means that there are better methods than OLS, and it is necessary to identify the strengths and weaknesses of those alternatives to determine which estimation method to finally choose.

The diagnostic test reported that OLS is not the best linear unbiased estimator (BLUE) due to its partial violation of Gauss–Markov assumptions. Therefore, estimation methods other than OLS should be considered as alternatives, and this research focused on GLS, panel fixed and random effects, GMM and 3SLS. General least squares uses robust estimation to remove the heteroscedasticity violation found in OLS. The Hausman test was conducted in the panel fixed and random effects models. Generalised method of moments was used as an alternative to the minimum estimation method, and an identification test was performed, while 3SLS was used to resolve the endogeneity issue of dependent and independent variables in the equation system.

In terms of explanatory power, the performance of the supply (development) side was not satisfactory for both flow and stock subsectors, while the demand side presented a high R-squared value. This is probably due to the gap between theory and the real-world office market, particularly in the respect that the four-quadrant model assumed a long-term equilibrium between subsectors while the actual supply-side response to demand change is quite rigid. The low R-squared value in the flow and stock development equations can be interpreted as an expression of such rigidity in the supply side, as demonstrated by the low explanatory power of the model. Despite this, expected and actual signs were mostly matched in each equation (i.e., subsector), and the results imply that theoretical operation processes between dependent and independent variables were properly adopted for each subsector in the regression model.

It was demonstrated that the theoretically explained rigidity in the supply side and the elasticity of the demand sector are empirically also proven in the European office markets. In the real estate market, the developer's actual decision on a new construction project tends to be myopic rather than based on a rational perspective for the future. In other words, the actions of participants on the supply side are more likely to be based on adaptive expectation rather than rational expectation, which is basically assumed by neoclassical economics. This deviation from the assumption of mainstream economics yields a slower response by the supply side to changes in demand, and in turn causes market inefficiency, particularly in the short term. In consequence, new construction cannot immediately supply the office market because construction takes a certain amount of time from starts to completion. In the modelling process for the office market, the time lag should be considered a supply-side variable for this reason. The difference is due to myopic expectation of the supply side, and the adjustment process of the real estate market follows adaptive expectation rather than the rational expectation hypothesis (Gardiner and Henneberry, 1998, 1991).

For the reasons stated above, the goodness of fit on the demand side is satisfactory for the real rent equation, while it is not on the supply side for the new construction and occupied stock equations. The finding therefore reconfirms the difficulty of supply-side estimations in terms of model performance and sign consistency, something that has repeatedly been noted in previous empirical studies.

Recent office research tends to produce empirical results using various estimation techniques in reflection of econometric development (Stevenson, 2007; De Francesco, 2008; Brounen and Jennen, 2009; Ibanez and Pennington-Cross, 2013; Chegut et al., 2015). Still, the use of a multi-equation model theoretically based on the four-quadrant model is still rare. In view of the advantages of the four-quadrant model and the multi-equation model discussed above, this area should be further developed. Therefore, considering the data collection, modelling and estimation process comprehensively, this study contributes to the overall development of European office market research.

6.5 Implication for Model Users in Practice

To recapitulate the overall modelling, estimation and interpretation process, the regression analysis and diagnostic tests were presented in Chapter 5, the regression analysis and diagnostic tests were presented in Chapter 5, and the key findings of the empirical model were discussed above in section 6.3. These findings are based on the empirical analysis model described in section 4.3. However, after the literature review discussed in Chapters 2 and 3, and the development of the initial model in section 3.3, the empirical model in section 4.3 has undergone a significant transformation process, dropping independent variables collected on an annual basis (e.g., regional GDP, tax rate, office service output, population, network effects between cities, vacancy and office investment) and treating the macroeconomic variable as an exogenous determinant. These changes were made for two key reasons, as discussed in section 4.3: 1) the insufficient number of samples in the annual data for performing regression analysis, and 2) the difficulty with including too many variables in the actual regression process due to the principle of parsimony. Based on this process, this section examines the implications of this study for practitioners in terms of data availability and forecasting.

(1) Improvement in Data Availability

In section 5.2, descriptive statistics of the four dependent variables are presented based on the quarterly data collection for seven areas, representing equations for the user, investment, flow and stock of the development subsectors. Descriptive statistics of the independent variables collected on an annual basis are also provided, with the aim of minimizing the gaps between the literature review and the model development process (Chapters 2 and 3), and their transformation and actual application in the regression analysis (Chapters 4 and 5). In addition, the time-series changes in the rents and related variables are provided in the graphs by area, to examine the existence of real estate cycles in the descriptive analysis.

From the descriptive statistics, practitioners and market participants can find additional information on development subsector indicators (e.g. new construction, occupied stock), macroeconomic (e.g. RGDP / GDP ratio, office service output, population) and geographical factors (e.g. global city and network connectivity index). Majority of existing reports from real estate service and investment companies (for instance, Frank Knight, Jones Lang LaSalle (JLL), CBRE, BNP Paribas) tends to analyse office market based on a few of key variables, for instance, rent and vacancy rate in the user subsector and yield and capital value in the investment subsector. The supply-side analysis is often skipped, and even if it is included, the analysis has been suffered by time-series discontinuity of important indicators, such as new construction, construction costs and total stock. The downside of the market reports somewhat resembles that of single equation approach (discussed in the subsection 2.5.1) due to its dependence on the demand-side. Therefore, practitioners can supplement lack of market information by considering previously overlooked indicators.

The increase in the sample size due to the improved data availability signifies an enhancement in the quantifiable domain. Despite theoretical progress in studies prior to the 2000s, empirical analyses were significantly constrained by data limitations. As shown in Tables 5 and 6, most studies had fewer than 30 observations, which made ensuring statistical significance and accurate predictions difficult (Hekman, 1985; Shilling et al., 1987; Hendershott, 1996a; Wheaton et al., 1997). In post-2000 studies, the number of observations increased: Mouzakis and Richards (2007) had 200 to 261; Brounen and Jennen (2009), 70 to 75; Fuerst (2006), 47; and Bruneau and Cherfouh (2015), 83 to 95. In the current study, the fully available data amounted to 336 observations; but due to omitted values, it had 276 observations for OLS and 154 for 3SLS, which required simultaneous estimation. However, Marcato and Tong (2023) had reported 2,280 observations, which indicates a significant improvement in data availability in the US MSAs. Overall, the steady increase in data availability in both Europe and the US is evident and acts as a positive factor in enhancing the accuracy of predictions, which is further discussed as follows.

(2) Model Application in Forecasting

The practical implications of this study are now discussed. The goal of analysts and asset managers is to invest in undervalued assets and achieve returns above the target within a relatively short period of time, which highlights the importance of short-term forecasting. While the theoretical studies that were examined in the current study tended to focus more on the user and development subsectors, the practical field emphasises the importance of the investment subsector and the prediction of returns for the same reason.

Analysts primarily aim to provide accurate forecasts for real estate, and they tend to seek models that are useful for short-term predictions with the highest fit or explanatory power. This tendency can lead to a focus on short-term forecasting suitability at the expense of long-term model robustness. Consequently, practical approaches may sometimes have a myopic limitation and may conflict with theoretical dynamics and the achievement of equilibrium in the long term. As a result, previous practical studies that on short-term rent forecasts showed greater interest in the instantaneous impact of the investment subsector and macroeconomic variables than in the role of the development sector (for instance, Gallimore and McAllister, 2004; McAllister et al., 2008; Watkins et al., 2012; Papastamos et al., 2015).

Therefore, short-term prediction models function properly when the included variables have low volatility or when there are no shocks from external factors that are not included in the model. Prediction is relatively easier when variables with low volatility and stability, such as GDP, or variables highly correlated with rent, such as CPI change and rental growth, are included. However, the prediction becomes more challenging when highly volatile variables, such as stock prices or bond yields, are included (McAllister et al., 2008).

In the alternative model in this study (Table 26), network connectivity emerged as an immediate and highly elastic variable for rent in the user subsector and for returns in the investment subsector. Hence, it has the potential to improve short-term prediction levels when the factor is applied in practice. As observed from the standard deviation in Table 10, the variable did not exhibit significant time-series variability, which means that it is stable over time. Additionally, the diagnostic test indicated that network connectivity has a cointegration relationship with rent, employment and GDP (Table 42), which enhances the model's explanatory power. Notably, however, a high explanatory power does not necessarily translate into accurate predictions, warranting caution in the model's application and in the interpretation of its results.

Conversely, a theoretically solid model may not necessarily have the best explanatory power. In this study, an example of this can be seen in the rent equation in the main model (Table 20), the explanatory power of which is 79.3%, lower than the 81.6% of the OLS estimation (Table 10). The OLS estimation reflects only the determinants within the rent equation, whereas the 3SLS estimation considers the indirect effects of the endogenous variable, occupied stock, which significantly affects rent. The 3SLS estimation accounts for the impacts of significant independent variables in the fourth equation (i.e., the occupied stock equation), such as rent, new construction and development permits, which are transmitted through the occupied stock variable in the first equation. Although the 3SLS estimation captured the influence of the user subsector from the development subsector, it still has lower explanatory power, supporting the argument that the model with the highest fit is not the optimal model.

In the real-world market, it is also true due to the existence of uncertainties, such as structural changes and turning points in terms of the market cyclicality. Examples of structural breaking events are the collapse of Long-Term Capital Management (LTCM) in 1998 and the global financial crisis (GFC) in 2008, which are within the time frame of this study. Our examination of their impacts on the real estate market between 2008 and 2009, as depicted in Table 11-17, showed a drastic drop in rents in London (i.e., in the West End and the city) and Paris, with yields rising in all cities except Frankfurt. This shock was the most significant within the observation period and clearly deviated from general cyclical trends. Had external factors, such as macroeconomic variables, driven such changes, these changes would have been difficult for short-term forecasting models to predict, as these models consider only the direct determinants of rents or yields.

Therefore, practitioners are required to bring theoretical complexity into the model, as its process can prevent them from missing possible structural changes or turning points. In this vein, considering the dynamics and interactions between cities or subsectors can provide important insights into the office market's more fundamental structure and the resulting changes.

Forecasting in the investment subsector involves a higher level of complexity than in the user subsector, primarily due to the uncertainty of returns. This uncertainty is exacerbated by non-quantitative factors, such as market sentiment, which existing models do not predict. A noteworthy perspective regarding predictive uncertainty is the argument that the issue with it is not the inaccuracy of its predictions but the non-quantitative factors that contradict the market rationality assumed in mainstream economics. Real estate forecasts are generated with combined quantitative (i.e., econometric estimation) and qualitative (i.e., subjective market overlay process) elements, and the subjective factors need to be more carefully considered (Watkins et al., 2012). Regarding this suggestion, incorporating qualitative elements in future research, through interviews and other means, is necessary to enhance the explanatory power of predictions.

6.6 Limitation of the Study / Suggestions for Further Research

In the past, single-equation models in the UK and Europe have primarily focused on single subsectors and spatially targeted individual markets and cities or analysed cities or regions within a country. This approach facilitated in-depth analysis and understanding of subsectors, which—in relation to the operation of the four-quadrant office market model discussed earlier—can be considered a static approach. Recent trends in office market research indicate the widespread adoption of ECMs, thereby suggesting that the methodology for analysing office markets has evolved from static approaches to dynamic approaches that address short-term adjustments and the achievement of long-term equilibrium. However, by using a simultaneous equation model, it is possible to more precisely explain the dynamic operations of the market described in the four-quadrant model, particularly the interactions and exchanges among subsectors and their components.

Therefore, the introduction of simultaneous equation models can contribute to the advancement of office market research by enhancing understanding of the linkages and interactions among subsectors that the ECM, with its focus on rental adjustment and convergence to equilibrium, may overlook.

Additionally, in terms of spatial analysis, there is an increasing number of cases that use panel data and panel data models. This development signifies a shift from past analyses that were limited to single time series or, even with multiple time series, executed separately for each cross-section. Now, analyses are evolving to combine time series with cross-sectional data.

From a regional perspective, the focus of analysis—which traditionally dealt with regions or cities within a single country—is increasingly expanding to include cities across Europe. However, when examining the analytical methods used in these studies on European cities, techniques such as ECMs, VAR, or ARIMA are commonly employed. There are very few instances in which simultaneous equation models have been used for extended spatial analysis.

When synthesising the current trends in office market research as described above, the justification for using the simultaneous equation model approach, derived from the analytical framework through theoretical and literature reviews, is evident in order to fill the gaps in office market research. Although there are cases that analyse European cities using panel data models and this trend is increasing, it is still rare to find studies that explore the dynamic processes of the office market with a focus on the interactions of its subsectors. This aspect differentiates the approach of this study, which aims to apply the interaction and linkage relationships of the four-quadrant model to the analysis of European cities.

The interrelationships among variables in the real estate market require econometric consideration, particularly regarding the characteristic of simultaneity. Simultaneity is a specific form of endogeneity and if it is not appropriately accounted for, using the OLS estimation method will tend to rely on the strong assumption of strong exogeneity, which will likely lead to inconsistent estimates. Thus, the issues of simultaneity, endogeneity, and consistency in econometrics should be referred to in terms of the following topics.

From a spatial perspective, this study aimed to examine whether the operating processes of the office market function significantly on a continental scale, beyond individual markets, cities, or national units. This requires econometric consideration of the fixed effects and random effects in panel models.

The model presented the operational process of the real estate economy/office market using multi-equations from an economic perspective; to overcome the simultaneity issue that occurs in OLS estimation, the 3SLS estimation was employed econometrically for the interaction among variables. In this process, the study achieved its goal by revealing that the multi-equation model, which has been developed in the US and frequently mentioned in previous studies due to improved data availability, can also be applied to the European office market. However, a few of the initial research objectives were not achieved due to the limitations arising from the structure of the multi-equation, specifically the identification issue that limits the number of variables.

The following are the reasons that a few of the research objectives were not achieved: 1) the limitations of the data, which prevented the collection of appropriate proxy variables or provided insufficient sample sizes over time to explore the variables included in the theoretical framework setting stage; 2) certain variables were excluded due to identification issues and the principle of parsimony in the multi-equation model. Therefore, despite the study's aim to explore the advantages of multi-equations compared to single equation models, detailed exploration of subsectors could be achieved by using single equation models or conducting in-depth analysis focused on individual cities, thereby achieving the research objectives that were missed in this study.

Additionally, using a panel model requires collecting variables of the same nature over the same period for each city, which also constrained variable availability. The models estimated with a panel structure yielded significantly different coefficient values compared to time-series estimates (OLS, GLS, and 3SLS) and were not satisfactory in terms of the sign and significance of the variables. This could be attributed to the between-effects offsetting the within-effects.

Therefore, the complementarity between the multi-equation model selected as the subject of exploration in this study and the single equation model and ECM mentioned as comparison targets should be acknowledged. While the multi-equation has strengths in explaining the overall structure and dynamic operation of the real estate/office market, the traditional single equation model—despite its limitations in static analysis—has the advantage of relatively fewer variable constraints, thereby allowing for a more detailed exploration of individual markets or subsectors. Thus, the ECM is suitable for explaining short-term adjustments and long-term equilibrium achievement using the error correction term.

Thus, these models are not superior to one another but have complementary aspects. Each approach is a suitable tool for partially explaining the theoretical approach to office research. Therefore, the choice of research methodology should align with the research objective, whether it is 1) static or dynamic, 2) aimed at explaining the overall structural operation of the market or exploring the detailed components of each subsector, or 3) focused on the connections and interactions among subsectors or on convergence to short-term adjustments and long-term equilibrium in the dynamic mechanisms of the office market. This ensures that a purposive research methodology is adopted accordingly.

Next, future research directions are suggested in consideration of the limitations of this study. While this study focused on the office market within the real estate subsectors, future research could expand to include other sectors such as residential, retail, and industrial markets. This broader scope would provide a more holistic view of the real estate market dynamics. Moreover, future studies could examine factors considered during theoretical modelling but those that were not fully explored in this empirical analysis. This can be approached from individual or integrated perspectives to provide a more comprehensive understanding.

In terms of data collection, future improvements in variable availability will likely enable further consideration on a longer time series, cyclicality and fluctuation, and adoption (or exchange) of addition key variables for the subsectors. This will enhance the current model's explanatory power and help align theoretical and empirical analyses more closely. Additional considerations on cycles and key variables will likely increase the explanatory power of the model and bridge the gap between theory and empirical analysis.

With regard to the approach with estimations, the factors considered in the theoretical modelling process but not addressed in the empirical analysis can be further examined from both individual and integrated perspectives in future research. For example, the role of the investment subsector and geographical factors were investigated in the 3SLS estimation (subsection 5.3.6), but there is potential of future development with additional adoption variables or theoretical considerations. The 3SLS estimation method used in this study can also be applied for the purpose of forecasting and future prediction. For the panel analysis, focusing on a single subsector is likely to increase the explanatory power of panel estimates, thereby providing more precise insights.

Lastly, this study would be valuable for practitioners and researchers who are interested in the European office market; it also offers insights that can be extended to other major economic regions such as the US and Asia since the theoretical four-quadrant framework can be applicable globally. Practitioners will benefit from the study's insights on utilising office market data from various cities in quantitative research, as it offers practical applications for real estate market analysis. Researchers who focus on various econometric techniques and seek a robust framework for quantitative analysis will also likely find this study useful for the analysis of real estate and office markets. In terms of the study's applicability to other submarkets, the developed model is not only limited to the office market but also applicable to other real estate sectors, including residential, retail, and industrial markets, thereby enhancing its utility across various domains.

References

Adams, Z. & Füss, R. (2012) 'Disentangling the Short and Long-Run Effects of Occupied Stock in the Rental Adjustment Process', *The Journal of Real Estate Finance and Economics*, 44(4), pp. 570-590.

Allison, O. & Jones, C. (2003) 'The Analysis and Prediction of Urban Office Market'. *Urban Studies*, 40(11), pp. 2255-2284.

Arestis, P. & Hadjimatheou, G. (1982) *Introducing Macroeconomic Modelling: An Econometric Study of the United Kingdom*, 1st Ed. Palgrave Macmillan.

Ball, M., Lizieri, C. & MacGregor, B. D. (1999) *The Economics of Commercial Property Markets*. 1st Ed. London; New York: Routledge.

Barras, R. (1994) 'Property and the Economic Cycle: Building Cycles Revisited'. *Journal of Property Research*, 11, pp. 183-197.

Barras, R. (2005) 'A Building Cycle Model for an Imperfect World', *Journal of Property Research*. 22(2-3), pp. 63-96.

Bera, A. K., and Jarque, C. M. (1981) 'An Efficient Large-sample Test for Normality of Observations and Regression Residuals', *Working Paper in Econometrics No. 40*, Canberra, Australian National University.

Breusch, T. S. and Pagan, A. R. (1979) 'A Simple Test for Heteroscedasticity and Random Coefficient Variation', *Econometrica*, 47, 1287-1294.

Brooks, C. & Tsolacos, S. (1999) The Impact of Economic and Financial Factors on UK Property Performance. Journal of Property Research, 16(2), pp. 139-152.

Brooks, C. & Tsolacos, S. (2008) 'Integration of International Office Markets and Signal Extraction'. *Journal of Real Estate Portfolio Management*, 14(4), pp. 351-362.

Brooks, C. & Tsolacos, S (2010) *Real Estate Modelling and Forecasting*, 1st Ed. Cambridge University Press.

Brounen, D. & Jennen, M. (2009) 'Local Office Rent Dynamics: A Tale of Ten Cities". *The Journal of Real Estate Finance and Economics*, 39(4), pp. 385-402.

Bruneau, C. & Cherfouh, S. (2015) 'Long-run equilibrium for the Greater Paris office market and short-run adjustments'. *Journal of Property Research*, 32(4), pp. 1-23.

Cagan, J. (1956) The Monetary Dynamics of Hyperinflation, *Studies in the Quantity Theory of Money* (M. Friedman, ed.), II: University of Chicago Press.

Cameron, A. & Trivedi, P. (1990) 'Regression-based tests for overdispersion in the Poisson model', *Journal of Econometrics, 46*(3), 347-364.

Cameron, A. & Trivedi, P. (2005) *Microeconometrics: Methods and Applications*, 1st Ed., Cambridge University Press.

Cameron, A. & Trivedi, P. (2010) *Microeconometrics Using Stata*, 2nd Ed., Stata Press.

Campbell, J. Y. & Shiller (1987) 'Cointegration and Tests of Present Value Models', *Journal of Political Economy*, 95(5), pp. 1062–1088.

Campbell, J. Y. & Shiller (1991) 'Yield Spreads and Interest Rate Movements: A Bird's Eye View'. *Review of Economic Studies*, 58, pp. 495-514.

Castells, M. (1994) 'European Cities, The Informational Society, and the Global Economy'. *New Left Review*, Issue 204, pp. 18-32.

Chaplin, R. (1999) 'The predictability of real office rents', *Journal of Property Research*, 16(1), pp. 21-49.

Chegut, A. M., Eichholtz, P. M. A. & Rodrigues, P. (2013) 'The London Commercial Property Price Index', *Journal of Real Estate Finance and Economics*, 47(4), pp. 588-616.

Colwell, P. F. (2002) 'Tweaking the DiPasquale-Wheaton Model'. *Journal of Housing Economics*, Volume 11, pp. 24-39.

Corsetti, G., Pericoli, M. & Sbracia, M. (2005) '"Some contagion, some interdependence": More pitfalls in tests of financial contagion'. *Journal of International Money and Finance*, Volume 24, pp. 1177-1199.

D'Arcy, E., McGough, T. & Tsolacos, S. (1997) 'National Economic Trends, Market Size and City Growth Effects on European Office Rents'. *Journal of Property Research*, 14(4), p. 297–308.

D'Arcy, É., McGough, T. & Tsolacos, S. (1999) 'An Econometric Analysis and Forecasts of the Office rental Cycle in the Dublin area'. *Journal of Property Research*, 16(4), pp. 309-21.

Dahesh, A. & Pugh, C. (2000) 'Property Cycles in a Global Economy', *Urban Studies*, 37(13), pp. 2581-2600.

De Francesco, A. J. (2008) 'Time-Series Characteristics and Long-Run Equilibrium for Major Australian Office Markets'. *Real Estate Economics*, 36(2), pp. 371–402.

Dickey, D. A., & Fuller, W. A. (1979) 'Distribution of the Estimators for Autoregressive Time Series with a Unit Root'. *Journal of the American Statistical Association*, 74(366a), pp. 427–431.

DiPasquale, D. & Wheaton, W. C. (1992) 'The Markets for Real Estate Assets and Space: A Conceptual Framework'. *Journal of American Real Estate and Urban Economics Association*, 20(1), pp. 181-197.

Dobson, S. M. and Goddard, J. A. (1992) 'The Determinants of Commercial Property Prices and Rents'. *Bulletin of Economic Research*, 44(4), pp. 301-321.

Dunse, N., Jones, C., White, M., Trevillion, E. & Wang, L. (2007) 'Modelling urban commercial property yields: Exogenous and endogenous influences'. *Journal of Property Research*, 24(4), pp. 335-354.

Dornbusch, R., Park, Y. C. & Claessens, S. (2000) 'Contagion: Understanding How It Spreads'. *The World Bank Research Observer*, 15(2), pp. 177-197.

Durbin, J. and Watson, G. S. (1950) 'Testing for Serial Correlation in Least Squares Regression I', *Biometrika*, 37, 409-428.

Durbin, J. and Watson, G. S. (1951) 'Testing for Serial Correlation in Least Squares Regression II', *Biometrika*, 38, 159-178.

Durbin, J. and Watson, G. S. (1971) 'Testing for Serial Correlation in Least Squares Regression III', *Biometrika*, 58, 1-19.

Eichholtz, P., Huisman, R., Koedijk, K. & Schuin, L. (1998) 'Continental Factors in International Real Estate Returns'. *Real Estate Economics*, 26(3), pp. 493-509.

Engle, R. F. & Granger, C. W. J. (1987) 'Co-Integration and Error Correction: Representation, Estimation, and Testing'. *Econometrica*, 55(2), pp. 251-276.

Englund, P. & Gunnelin, Å. H. P. H. S. B. (2008) 'Adjustment in Property Space Markets: Taking Long-Term Leases and Transaction Costs Seriously'. *Real Estate Economics*, 36(1), pp. 81-109.

Farrelly, K. & Sanderson, B. (2005) 'Modelling Regime Shifts in the City of London Office Rental Cycle'. *Journal of Property Research*, 22(4), p. 325–344.

Fisher, J. D. (1992) 'Integrating Research on Markets for Space and Capital'. *Journal of American Real Estate and Urban Economics Association*, 20(1), pp. 161-180.

Fraser, W. (1986) 'Supply Elasticity and the Rental Value of Investment Property'. *Journal of Property Valuation and Investment*, 4(4), pp. 354-369.

Friedmann, J. (1986) 'The World City Hypothesis'. *Development and Change*, 17(1), pp. 69-83.

Friedmann, J. & Wolff, G. (1982) 'World City Formation: An Agenda for Research and Action'. *International Journal of Urban and Regional Research*, 6(3), pp. 309-344.

Gallimore, P. & McAllister, P. (2004) 'Expert Judgement in the Processes of Commercial Property Market Forecasting', *Journal of Property Research*. 21(4), pp. 337–360.

Gardiner, C. & Henneberry, J. (1989) 'The Development of a Simple Regional Office Rent Prediction Model'. *Journal of Valuation*, 7(1), pp. 36-52.

Gardiner, C. & Henneberry, J. (1991) 'Predicting Regional Office Rents Using Habit-persistence Theories'. *Journal of Property Valuation and Investment*, 9(3), pp. 215–226.

Giussani, B., Hsia, M. & Tsolacos, S. (1993) 'A Comparative Analysis of the Major Determinants of Office Rental Values in Europe'. *Journal of Property Valuation and Investment*, 11(2), pp. 157-173.

Gujarati, D. N., (2004) *Basic Econometrics*, 4th Ed, McGraw-Hill

Fuerst, F. (2006) 'Predictable or Not? Forecasting Office Markets with a Simultaneous Equation Approach'. SSRN Electronic Journal. doi: http://dx.doi.org/10.2139/ssrn.909306

Hall, P. (1995) 'The Future of Cities in Western Europe'. *European Review*, 3(2), pp. 161-169.

Hansen, G. D. & Prescott, E. C. (2002) 'Malthus to Solow'. *NBER Working Papers*, 6858, National Bureau of Economic Research, Inc.

Harrod, R. (1973) *Economic Dynamics*, 1st Ed., Basingstoke, Palgrave Macmillan.

Hausman, J. A. (1978) 'Specification Tests in Econometrics', *Econometrica*, 46, pp. 1251-1272.

Hausman, J. A. & Taylor, W. E. (1981) 'Panel Data and Unobservable Individual Effects', *Econometrica*, 49, pp. 1377-1398.

Hausman, J. A. & Taylor, W. E. (1983) 'Identification in Linear Simultaneous Equations Models with Covariance Restrictions: An Instrumental Variables Interpretation', *Econometrica*, 51, pp. 1527-1549.

Hekman, J. S. (1985) 'Rental Price Adjustment and Investment in the Office Market'. *Real Estate Economics*, 13(1), pp. 32–47.

Hendershott, P. H. (1996a) 'Real effective rent determination: Evidence from the Sydney office market'. *Journal of Property Research*, 12(2), pp. 127-135.

Hendershott, P. H. (1996b) 'Rental adjustment and valuation in overbuilt markets: evidence from the Sydney office market'. *Journal of Urban Economics*, 39, pp. 51-67.

Hendershott, P. H., Jennen, M. & MacGregor, B. D. (2013) 'Modeling Space Market Dynamics: An Illustration Using Panel Data for US Retail'. *The Journal of Real Estate Finance and Economics*, 47(4), pp. 659–687.

Hendershott, P. H., Lizieri, C. M. & Matysiak, G. A. (1999) 'The Workings of the London Office Market'. *Real Estate Economics*, 27(2), pp. 365-387.

Hendershott, P. H., MacGregor, B. D. & Tse, R. Y. C. (2002a) 'Estimation of the Rental Adjustment Process'. *Real Estate Economics*, 30(2), pp. 165-183.

Hendershott, P. H., MacGregor, B. D. & White, M. (2002b) 'Explaining Real Commercial Rents Using an Error Correction Model with Panel Data'. *The Journal of Real Estate Finance and Economics*, 24(1-2), pp. 59-87.

Henneberry, J., McGough, T. & Mouzakis, F. (2005) 'Estimating the Impact of Planning on Commercial Property Markets'. *Urban Studies*, 42(3), pp. 471-502.

Henneberry, J. & Mouzakis, F. (2004) *Planning Regimes and Property Investment*. Milan, European Real Estate Society.

Henneberry, J. & Mouzakis, F. (2014) 'Familiarity and the determination of yields for regional office property investments in the UK'. *Regional Studies*, 48(3), pp. 530-546.

Hollies, R. (2007) 'International Variation in Office Yields: A Panel Approach'. *Journal of Property Investment and Finance*, 25(4), pp. 370-387.

Ibanez, M. R. & Pennington-Cross, A. (2013) 'Commercial Property Rent Dynamics in U.S. Metropolitan Areas: An Examination of Office, Industrial, Flex and Retail Space'. *The Journal of Real Estate Finance and Economics*, 46(2), pp. 232–259.

Jackson, C. & Watkins, C. (2005) 'Planning Policy and Retail Property Markets: Measuring the Dimensions of Planning Intervention'. *Urban Studies*, 42(8), pp. 1453-1469.

Jackson, C. & Watkins, C. (2007) 'Supply-side policies and retail property market performance'. *Environment and Planning* A, 39(5), pp. 1134-1146.

Jackson, C., Stevenson, S. & Watkins, C. (2008) 'NY-LON: Does a Single-Cross Continental Office Market Exist?' *Journal of Real Estate Portfolio Management*, 14(2), pp. 79-92.

Jones, C. (2013) *Office Markets & Public Policy*. s.l.: Wiley-Blackwell.

Judge, G. G, Griffiths, W. E., Hill, R. C. Lütkepohl, H. & Lee, T. C. (1985) The Theory and Practice of Econometrics. 2nd ed. New York: John Wiley.

Kao, C. (1999) 'Spurious Regression and Residual-Based Tests for Cointegration in Panel Data'. *Journal of Econometrics*, 90, pp. 1-44.

Ke, Q. and White, M. (2009) 'A Tale of Two Chinese Cities: The Dynamics of Beijing and Shanghai Office Markets', *Journal of Real Estate Portfolio Management*, 19(1), pp. 31-47.

Ke, Q. and White, M. (2013) 'An Econometric Analysis of Shanghai Office Rents'. *Journal of Property Investment and Finance*, 27(2), pp. 120-139.

Keogh, G. (1994) 'Use and Investment Markets in British Real Estate'. *Journal of Property Valuation & Investment*, 12(4), pp. 58-72.

Kmenta, J. (1997) *Elements of Econometrics*. 2nd Ed. The University of Michigan Press.

KPMG (2012) *European Real SnapShot!*. KPMG.

KPMG (2013) *European Real SnapShot!*. KPMG.

KPMG (2014) *European Real SnapShot!*. KPMG.

KPMG (2015) *European Real SnapShot!*. KPMG.

KPMG (2016) *European Real SnapShot!*. KPMG.

KPMG (2017) *European Real SnapShot!*. KPMG.

Leitner, H. (1994) 'Capital Markets, the Development Industry, and Urban Office Market Dynamics: Rethinking Building Cycles'. Environment and Planning A, 26(5), pp. 779-802.

Levin, A., Lin, C.F. & Chu, C.S.J. (2002) 'Unit Root Tests in Panel Data: Asymptotic and Finite-Sample Properties'. *Journal of Econometrics*, 108, pp. 1-24.

Liow, K. H. & Schindler, F. (2017) 'Linkages between Office Markets in Europe: a Volatility Spillover Perspective'. *Journal of Property Investment & Finance*, 35(1), pp. 3-25.

Lizieri, C. (2003) 'Occupier Requirements in Commercial Real Estate Markets'. Urban studies, 40(5/6), pp. 1151-1169.

Lizieri, C. (2009) *Towers of Capital: Office Markets & International Financial Services*. s.l.: Wiley-Blackwell.

Lizieri, C. & Kutsch, N. (2006) *Who Owns the City 2006 – Office Ownership in the City of London*. Reading, Development Securities Plc.

Lizieri, C. & Pain, K. (2014) 'International Office Investment in Global Cities: The Production of Financial Space and Systemic Risk'. *Regional Studies*, 48(3), pp. 439-455.

Lizieri, C., Baum, A. & Scott, P. (2000) 'Ownership, Occupation and Risk: A View of the City of London Office Market'. *Urban Studies*, 37(7), pp. 1109-1129.

Maddala, G. S. (1971) 'Generalized Least Squares with an Estimated Variance-Covariance Matrix'. *Econometrica* 39, pp. 23-33.

Maddala, G. S. (1974) 'Some Small Sample Evidence on Tests of Significance in Simultaneous Equations Models'. *Econometrica* 42, pp. 841-51.

Maddala, G. S. (1988) *Introduction to Econometrics*. New York: Macmillan.

Maddala, G. S. & Lahiri, K. (2009) *Introduction to Econometrics*. 4th Ed. Chichester: Wiley.

Marcato, G. & Tong, L. M. M. (2023) 'Supply Constraints and Search Equilibrium in Office Markets'. *Journal of Real Estate Finance and Economics*. ISSN 1573-045X doi: https://doi.org/10.1007/s11146-023-09955-y

Markowitz, H. (1952) 'Portfolio Selection'. *Journal of Finance*, 7(1), pp. 77-91.

Marquardt, D. W. and R. D. Snee (1975) 'Ridge Regression in Practice'. *American Statistician,* 29, pp. 3–20.

Matysiak, G. & Tsolacos, S. (2003) 'Identifying Short-term Leading Indicators for Real Estate Rental Performance'. *Journal of Property Investment & Finance*, 21(3), pp. 212–232.

McAllister, P., Newell, G. & Matysiak, G. (2008) 'Agreement and Accuracy in Consensus Forecasts of the UK Commercial Property Market, *Journal of Property Research*, 25 (1), pp. 1-22.

McCartney, J. (2012) 'Short and Long-Run Rent Adjustment in the Dublin Office Market'. Journal of Property Research, 29 (3), pp. 201-226.

McDonald, J. (2002) 'A Survey of Econometric Models of Office Markets'. *Journal of Real Estate Literature*, 10(2), pp. 223-242.

McGough, T. & Tsolacos, S. (1995) 'Forecasting commercial rental values in the UK using ARIMA models'. *Journal of Property Valuation and Investment*, 13(5), pp. 6–22.

McGough, T. & Tsolacos, S. (1999) 'Interactions within the Office Market Cycle in Great Britain'. *Journal of Real Estate Research*, 18(1), pp. 219-232.

Meen, G. (1996) 'Ten Propositions in UK Housing Macroeconomics: An Overview of the 1980s and Early 1990s'. *Urban studies*, 33(3), pp. 425-444.

Meen, G. (2000) *Housing Cycles and Efficiency*. Oxford, UK and Boston, USA: Blackwell

Mouzakis, F. & Richards, D. (2007) 'Panel Data Modelling of Prime Office Rents: A Study of 12 Major European Markets'. *Journal of Property Research*, 24(1), pp. 31–53.

Nanthakumaran, N. & Watkins, C. (2000) 'Understanding property market dynamics: insights from modelling the supply-side adjustment mechanism'. *Environment and Planning* A, Volume 32, pp. 655-671.

Orr, A. M. & Jones, C. (2003) 'The Analysis and Prediction of Urban Office Rents'. *Urban Studies*, 40(11), pp. 2255-2284.

Papastamos, D., Stevenson, S. & Matysiak, G. (2015) 'Assessing the Accuracy and Dispersion of Real Estate Investment Forecasts', *International Review of Financial Analysis*. 42, pp. 141-152.

Pedroni, P. (1999). 'Critical Values for Cointegration Tests in Heterogeneous Panels with Multiple Regressors'. *Oxford Bulletin of Economics and Statistics*, 61, pp. 653-670.

Pereira, R. A. O. & Derudder, B. (2010) 'Determinants of Dynamics in the World City Network, 2000–2004'. *Urban Studies*, 47(9), pp. 1948-1967.

Phillips, P.C.B. & Perron, P. (1988) 'Testing for a Unit Root in Time Series Regression'. *Biometrika*, 75, pp. 335-346.

Ramsey, J. B. (1969) 'Tests for specification errors in classical linear least-squares regression analysis', *Journal of the Royal Statistical Society* B 31(2), pp. 350–71.

Ratcliffe, J., Stubbs, M. & Keeping, M. (2009) *Urban Planning and Real Estate Development*. 3rd ed. s.l.: Routledge.

Rosen, K. T. (1984) 'Toward a Model of the Office Building Sector'. *AREUEA Journal*, 12(3), pp. 261-269.

Sargent, T. J. & Wallace, N. (1976) 'Rational Expectations and the Theory of Economic Policy', Journal of Monetary Economics (April) pp. 169-83.

Sassen, S. (1991) *The Global City: New York, London, Tokyo*. Princeton N.J: Princeton University Press.

Sassen, S. (2000) 'The Global City: Strategic Site/New Frontier'. *American Studies*, 41(2/3), pp. 79-95.

Schätz, A. & Sebastian, S. (2009) 'The links between property and the economy - Evidence from the British and German markets'. *Journal of Property Research*, 26(2), pp. 171-191.

Shadish, W. R., Cook, T. D. & Campbell, D. T. (2002), *Experimental and Quasi-Experimental Designs for Generalized Causal Inference*, 2nd Ed., Cengage Learning.

Shilling, J. D., Sirmans, C. & Corgel, J. B. (1987) 'Price adjustment process for rental office space'. *Journal of Urban Economics*, 22(1), pp. 90-100.

Stevenson, S. (2007) 'A Comparison of the Forecasting Ability of ARIMA Models'. *Journal of Property Investment and Finance*, 25(3), pp. 223-240.

Stevenson, S., Akimov, A., Hutson, E. & Krystalogianni, A. (2014) 'Concordance in Global Office Market Cycles'. *Regional Studies*, 48(3), pp. 456-470.

Stevenson, S. & McGarth, O. (2003) 'A Comparison of Alternative Rental Forecasting Models: Empirical Tests on the London Office Market'. *Journal of Property Research*, 20(3), pp. 235-260.

Taylor, P. J. (2002) 'Measurement of the World City Network'. *Urban Studies*, 39(13), pp. 2367-2376.

Thompson, R. & Tsolacos, S. (2000) 'Projections in the Industrial Property Market using a Simultaneous Equation System'. *Journal of the Real Estate Research*, 19(1/2), pp. 165-188.

Tsolacos, S., Keogh, G. & McGough, T. (1998) 'Modelling Use, Investment, and Development in the British Office Market', *Environment and Planning A*, 30(8), pp.1409-1427.

Tsolacos, S. & McGough, T. (1999) 'Rational expectations, uncertainty and cyclical activity in the British office market'. *Urban Studies*, 36(7), pp. 1137-1149.

Viezer, T. W. (1999) 'Econometric Integration of Real Estate's Space and Capital Markets'. *Journal of Real Estate Research*. 18(3), pp. 503-519.

Watkins, C., White, M. & Keskin, B. (2012). *The Future of Property Forecasting*, Investment Property Forum, London.

Westerlund, J. (2005) 'New Simple Tests for Panel Cointegration'. *Econometric Reviews*, 24, pp. 297-316.

Wheaton, W. C. (1987) 'The Cyclic Behavior of the National Office Market'. *AREUEA Journal*, 15(4), pp. 281-299.

Wheaton, W. C. & Torto, R. G. (1988) 'Vacancy Rates and the Future of Office Rents'. *Real Estate Economics*, 16(4), p. 430–436.

Wheaton, W. C., Torto, R. G. & Evans, P. (1997) 'The Cyclic Behavior of the Greater London Office Market'. *Journal of Real Estate Finance and Economics*, 15(1), pp. 77-92.

White, H. (1980) 'A Heteroscedasticity-Consistent Covariance Matrix Estimator and A Direct Test for Heteroscedasticity', *Econometrica*, 48(4), pp. 817-838.

Bibliography

Antwi, A. & Henneberry, J. (1995) ‘Developers, Non-linearity and Asymmetry in the Development Cycle’, *Journal of Property Research*, 12(3), pp. 217-239.

Ball, M. (1986) 'The built environment and the urban question'. *Environment & Planning D: Society & Space*, 4(4), pp. 447-464.

Ball, M., Meen, G. & Nygaard, C. (2010) 'Housing Supply Price Elasticities Revisited: Evidence from International, National, Local and Company Data'. *Journal of Housing Economics*, 19(4), pp. 255-268.

Brooks, C. (2019) *Introductory Econometrics for Finance*. 4th Ed. Cambridge University Press.

Brunet, R. (1989) *'Les villes "européennes": rapport pour la DATAR'*. s.l.: Paris: La Documentation Française.

Chaney, A. & Hoesli, M. (2010) 'The Interest Rate Sensitivity of Real Estate'. *Journal of Property Research*, 27(1), pp. 61-85.

Cheshire, P. & Sheppard, S. (1998) 'Estimating the Demand for Housing, Land and Neighbourhood Characteristics'. *Oxford Bulletin of Economics and Statistics*, 60(3), pp. 357-382.

Cheshire, P. C. & Hilber, C. A. L. (2008) 'Office space supply restrictions in Britain: The political economy of market revenge'. *Economic Journal*, 118 (June), pp. 185-221.

Clapp, J. M. & Giaccotto, C. (1994) The Influence of Economic Variables on Local House Price Dynamics. *Journal of Urban Economics*, 36(2), pp. 161-183.

Crosby, N., Devaney, S. & Nanda, A. (2016) 'Which Factors Drive Rental Depreciation Rates for Office and Industrial Properties?'. *The Journal of Real Estate Research*, 38(3), pp. 359-392.

Crosby, N., Jackson, C. and Orr, A. (2016) 'Refining the real estate pricing model'. *Journal of Property Research*, 33(4), pp. 332-358.

D'Arcy, E. (1994) 'Market Maturity and Property Market Behaviour: A European Comparison of Mature and Emergent Markets'. *Journal of Property Research*, 11(3), pp. 215-23.

D'Arcy, É. & Keogh, G. (1998) 'Territorial competition and property market process: an exploratory analysis'. *Urban Studies*, 35(8), pp. 1215-1230.

D'Arcy, É. & Tsolacos, S. (2000) 'Property Research in Europe: Moving forward through Engagement'. *Journal of Property Investment & Finance*, 18(3), https://doi.org/10.1108/jpif.2000.11218caf.001

Devaney, S., Livingstone, N., McAllister, P. & Nanda, A. (2017) 'Institutional Convergence in Real Estate Markets: A Comparative Study of Brokerage Models and Transaction Costs'. *Journal of Real Estate Literature*, 25(1), pp. 169-188.

Dunse, N. & Jones, C. (2005) 'Rental Depreciation, Obsolescence and Location: The Case of Industrial Properties'. *The Journal of Property Research*. 22(2), pp. 205-223.

Fraser, W. (1996) 'Supply Elasticity and the Rental Value of Investment Property'. *Journal of Valuation*, 4(4), pp. 354-369.

Glaeser, E. L. & Gyourko, J. & Saiz, A. (2008) 'Housing Supply and Housing Bubbles'. *Journal of Urban Economics*, 64(2), pp. 198-217.

Gore, T. and Nicholson, D. (1991) 'Models of the land-development process: a critical review'. *Environment & Planning A*, 23(5), pp. 705-730.

Grenadier, S. R. (1995) 'The Persistence of Real Estate Cycles'. *The Journal of Real Estate Finance and Economics*, 10(2), pp. 95-119.

Hendershott, P. H., Robert J. W. & Charles R. W. (2003) 'Corporate Equity and Commercial Property Market 'Bubbles''. *Urban Studies*, 40(5-6), pp. 993-1009.

Hendershott, Patric H. and MacGregor, Bryan D. (2005) 'Investor Rationality: Evidence from U.K. Property Capitalization Rates'. *Real Estate Economics*, 33(2), pp. 299-322.

Henneberry, J. (1999) 'Convergence and Difference in Regional Office Development Cycles'. *Urban Studies*, 36(9), pp. 1439-1465

Hoesli, M. & MacGregor, B. (1997) 'European Real Estate Research and Education: Development, Globalizaiton, and Maturity'. *The Journal of Real Estate Finance and Economics*, 15(1), pp. 5-10.

Hospers, G.-J. (2003) 'Beyond the Blue Banana?' *Intereconomics*, 38(2), pp. 76-85.

Hsiao, C. (1976) 'Identification and Estimation of Simultaneous Equation Models with Measurement Error', *International Economic Review*, 17, pp. 319-339.

Huston, S. (2015) 'Property market modelling and forecasting: Simple vs complex models'. *Journal of Property Investment and Finance*, 33(4), pp. 337-361.

Hwang, M. & Quigley, J. M. (2010) 'Housing Price Dynamics in Time and Space - Predictability, Liquidity, and Investor Returns'. *The Journal of Real Estate Finance and Economics*, 41(1), pp. 3-23.

Jadevicius, A., Stevenson, S. & McGarth, O. (2003) 'A comparison of alternative rental forecasting models: Empirical tests on the London office market'. *Journal of Property Research*, 20(3), pp. 235-260.

Karakozova, O. (2004) 'Modelling and forecasting office returns in the Helsinki area'. *Journal of Property Research*, 21(1), pp. 51-73.

Kennedy, P. (2008) *A Guide to Econometrics*. 6th Ed. Wiley-Blackwell.

Kunzmann, K. R. & Wegener, M. (1991) 'The Pattern of Urbanization in Western Europe'. *Ekistics*, 58 (350/351), pp. 282-291.

Liu, C. H., Nowak, A. & Rosenthal, S. S. (2016) 'Housing Price Bubbles, New Supply, and Within-City Dynamics'. *Journal of Urban Economics*, 96, pp. 55-72.

Lizieri, C. M. (2003) 'Occupier Requirements in Commercial Real Estate Markets', *Urban Studies*, 40(5-6), pp.1151-1169.

McAllister, P. & Lizieri, C. (2006) 'Monetary Integration and Real Estate Markets: The Impact of Euro on European Real Estate Equities', *Journal of Property Research*, 23(4), pp. 281-303.

McGough, T., Tsolacos, S. and Olkkonen, O. (2000) 'The predictability of office property returns in Helsinki'. Journal of Property Investment & Finance, 18(6), pp. 565-585.

Meen, G. (1988) 'International Comparisons of the UK's Long-Run Economic Performance'. *Oxford Review of Economic Policy*, 1988, Vol.4(1), pp. xxii-xli.

Nneji, O., Brooks, C. & Ward, C. W. R. (2013) 'House Price Dynamics and Their Reaction to Macroeconomic Changes'. *Economic modelling*, 32, pp. 172-178.

Oikarinen, E. & Hoesli, M. (2009) 'The Long-Run Dynamics between Direct and Securitized Real Estate'. *The Journal of Real Estate Research*, 33(1), pp. 73-104.

Pollakowski, H, O., Wachter, S. M., and Lynford, L. (1992) 'Did Office Market Size Matter in the 1980s? A Time-Series Cross-Sectional Analysis of Metropolitan Area Office Markets'. *Real Estate Economics*, 20(2), pp. 302-324.

Taylor, P. & Derudder, B. (2016) *World City Network: A Global Urban Analysis*, 2nd Ed., Routledge.

Unbehaun, F. and Fuerst, F. (2018) 'Cap Rates and Risk: A Spatial Analysis of Commercial Real Estate'. *Studies in Economics and Finance*, 35(1), pp. 25-43.

Wheaton, W. C. & Simonton, W. E. (2007) 'The Secular and Cyclic Behavior of ‘True’ Construction Costs'. *The Journal of Real Estate Research*, 29(1), pp. 1-26.

White, M., Mackay, D., and Gibb, K. (2000) 'A comparative analysis of Scottish property rents'. *Journal of Property Investment & Finance*, 18(3), pp. 332-351.

Wooldridge, J. M. (2013) *Introductory Econometrics: A Modern Approach*. 5th Ed. Cengage Learning.

Yunus, N. (2013) 'Dynamic Interactions among Property Types: International Evidence Based on Cointegration Tests', *Journal of Property Investment & Finance*, 31(2), pp. 135-159.

List of Appendices

Appendix 1 Regression Output for All Cities (pooled panel data)

APP 1.1 OLS (ordinary least squares)

APP 1. 1. 1 OLS Estimation of Rent Equation

Table. 1. 1a: OLS Estimation of Rent Equation without Lags

lrr1	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lgdpr	.611607	.0274991	22.24	0.000	.5574671	.6657469
le	.1988067	.0272551	7.29	0.000	.1451471	.2524664
ltkp	.0868223	.0228354	3.80	0.000	.0418642	.1317803
los	-.4190079	.0315739	-13.27	0.000	-.4811703	-.3568455
lcons	.0702893	.0183109	3.84	0.000	.034239	.1063396
_cons	-.3207364	.3603801	-0.89	0.374	-1.030249	.388776

Table. 1. 1b: OLS Estimation of Rent Equation with Lags

lrr1	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lgdpr	.6493068	.0270924	23.97	0.000	.5959045	.702709
le	.198716	.0271212	7.33	0.000	.145257	.252175
ltkp						
--.	.092219	.0257156	3.59	0.000	.0415308	.1429073
L1.	.0819668	.0269222	3.04	0.003	.0289001	.1350336
los	-.4643361	.0337663	-13.75	0.000	-.5308932	-.3977791
lcons						
L12.	.0278974	.0167804	1.66	0.098	-.0051785	.0609734
_cons	-.5717885	.3591409	-1.59	0.113	-1.279695	.1361181

APP 1. 1. 2 OLS Estimation of Yield Equation

Table. 1. 1c: OLS Estimation of Yield Equation

ly	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
li	.1390434	.0135851	10.24	0.000	.1123191	.1657677
_cons	-2.518879	.0543396	-46.35	0.000	-2.625774	-2.411983

APP 1. 1. 3 OLS Estimation of New Construction

Table. 1. 1d: OLS Estimation of New Construction Equation without Lags

lcons	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	.4277337	.1463546	2.92	0.004	.138815	.7166524
le	.3139253	.1763058	1.78	0.077	-.0341202	.6619707
li	.0600472	.0734072	0.82	0.415	-.0848659	.2049604
ldev	.2232089	.0461857	4.83	0.000	.1320337	.3143841
_cons	-.6698746	1.470267	-0.46	0.649	-3.57233	2.232581

Table. 1. 1e: OLS Estimation of New Construction Equation with Lags

lcons	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	.2749373	.1619545	1.70	0.092	-.0457768	.5956514
le	.5452533	.2041444	2.67	0.009	.1409918	.9495149
li	-.1436821	.1061012	-1.35	0.178	-.3537914	.0664272
ldev						
L12.	.1161791	.0578091	2.01	0.047	.0017014	.2306569
_cons	-2.682715	1.72945	-1.55	0.124	-6.107496	.7420663

APP 1. 1. 4 OLS Estimation of Occupied Stock

Table. 1. 1f: OLS estimation of Occupied Stock Equation without Lags

los	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	-.2760937	.0691934	-3.99	0.000	-.4126769	-.1395105
lcons	.1912794	.0396836	4.82	0.000	.1129466	.2696122
li	-.0035402	.03971	-0.09	0.929	-.0819251	.0748447
ldev	.1364612	.0262016	5.21	0.000	.0847409	.1881814
_cons	9.349403	.4705495	19.87	0.000	8.42057	10.27824

Table. 1. 1g: OLS Estimation of Occupied Stock Equation with Lags

los	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	-.2096754	.0843014	-2.49	0.014	-.3767078	-.0426431
lcons						
L12.	.1275377	.0446318	2.86	0.005	.0391055	.2159699
li	.0019759	.0703425	0.03	0.978	-.1373987	.1413505
ldev						
L12.	.1484785	.0375316	3.96	0.000	.0741144	.2228425
_cons	9.2727	.6692517	13.86	0.000	7.946663	10.59874

APP 1.2 GLS (generalised least squares)

APP 1. 2. 1 GLS Estimation of Rent Equation

Table. 1. 2a: GLS Estimation of Rent Equation without Lags

lrr1	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lgdpr	.5428759	.0240218	22.60	0.000	.495794	.5899577
le	.1686388	.0148124	11.39	0.000	.1396071	.1976705
ltkp	.0845925	.0148049	5.71	0.000	.0555753	.1136096
los	-.3735929	.0298539	-12.51	0.000	-.4321055	-.3150803
lcons	.1114375	.0152143	7.32	0.000	.0816181	.1412569
_cons	.196474	.2265942	0.87	0.386	-.2476424	.6405904

Table. 1. 2b: GLS Estimation of Rent Equation with Lags

lrr1	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lgdpr	.6183358	.0228108	27.11	0.000	.5736273	.6630442
le	.1993658	.0157919	12.62	0.000	.1684143	.2303173
ltkp						
--.	.1051559	.0154326	6.81	0.000	.0749085	.1354032
L1.	.0911487	.0162322	5.62	0.000	.0593342	.1229632
los	-.4779391	.0280513	-17.04	0.000	-.5329185	-.4229596
lcons						
L12.	.0606308	.0157141	3.86	0.000	.0298317	.0914299
_cons	-.3579911	.2305558	-1.55	0.120	-.8098721	.0938899

APP 1. 2. 2 GLS Estimation of Yield Equation

Table. 1. 2c: GLS Estimation of Yield Equation

ly	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
li	.1353186	.0115493	11.72	0.000	.1126823	.1579548
_cons	-2.532218	.0466437	-54.29	0.000	-2.623638	-2.440798

Table. 1. 2d: GLS Estimation of New Construction Equation without Lags

lcons	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lrr1	.4826641	.122792	3.93	0.000	.2419962	.723332
le	.3192959	.147472	2.17	0.030	.0302562	.6083357
li	.0904025	.0557637	1.62	0.105	-.0188924	.1996974
ldev	.1143795	.0397792	2.88	0.004	.0364136	.1923453
_cons	-.6053531	1.198651	-0.51	0.614	-2.954666	1.74396

APP 1. 2. 3 GLS Estimation of New Construction

Table. 1. 2e: GLS Estimation of New Construction Equation with Lags

lcons	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lrr1	-.1047521	.1227288	-0.85	0.393	-.3452961	.135792
le	.8436394	.224846	3.75	0.000	.4029493	1.284329
li	-.0620286	.0964961	-0.64	0.520	-.2511574	.1271003
ldev						
L12.	-.0606188	.0489306	-1.24	0.215	-.1565211	.0352834
_cons	-2.386682	1.689167	-1.41	0.158	-5.697389	.9240252

APP 1. 2. 4 GLS Estimation of Occupied Stock

Table. 1. 2f: GLS estimation of Occupied Stock Equation without Lags

los	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
lrr1	-.4026821	.0432363	-9.31	0.000	-.4874236	-.3179405
lcons	.0559901	.0291479	1.92	0.055	-.0011388	.1131191
li	-.013114	.0279172	-0.47	0.639	-.0678307	.0416028
ldev	.0151844	.0184235	0.82	0.410	-.020925	.0512939
_cons	11.32349	.3447732	32.84	0.000	10.64775	11.99923

Table. 1. 2g: GLS Estimation of Occupied Stock Equation with Lags

los	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
lrr1	-.3993415	.053592	-7.45	0.000	-.5043799	-.2943031
lcons						
L12.	-.0122065	.0314999	-0.39	0.698	-.0739451	.0495321
li	-.0059689	.0513046	-0.12	0.907	-.106524	.0945862
ldev						
L12.	.0067317	.0265474	0.25	0.800	-.0453004	.0587637
_cons	11.7673	.470134	25.03	0.000	10.84585	12.68874

APP 1.3 Panel Analysis, FE (fixed effects)

APP 1. 3. 1 Panel FE Estimation of Rent Equation

Table. 1. 3a: Panel FE Estimation of Rent Equation without Lags

lrr1	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
lgdpr	.2093802	.0925224	2.26	0.024	.0272045	.391556
le	2.187757	.2175494	10.06	0.000	1.759405	2.61611
ltkp	-.0028452	.0134121	-0.21	0.832	-.0292536	.0235631
los	-1.148172	.251448	-4.57	0.000	-1.643271	-.6530736
lcons	.0490623	.008978	5.46	0.000	.0313846	.06674
_cons	-7.929377	1.982921	-4.00	0.000	-11.83373	-4.025025

Table. 1. 3b: Panel FE Estimation of Rent Equation with Lags

lrr1	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lgdpr	.1638764	.0928586	1.76	0.079	-.0191884	.3469411
le	1.766613	.2592481	6.81	0.000	1.255522	2.277703
ltkp						
--.	-.009561	.0110584	-0.86	0.388	-.031362	.01224
L1.	-.0040285	.011343	-0.36	0.723	-.0263905	.0183335
los	-.8008872	.2189584	-3.66	0.000	-1.232549	-.369225
lcons						
L12.	-.0069011	.0076276	-0.90	0.367	-.0219383	.0081361
_cons	-5.944936	1.738544	-3.42	0.001	-9.372362	-2.517511

APP 1. 3. 2 Panel FE Estimation of Yield Equation

Table. 1. 3c: Panel FE Estimation of Yield Equation

ly	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
li	.187061	.0119904	15.60	0.000	.1634721	.2106499
_cons	-2.330425	.0477687	-48.79	0.000	-2.424401	-2.236449

APP 1. 3. 3 Panel FE Estimation of New Construction

Table. 1. 3d: Panel FE Estimation of New Construction Equation without Lags

lcons	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	2.968628	.6017342	4.93	0.000	1.780429	4.156827
le	-.8183847	2.04675	-0.40	0.690	-4.859948	3.223178
li	.1696096	.1047177	1.62	0.107	-.0371685	.3763877
ldev	.0127715	.0495672	0.26	0.797	-.0851052	.1106481
_cons	-4.374688	18.73868	-0.23	0.816	-41.37655	32.62718

Table. 1. 3e: Panel FE Estimation of New Construction Equation with Lags

lcons	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	.0928963	.5805397	0.16	0.873	-1.057369	1.243161
le	5.988813	1.648851	3.63	0.000	2.721826	9.2558
li	.0193356	.1080446	0.18	0.858	-.1947409	.2334121
ldev						
L12.	-.1266914	.04029	-3.14	0.002	-.2065209	-.046862
_cons	-55.28276	14.15385	-3.91	0.000	-83.3268	-27.23873

APP 1. 3. 4 Panel FE Estimation of Occupied Stock

Table. 1. 3f: Panel FE estimation of Occupied Stock Equation without Lags

los	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	.1652157	.0267423	6.18	0.000	.1124145	.218017
lcons	-.0068228	.0037226	-1.83	0.069	-.0141729	.0005274
li	-.0441058	.0040198	-10.97	0.000	-.0520427	-.0361689
ldev	.0041126	.0023969	1.72	0.088	-.00062	.0088452
_cons	7.989038	.1592556	50.16	0.000	7.674596	8.303479

Table. 1. 3g: Panel FE Estimation of Occupied Stock Equation with Lags

los	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	.2226188	.0279763	7.96	0.000	.1671531	.2780845
lcons						
L12.	-.0053279	.0027758	-1.92	0.058	-.0108313	.0001754
li	-.0348967	.0055107	-6.33	0.000	-.0458223	-.0239712
ldev						
L12.	-.0019298	.002431	-0.79	0.429	-.0067494	.0028899
_cons	7.658998	.1833444	41.77	0.000	7.2955	8.022496

APP 1.4 Panel Analysis, RE (random effects)

APP 1. 4. 1 Panel RE Estimation of Rent Equation

Table. 1. 4a: Panel RE Estimation of Rent Equation without Lags

lrr1	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lgdpr	.231174	.0831566	2.78	0.005	.06819	.394158
le	1.580194	.1880762	8.40	0.000	1.211572	1.948817
ltkp	.0020609	.0139115	0.15	0.882	-.0252052	.0293269
los	-.7591643	.1944358	-3.90	0.000	-1.140251	-.3780771
lcons	.0562431	.0092258	6.10	0.000	.0381608	.0743254
_cons	-5.741554	1.684481	-3.41	0.001	-9.043077	-2.440032

Table. 1. 4b: Panel RE Estimation of Rent Equation with Lags

lrr1	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lgdpr	.6493068	.0270924	23.97	0.000	.5962065	.702407
le	.198716	.0271212	7.33	0.000	.1455594	.2518727
ltkp						
--.	.092219	.0257156	3.59	0.000	.0418175	.1426206
L1.	.0819668	.0269222	3.04	0.002	.0292002	.1347335
los	-.4643361	.0337663	-13.75	0.000	-.5305168	-.3981555
lcons						

L12.	.0278974	.0167804	1.66	0.096	-.0049915	.0607863
_cons	-.5717885	.3591409	-1.59	0.111	-1.275692	.1321147

APP 1. 4. 2 Panel RE Estimation of Yield Equation

Table. 1. 4c: Panel RE Estimation of Yield Equation

ly	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
li	.1849087	.0119752	15.44	0.000	.1614376	.2083797
_cons	-2.338922	.0642019	-36.43	0.000	-2.464756	-2.213089

APP 1. 4. 3 Panel RE Estimation of New Construction

Table. 1. 4d: Panel RE Estimation of New Construction Equation without Lags

lcons	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
lrr1	1.310256	.3285181	3.99	0.000	.6663721	1.954139
le	.0318962	.3555416	0.09	0.929	-.6649526	.728745
li	.0818541	.0781739	1.05	0.295	-.071364	.2350723
ldev	.0685579	.0489354	1.40	0.161	-.0273537	.1644695
_cons	-2.720736	3.020989	-0.90	0.368	-8.641766	3.200295

Table. 1. 3e: Panel RE Estimation of New Construction Equation with Lags

lcons	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
lrr1	.7880633	.3098242	2.54	0.011	.180819	1.395308
le	.7027032	.3408292	2.06	0.039	.0346903	1.370716
li	-.2371175	.0891798	-2.66	0.008	-.4119067	-.0623284
ldev						
L12.	-.0856729	.0439502	-1.95	0.051	-.1718138	.000468
_cons	-7.091442	2.86617	-2.47	0.013	-12.70903	-1.473853

APP 1. 4. 4 Panel RE Estimation of Occupied Stock

Table. 1. 4f: Panel RE estimation of Occupied Stock Equation without Lags

los	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
lrr1	.1637906	.0294723	5.56	0.000	.1060259	.2215553
lcons	-.006364	.0041349	-1.54	0.124	-.0144683	.0017402
li	-.0442411	.0044642	-9.91	0.000	-.0529907	-.0354916
ldev	.0044068	.0026652	1.65	0.098	-.0008168	.0096305
_cons	8.081115	.1928787	41.90	0.000	7.70308	8.45915

Table. 1. 4g: Panel RE Estimation of Occupied Stock Equation with Lags

los	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lrr1	.2217143	.0316471	7.01	0.000	.1596871	.2837415
lcons						
L12.	-.0051709	.0031683	-1.63	0.103	-.0113807	.0010389
li	-.0350638	.0062884	-5.58	0.000	-.0473889	-.0227387
ldev						
L12.	-.0017114	.0027775	-0.62	0.538	-.0071552	.0037324
_cons	7.767949	.2249233	34.54	0.000	7.327107	8.20879

APP 1.5 SUR (seemingly unrelated regressions)

Table. 1. 5a: SUR Estimation of Rent Equation without Lags

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lrr1						
lgdpr	.6401623	.042216	15.16	0.000	.5574205	.7229042
le	.1874564	.0505208	3.71	0.000	.0884373	.2864754
ltkp	.0722598	.0350605	2.06	0.039	.0035424	.1409772
los	-.4363587	.0444505	-9.82	0.000	-.52348	-.3492374
lcons	.0796287	.0237078	3.36	0.001	.0331622	.1260952
_cons	-.4109437	.6540413	-0.63	0.530	-1.692841	.8709537
ly						
li	.1543803	.020254	7.62	0.000	.1146832	.1940774
_cons	-2.481571	.0818368	-30.32	0.000	-2.641968	-2.321174
lcons						
lrr1	.7069461	.1541965	4.58	0.000	.4047266	1.009166
le	.2541326	.1974849	1.29	0.198	-.1329307	.6411959
li	.0662583	.0789121	0.84	0.401	-.0884067	.2209232
ldev	.2394979	.0478854	5.00	0.000	.1456442	.3333516
_cons	-1.899764	1.64014	-1.16	0.247	-5.11438	1.314852
los						
lrr1	-.5519217	.0633342	-8.71	0.000	-.6760545	-.4277888
lcons	.238895	.0360088	6.63	0.000	.168319	.309471
li	-.0220331	.0415313	-0.53	0.596	-.103433	.0593668
ldev	.1450219	.0233377	6.21	0.000	.0992809	.190763
_cons	10.77191	.4245207	25.37	0.000	9.93986	11.60395

Table. 1. 5b: SUR Estimation of Rent Equation with Lags

	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
lrr1						
lgdpr	.7233148	.0474625	15.24	0.000	.63029	.8163397
le	.1456611	.0619771	2.35	0.019	.0241882	.2671339
ltkp						
--.	.0994754	.045387	2.19	0.028	.0105185	.1884324
L1.	-.0024779	.0549067	-0.05	0.964	-.1100931	.1051373
los	-.4678196	.0563069	-8.31	0.000	-.578179	-.3574602
lcons						
L12.	.021853	.0199493	1.10	0.273	-.0172469	.0609529
_cons	-.5573992	.827994	-0.67	0.501	-2.180238	1.065439
ly						
li	.0624933	.028689	2.18	0.029	.0062639	.1187228
_cons	-2.891184	.1237624	-23.36	0.000	-3.133754	-2.648614
lcons						
lrr1	.4956523	.1432394	3.46	0.001	.2149083	.7763964
le	.3205454	.1320854	2.43	0.015	.0616628	.5794279
li	-.1218482	.1114711	-1.09	0.274	-.3403275	.0966312
ldev						
L12.	.1467679	.0554682	2.65	0.008	.0380522	.2554835
_cons	-1.840251	1.389089	-1.32	0.185	-4.562817	.8823136
los						
lrr1	-.3908099	.0809787	-4.83	0.000	-.5495253	-.2320945
lcons						
L12.	.1223872	.0253307	4.83	0.000	.07274	.1720344
li	-.0011865	.073142	-0.02	0.987	-.1445423	.1421692
ldev						
L12.	.1365005	.0350182	3.90	0.000	.0678662	.2051348
_cons	10.53308	.6470869	16.28	0.000	9.264817	11.80135

Table. 1. 5c: SUR Estimation Results (non-lag, positive scenario)

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lrr1						
lgdpr	.6258243	.0492966	12.70	0.000	.5292048	.7224439
le	.2188773	.0618513	3.54	0.000	.0976511	.3401036
ltkp	.0693832	.0401367	1.73	0.084	-.0092832	.1480496
los	-.4306694	.0482455	-8.93	0.000	-.5252289	-.3361099
lcons	.087248	.0246085	3.55	0.000	.0390161	.1354798
_cons	-.6295333	.7358179	-0.86	0.392	-2.07171	.8126434
ly2						
li2	.118506	.0192989	6.14	0.000	.0806808	.1563312
_cons	-2.701013	.0837082	-32.27	0.000	-2.865079	-2.536948
lcons						
lrr1	.8021365	.1666556	4.81	0.000	.4754975	1.128776
le	.0319614	.2349875	0.14	0.892	-.4286057	.4925284
li2	.0247401	.0665043	0.37	0.710	-.1056059	.1550861
ldev	.2492875	.0517982	4.81	0.000	.147765	.3508101
_cons	-.4431504	1.897495	-0.23	0.815	-4.162171	3.275871
los						
lrr1	-.5515868	.0658804	-8.37	0.000	-.68071	-.4224635
lcons	.2293897	.0381697	6.01	0.000	.1545784	.3042009
li2	-.0445605	.0356828	-1.25	0.212	-.1144975	.0253764
ldev	.1440696	.0256006	5.63	0.000	.0938933	.1942458
_cons	10.73726	.4243873	25.30	0.000	9.905476	11.56904

Table. 1. 5d: SUR Estimation Results (non-lag, negative scenario)

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lrr1						
lgdpr	.640983	.0421845	15.19	0.000	.558303	.7236631
le	.1849112	.0505161	3.66	0.000	.0859015	.2839209
ltkp	.0739544	.0350544	2.11	0.035	.005249	.1426598
los	-.4376382	.0444426	-9.85	0.000	-.5247441	-.3505324
lcons	.0801532	.0237048	3.38	0.001	.0336927	.1266137
_cons	-.394955	.6539708	-0.60	0.546	-1.676714	.8868042
ly1						
li1	.2072835	.0249736	8.30	0.000	.1583361	.2562308
_cons	-2.223864	.0929636	-23.92	0.000	-2.40607	-2.041659
lcons						
lrr1	.7155357	.1530038	4.68	0.000	.4156536	1.015418
le	.2470052	.1961657	1.26	0.208	-.1374724	.6314829
li1	.097128	.1101776	0.88	0.378	-.1188162	.3130721
ldev	.2410079	.0479936	5.02	0.000	.1469422	.3350736
_cons	-1.793577	1.649457	-1.09	0.277	-5.026453	1.439298
los						
lrr1	-.5522003	.0629487	-8.77	0.000	-.6755774	-.4288231
lcons	.2384208	.0358498	6.65	0.000	.1681565	.3086851
li1	-.0428682	.0583642	-0.73	0.463	-.1572599	.0715236
ldev	.1470961	.0232856	6.32	0.000	.1014573	.192735
_cons	10.69827	.4403558	24.29	0.000	9.835192	11.56136

Table. 1. 5e: SUR Estimation Results (non-lag / FTSE 100 included)

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lrr1						
lgdpr	.6148119	.0410137	14.99	0.000	.5344265	.6951972
le	.1585144	.0489967	3.24	0.001	.0624827	.2545462
ltkp	.0652524	.0340471	1.92	0.055	-.0014787	.1319835
los	-.4187777	.0431435	-9.71	0.000	-.5033374	-.334218
lcons	.0801472	.0229486	3.49	0.000	.0351688	.1251256
_cons	.073976	.6329225	0.12	0.907	-1.166529	1.314481
ly						
li	.081322	.020266	4.01	0.000	.0416013	.1210426
lftse	-.7445294	.1099313	-6.77	0.000	-.9599909	-.529068
_cons	3.73401	.9208333	4.06	0.000	1.92921	5.53881
lcons						
lrr1	.6901295	.1539038	4.48	0.000	.3884835	.9917755
le	.2314936	.197218	1.17	0.240	-.1550466	.6180339
li	.066912	.0788683	0.85	0.396	-.087667	.2214909
ldev	.244598	.0477301	5.12	0.000	.1510486	.3381473
_cons	-1.578374	1.638953	-0.96	0.336	-4.790663	1.633914
los						
lrr1	-.5376777	.0687903	-7.82	0.000	-.6725043	-.4028512
lcons	.2364535	.0390609	6.05	0.000	.1598955	.3130115
li	-.024173	.0416389	-0.58	0.562	-.1057838	.0574378
ldev	.1395619	.0253137	5.51	0.000	.0899479	.1891758
_cons	10.70649	.4563018	23.46	0.000	9.812156	11.60083

Table. 1. 5f: SUR Estimation Results (non-lag, network connectivity included in the user subsector)

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lrr1						
lgdpr	.609939	.0511098	11.93	0.000	.5097658	.7101123
le	.1264013	.0618502	2.04	0.041	.0051772	.2476255
ltkp	.0388846	.0391903	0.99	0.321	-.037927	.1156962
los	-.2545716	.0762564	-3.34	0.001	-.4040314	-.1051118
lnc1	.7890118	.3314709	2.38	0.017	.1393407	1.438683
_cons	-5.631119	1.960194	-2.87	0.004	-9.473028	-1.78921
ly						
li	.1569703	.0202198	7.76	0.000	.1173402	.1966003
_cons	-2.471292	.0817035	-30.25	0.000	-2.631428	-2.311156
lcons						
lrr1	.6686868	.1545431	4.33	0.000	.3657879	.9715857
le	.2843499	.1976907	1.44	0.150	-.1031167	.6718165
li	.0800588	.0793141	1.01	0.313	-.075394	.2355116
ldev	.2387264	.0480894	4.96	0.000	.1444729	.3329799
_cons	-1.902538	1.640184	-1.16	0.246	-5.117238	1.312163
los						
lrr1	-.5453246	.0633336	-8.61	0.000	-.6694562	-.421193
lcons	.2379179	.0360071	6.61	0.000	.1673453	.3084904
li	-.0251339	.0415629	-0.60	0.545	-.1065957	.056328
ldev	.145868	.0233374	6.25	0.000	.1001275	.1916085
_cons	10.71972	.4245802	25.25	0.000	9.887559	11.55188

Table. 1. 5g: SUR Estimation Results (non-lag, FTSE 100 and network connectivity included)

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lrr1						
lgdpr	.5842486	.0488211	11.97	0.000	.4885611	.6799361
le	.0769309	.0582567	1.32	0.187	-.0372501	.1911118
ltkp	.023991	.0368975	0.65	0.516	-.0483268	.0963088
los	-.2085943	.0715268	-2.92	0.004	-.3487842	-.0684044
lnc1	1.144519	.3167276	3.61	0.000	.5237439	1.765293
_cons	-7.484907	1.876291	-3.99	0.000	-11.16237	-3.807445
ly						
li	.0579669	.0186542	3.11	0.002	.0214053	.0945286
lftse	-.9546441	.0965669	-9.89	0.000	-1.143912	-.7653764
lnc1	-.7845345	.1090234	-7.20	0.000	-.9982164	-.5708526
_cons	10.61799	1.237422	8.58	0.000	8.192685	13.04329
lcons						
lrr1	.6673231	.1536276	4.34	0.000	.3662184	.9684277
le	.2505456	.1965469	1.27	0.202	-.1346793	.6357705
li	.0804633	.0792245	1.02	0.310	-.0748138	.2357404
ldev	.2441864	.0476785	5.12	0.000	.1507383	.3376345
_cons	-1.56962	1.634981	-0.96	0.337	-4.774123	1.634883
los						
lrr1	-.4294506	.0682167	-6.30	0.000	-.563153	-.2957482
lcons	.2364493	.0356512	6.63	0.000	.1665742	.3063244
li	-.0337384	.0415965	-0.81	0.417	-.1152661	.0477893
ldev	.1371564	.0231597	5.92	0.000	.0917642	.1825486
_cons	9.981306	.4539421	21.99	0.000	9.091596	10.87102

APP 1.6 Dynamic Panel Analysis, GMM (generalised method of moments)

APP 1. 6. 1 GMM Estimation of Rent Equation

Table. 1. 6a: GMM Estimation of Rent Equation without Lags

lrr1	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lrr1						
L1.	.9175056	.0177011	51.83	0.000	.882812	.9521992
lgdpr	.0561146	.0153312	3.66	0.000	.0260659	.0861632
le	.0251938	.0207428	1.21	0.225	-.0154613	.0658489
ltkp	.0207297	.0053617	3.87	0.000	.010221	.0312384
los	.0055243	.0150884	0.37	0.714	-.0240484	.0350969
lcons	-.018208	.0037983	-4.79	0.000	-.0256525	-.0107635
_cons	-.4844017	.1793252	-2.70	0.007	-.8358726	-.1329308

Table. 1. 6b: GMM Estimation of Rent Equation with Lags

lrr1	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lrr1						
L1.	.8837495	.0243788	36.25	0.000	.8359679	.931531
lgdpr	.0806602	.0226951	3.55	0.000	.0361786	.1251418
le	.0279956	.023204	1.21	0.228	-.0174833	.0734745
ltkp						
--.	.0134706	.0062103	2.17	0.030	.0012987	.0256425
L1.	.0077382	.0066825	1.16	0.247	-.0053592	.0208357
los	-.0348253	.0168058	-2.07	0.038	-.0677641	-.0018865
lcons						
L12.	-.0015359	.0036569	-0.42	0.674	-.0087032	.0056314
_cons	-.3343261	.1894469	-1.76	0.078	-.7056351	.036983

APP 1. 6. 2 GMM Estimation of Yield Equation

Table. 1. 6c: GMM Estimation of Yield Equation

ly	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
ly						
L1.	.9362305	.0136309	68.68	0.000	.9095145	.9629465
li	.0301049	.003825	7.87	0.000	.0226081	.0376018
_cons	-.0818245	.0344262	-2.38	0.017	-.1492987	-.0143503

APP 1. 6. 3 GMM Estimation of New Construction

Table. 1. 6d: GMM Estimation of New Construction Equation without Lags

lcons	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lcons						
L1.	.9004627	.0432309	20.83	0.000	.8157317	.9851937
lrr1	.2028009	.1613704	1.26	0.209	-.1134793	.5190811
le	-.019686	.2468657	-0.08	0.936	-.503534	.464162
li	-.0439242	.0622826	-0.71	0.481	-.1659957	.0781474
ldev	-.0528901	.0306107	-1.73	0.084	-.1128859	.0071058
_cons	-.5409148	2.008518	-0.27	0.788	-4.477538	3.395708

Table. 1. 6e: GMM Estimation of New Construction Equation with Lags

lcons	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lcons						
L1.	.8214923	.0521307	15.76	0.000	.7193181	.9236666
lrr1	-.0684853	.1396345	-0.49	0.624	-.342164	.2051933
le	.2727664	.3243309	0.84	0.400	-.3629105	.9084433
li	-.0003236	.0647572	-0.00	0.996	-.1272453	.1265981
ldev						
L12.	-.0045816	.0266038	-0.17	0.863	-.0567241	.047561
_cons	-1.280753	2.620442	-0.49	0.625	-6.416726	3.85522

APP 1. 6. 4 GMM Estimation of Occupied Stock

Table. 1. 6f: GMM estimation of Occupied Stock Equation without Lags

los	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
los						
L1.	1.002236	.0025747	389.27	0.000	.9971902	1.007283
lrr1	.0108035	.0027115	3.98	0.000	.0054891	.016118
lcons	-.0043424	.000721	-6.02	0.000	-.0057555	-.0029292
li	-.002726	.0012582	-2.17	0.030	-.0051919	-.00026
ldev	.0009736	.0005957	1.63	0.102	-.0001939	.0021412
_cons	-.076191	.0291103	-2.62	0.009	-.1332461	-.0191359

Table. 1. 6g: GMM Estimation of Occupied Stock Equation with Lags

los	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
los						
L1.	1.002962	.0024915	402.56	0.000	.9980785	1.007845
lrr1	.0063041	.0025226	2.50	0.012	.0013599	.0112484
lcons						
L12.	.0004947	.0005314	0.93	0.352	-.0005469	.0015363
li	-.0003201	.0016538	-0.19	0.847	-.0035615	.0029212
ldev						
L12.	-.0001592	.0006047	-0.26	0.792	-.0013443	.001026
_cons	-.068694	.0279751	-2.46	0.014	-.1235242	-.0138638

Appendix 2 Regression Output for Individual Cities

APP 2.1 London, West End

APP 2. 1. 1 OLS Estimation of London, West End

Table. 2. 1a: OLS Estimation of Rent Equation without Lags (London, West End)

lrr1	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
lgdpr	.0060597	.2614395	0.02	0.982	-.527871	.5399904
le	.8327298	1.148451	0.73	0.474	-1.51272	3.17818
ltkp	.0472119	.0557942	0.85	0.404	-.0667349	.1611588
los	2.001495	.9435494	2.12	0.042	.07451	3.92848
lcons	.0970311	.0152273	6.37	0.000	.0659328	.1281295
_cons	-20.12398	8.864205	-2.27	0.031	-38.2271	-2.020859

Table. 2. 1b: OLS Estimation of Rent Equation with Lags (London, West End)

lrr1	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
lgdpr	-.1145526	.1630284	-0.70	0.491	-.4570625	.2279573
le	1.700334	.79769	2.13	0.047	.0244499	3.376219
ltkp						
--.	.0524451	.0319144	1.64	0.118	-.0146046	.1194949
L1.	.0323154	.0343231	0.94	0.359	-.0397948	.1044255
los	1.234673	1.087328	1.14	0.271	-1.049718	3.519064
lcons						
L12.	-.0411847	.0084867	-4.85	0.000	-.0590146	-.0233549
_cons	-20.06932	5.507104	-3.64	0.002	-31.63932	-8.499321

Table. 2. 1c: OLS Estimation of Yield Equation (London, West End)

ly	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
li	.2586586	.0383881	6.74	0.000	.1813411	.3359761
_cons	-2.224685	.1470173	-15.13	0.000	-2.520793	-1.928577

Table. 2. 1d: OLS Estimation of New Construction Equation without Lags (London, West End)

lcons	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
lrr1	4.282334	.8384446	5.11	0.000	2.584991	5.979676
le	-3.538734	4.14993	-0.85	0.399	-11.93983	4.862361
li	.7325114	.3918677	1.87	0.069	-.0607833	1.525806
ldev	-.1191794	.1062909	-1.12	0.269	-.334354	.0959953
_cons	15.14034	40.35335	0.38	0.710	-66.55074	96.83142

Table. 2. 1e: OLS Estimation of New Construction Equation with Lags (London, West End)

lcons	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	2.603361	.3710536	7.02	0.000	1.845568	3.361154
le	-3.936814	1.343718	-2.93	0.006	-6.681052	-1.192576
li	-.2211617	.1211113	-1.83	0.078	-.468504	.0261806
ldev						
L12.	-.0229707	.0306926	-0.75	0.460	-.0856533	.039712
_cons	26.89666	12.19046	2.21	0.035	2.000426	51.79289

Table. 2. 1f: OLS Estimation of Occupied Stock Equation without Lags (London, West End)

los	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	.1793794	.0227024	7.90	0.000	.1334594	.2252993
lcons	-.0179538	.0037909	-4.74	0.000	-.0256217	-.010286
li	-.0516221	.0062097	-8.31	0.000	-.0641825	-.0390617
ldev	.0014392	.0023072	0.62	0.536	-.0032276	.0061061
_cons	7.507236	.1302136	57.65	0.000	7.243854	7.770617

Table. 2. 1g: OLS Estimation of Occupied Stock Equation with Lags (London, West End)

los	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	.2368686	.0307127	7.71	0.000	.1738513	.2998859
lcons						
L12.	.0029656	.002839	1.04	0.305	-.0028595	.0087907
li	-.0352709	.0050669	-6.96	0.000	-.0456673	-.0248745
ldev						
L12.	.001247	.0018019	0.69	0.495	-.0024502	.0049441
_cons	7.050969	.227379	31.01	0.000	6.584426	7.517512

APP 2. 1. 2 Panel Fixed Effects Estimation of London, West End

Table. 2. 1h: Panel Fixed Effects Estimation of Rent Equation without Lags (London, West End)

lrr1	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lgdpr	.0060597	.2614395	0.02	0.982	-.527871	.5399904
le	.8327298	1.148451	0.73	0.474	-1.51272	3.17818
ltkp	.0472119	.0557942	0.85	0.404	-.0667349	.1611588
los	2.001495	.9435494	2.12	0.042	.07451	3.92848
lcons	.0970311	.0152273	6.37	0.000	.0659328	.1281295
_cons	-20.12398	8.864205	-2.27	0.031	-38.2271	-2.020859

Table. 2. 1i: Panel Fixed Effects Estimation of Yield Equation (London, West End)

ly	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
li	.2586586	.0383881	6.74	0.000	.1813411	.3359761
_cons	-2.224685	.1470173	-15.13	0.000	-2.520793	-1.928577

Table. 2. 1j: Panel Fixed Effects Estimation of New Construction Equation without Lags (London, West End)

lcons	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	4.282334	.8384446	5.11	0.000	2.584991	5.979676
le	-3.538734	4.14993	-0.85	0.399	-11.93983	4.862361
li	.7325114	.3918677	1.87	0.069	-.0607833	1.525806
ldev	-.1191794	.1062909	-1.12	0.269	-.334354	.0959953
_cons	15.14034	40.35335	0.38	0.710	-66.55074	96.83142

Table. 2. 1k: Panel Fixed Effects Estimation of Occupied Stock Equation without Lags (London, West End)

los	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	.1793794	.0227024	7.90	0.000	.1334594	.2252993
lcons	-.0179538	.0037909	-4.74	0.000	-.0256217	-.010286
li	-.0516221	.0062097	-8.31	0.000	-.0641825	-.0390617
ldev	.0014392	.0023072	0.62	0.536	-.0032276	.0061061
_cons	7.507236	.1302136	57.65	0.000	7.243854	7.770617

APP 2. 1. 3 3SLS (three-stage least squares) Estimation of London, West End

Table. 2. 1l: 3SLS Estimation without Lags (London, West End)

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lrr1						
lgdpr	.0479843	.1481469	0.32	0.746	-.2423782	.3383468
le	.3750564	.6671884	0.56	0.574	-.9326089	1.682722
ltkp	.0070128	.0331032	0.21	0.832	-.0578682	.0718938
los	2.365819	.584367	4.05	0.000	1.22048	3.511157
lcons	.1239	.0118127	10.49	0.000	.1007474	.1470525
_cons	-19.15683	5.31753	-3.60	0.000	-29.579	-8.734665
ly						
li	.3771867	.0524868	7.19	0.000	.2743145	.480059
_cons	-1.766726	.1990911	-8.87	0.000	-2.156938	-1.376515
lcons						
lrr1	5.805364	.5815815	9.98	0.000	4.665485	6.945242
le	-7.09537	3.179418	-2.23	0.026	-13.32692	-.8638248
li	1.127287	.2882936	3.91	0.000	.5622422	1.692332
ldev	-.0454315	.0696188	-0.65	0.514	-.1818818	.0910189
_cons	42.25552	30.48029	1.39	0.166	-17.48474	101.9958
los						
lrr1	.2186379	.0179195	12.20	0.000	.1835163	.2537594
lcons	-.0224646	.0028962	-7.76	0.000	-.0281411	-.016788
li	-.0402557	.0064077	-6.28	0.000	-.0528146	-.0276968
ldev	.0016937	.0018464	0.92	0.359	-.0019251	.0053125
_cons	7.298076	.1059944	68.85	0.000	7.090331	7.505821

Table. 2. 1m: 3SLS Estimation with Lags (London, West End)

	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
lrr1						
lgdpr	-.058557	.1036826	-0.56	0.572	-.2617711	.1446572
le	.4885821	.5046686	0.97	0.333	-.5005501	1.477714
ltkp						
--.	.0322305	.0209686	1.54	0.124	-.0088672	.0733282
L1.	.0121644	.0209255	0.58	0.561	-.0288488	.0531777
los	2.497462	.6831572	3.66	0.000	1.158498	3.836425
lcons						
L12.	-.0342297	.0066214	-5.17	0.000	-.0472073	-.0212521
_cons	-19.38248	3.877946	-5.00	0.000	-26.98311	-11.78184
ly						
li	.1395316	.0470808	2.96	0.003	.0472548	.2318083
_cons	-2.729392	.1852526	-14.73	0.000	-3.09248	-2.366303
lcons						
lrr1	3.695327	.4988534	7.41	0.000	2.717593	4.673062
le	-8.092133	1.651038	-4.90	0.000	-11.32811	-4.856157
li	-.274967	.1009415	-2.72	0.006	-.4728086	-.0771253
ldev						
L12.	-.0176623	.0229871	-0.77	0.442	-.0627161	.0273915
_cons	61.79542	13.9556	4.43	0.000	34.44295	89.1479
los						
lrr1	.2713432	.0219378	12.37	0.000	.228346	.3143404
lcons						
L12.	.0061327	.0019886	3.08	0.002	.0022351	.0100303
li	-.0182757	.0050083	-3.65	0.000	-.0280917	-.0084597
ldev						
L12.	-.0001245	.0011648	-0.11	0.915	-.0024074	.0021584
_cons	6.857176	.1618896	42.36	0.000	6.539878	7.174474

APP 2.2 London, the City

APP 2. 2. 1 OLS Estimation of London, the City

Table. 2. 2a: OLS Estimation of Rent Equation without Lags (London, the City)

lrr1	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lgdpr	-.3166382	.1745002	-1.81	0.080	-.6730152	.0397388
le	-3.05686	1.133544	-2.70	0.011	-5.371865	-.7418556
ltkp	-.0212738	.0285252	-0.75	0.462	-.0795301	.0369824
los	3.747075	.7413141	5.05	0.000	2.23311	5.261041
lcons	.0755697	.0120326	6.28	0.000	.0509959	.1001435
_cons	8.025401	6.883837	1.17	0.253	-6.033268	22.08407

Table. 2. 2b: OLS Estimation of Rent Equation with Lags (London, the City)

lrr1	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lgdpr	.1209933	.1254143	0.96	0.347	-.1424924	.384479
le	.8306997	1.078832	0.77	0.451	-1.435843	3.097242
ltkp						
--.	-.0154864	.0287933	-0.54	0.597	-.0759788	.0450059
L1.	-.0018061	.0248435	-0.07	0.943	-.0540003	.0503881
los	1.024761	.8526969	1.20	0.245	-.7666888	2.816211
lcons						
L12.	.0294866	.0079644	3.70	0.002	.012754	.0462192
_cons	-12.99137	4.680865	-2.78	0.012	-22.8255	-3.157235

Table. 2. 2c: OLS Estimation of Yield Equation (London, the City)

ly	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
li	.2751995	.0395595	6.96	0.000	.1955704	.3548287
_cons	-1.983236	.1520396	-13.04	0.000	-2.289276	-1.677196

Table. 2. 2d: OLS Estimation of New Construction Equation without Lags (London, the City)

lcons	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	6.957459	1.603648	4.34	0.000	3.701881	10.21304
le	9.830778	6.759526	1.45	0.155	-3.89179	23.55335
li	1.46161	.6048197	2.42	0.021	.233761	2.68946
ldev	.0943264	.1242359	0.76	0.453	-.1578859	.3465387
_cons	-135.3029	66.29229	-2.04	0.049	-269.8834	-.7223837

Table. 2. 2e: OLS Estimation of New Construction Equation with Lags (London, the City)

lcons	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	-.3262822	1.419608	-0.23	0.820	-3.239078	2.586513
le	16.867	2.927442	5.76	0.000	10.86038	22.87361
li	.3478766	.2921934	1.19	0.244	-.2516546	.9474079
ldev						
L12.	-.0548206	.0702198	-0.78	0.442	-.1988998	.0892585
_cons	-164.559	27.36349	-6.01	0.000	-220.7043	-108.4138

Table. 2. 2f: OLS Estimation of Occupied Stock Equation without Lags (London, the City)

los	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	.1224825	.062108	1.97	0.056	-.0034784	.2484433
lcons	-.0057019	.0058192	-0.98	0.334	-.0175039	.0061001
li	-.1188077	.0110036	-10.80	0.000	-.141124	-.0964913
ldev	.0041347	.004319	0.96	0.345	-.0046246	.012894
_cons	7.792115	.362136	21.52	0.000	7.057669	8.526561

Table. 2. 2g: OLS Estimation of Occupied Stock Equation with Lags (London, the City)

los	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	.2984696	.1030947	2.90	0.008	.0856926	.5112467
lcons						
L12.	-.0100879	.0043067	-2.34	0.028	-.0189764	-.0011994
li	-.0772518	.0190865	-4.05	0.000	-.1166445	-.0378592
ldev						
L12.	-.0024478	.0053712	-0.46	0.653	-.0135334	.0086378
_cons	6.862437	.6334513	10.83	0.000	5.555058	8.169816

APP 2. 2. 2 Panel Fixed Effects Estimation of London, the City

Table. 2. 1h: Panel Fixed Effects Estimation of Rent Equation without Lags (London, the City)

lrr1	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lgdpr	-.3166382	.1745002	-1.81	0.080	-.6730152	.0397388
le	-3.05686	1.133544	-2.70	0.011	-5.371865	-.7418556
ltkp	-.0212738	.0285252	-0.75	0.462	-.0795301	.0369824
los	3.747075	.7413141	5.05	0.000	2.23311	5.261041
lcons	.0755697	.0120326	6.28	0.000	.0509959	.1001435
_cons	8.025401	6.883837	1.17	0.253	-6.033268	22.08407

Table. 2. 1i: Panel Fixed Effects Estimation of Yield Equation (London, the City)

ly	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
li	.2751995	.0395595	6.96	0.000	.1955704	.3548287
_cons	-1.983236	.1520396	-13.04	0.000	-2.289276	-1.677196

Table. 2. 1j: Panel Fixed Effects Estimation of New Construction Equation without Lags (London, the City)

lcons	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	6.957459	1.603648	4.34	0.000	3.701881	10.21304
le	9.830778	6.759526	1.45	0.155	-3.89179	23.55335
li	1.46161	.6048197	2.42	0.021	.233761	2.68946
ldev	.0943264	.1242359	0.76	0.453	-.1578859	.3465387
_cons	-135.3029	66.29229	-2.04	0.049	-269.8834	-.7223837

Table. 2. 1k: Panel Fixed Effects Estimation of Occupied Stock Equation without Lags (London, the City)

los	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	.1224825	.062108	1.97	0.056	-.0034784	.2484433
lcons	-.0057019	.0058192	-0.98	0.334	-.0175039	.0061001
li	-.1188077	.0110036	-10.80	0.000	-.141124	-.0964913
ldev	.0041347	.004319	0.96	0.345	-.0046246	.012894
_cons	7.792115	.362136	21.52	0.000	7.057669	8.526561

APP 2. 2. 3 3SLS (three-stage least squares) Estimation of London, the City

Table. 2. 2l: 3SLS Estimation without Lags (London, the City)

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lrr1						
lgdpr	-.2593316	.1265481	-2.05	0.040	-.5073613	-.0113018
le	-1.843859	.9375642	-1.97	0.049	-3.681451	-.0062669
ltkp	-.0418075	.0199372	-2.10	0.036	-.0808837	-.0027314
los	2.942469	.6086209	4.83	0.000	1.749593	4.135344
lcons	.0740278	.0094948	7.80	0.000	.0554183	.0926374
_cons	2.13456	5.509333	0.39	0.698	-8.663534	12.93265
ly						
li	.3877541	.0504266	7.69	0.000	.2889198	.4865885
_cons	-1.538993	.1904837	-8.08	0.000	-1.912334	-1.165651
lcons						
lrr1	10.24473	1.535651	6.67	0.000	7.234907	13.25455
le	8.801317	6.667655	1.32	0.187	-4.267047	21.86968
li	2.13389	.542773	3.93	0.000	1.070075	3.197706
ldev	.0046123	.1118228	0.04	0.967	-.2145564	.223781
_cons	-143.2848	64.38689	-2.23	0.026	-269.4808	-17.08882
los						
lrr1	.2024133	.0332074	6.10	0.000	.1373279	.2674986
lcons	-.0108234	.0029161	-3.71	0.000	-.0165389	-.0051079
li	-.0928083	.0122332	-7.59	0.000	-.1167849	-.0688316
ldev	.0009239	.0020296	0.46	0.649	-.003054	.0049018
_cons	7.409568	.194481	38.10	0.000	7.028392	7.790744

Table. 2. 2m: 3SLS Estimation with Lags (London, the City)

	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
lrr1						
lgdpr	.0303823	.0668776	0.45	0.650	-.1006954	.1614601
le	.4230195	.4708347	0.90	0.369	-.4997997	1.345839
ltkp						
--.	-.0022743	.0132471	-0.17	0.864	-.0282383	.0236896
L1.	.0006197	.0132287	0.05	0.963	-.025308	.0265474
los	1.572728	.395946	3.97	0.000	.7966886	2.348768
lcons						
L12.	.026235	.0049271	5.32	0.000	.0165779	.035892
_cons	-12.60063	2.172929	-5.80	0.000	-16.85949	-8.341764
ly						
li	.2407386	.0854841	2.82	0.005	.0731928	.4082844
_cons	-2.10586	.3354677	-6.28	0.000	-2.763365	-1.448356
lcons						
lrr1	-5.307828	1.308788	-4.06	0.000	-7.873005	-2.742651
le	31.11945	3.107277	10.02	0.000	25.0293	37.2096
li	.0254409	.227824	0.11	0.911	-.4210859	.4719678
ldev						
L12.	-.0179199	.0706203	-0.25	0.800	-.1563331	.1204934
_cons	-280.4662	27.67991	-10.13	0.000	-334.7179	-226.2146
los						
lrr1	.4635143	.0337197	13.75	0.000	.397425	.5296036
lcons						
L12.	-.0111691	.0017477	-6.39	0.000	-.0145946	-.0077436
li	-.008377	.0064234	-1.30	0.192	-.0209667	.0042127
ldev						
L12.	-.0001517	.0018164	-0.08	0.933	-.0037119	.0034084
_cons	6.046351	.2122865	28.48	0.000	5.630277	6.462424

APP 2.3 Paris

APP 2. 3. 1 OLS Estimation of Paris

Table. 2. 3a: OLS Estimation of Rent Equation without Lags (Paris)

lrr1	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lgdpr	-.3674784	.5124855	-0.72	0.479	-1.415629	.6806721
le	.1618008	.8275587	0.20	0.846	-1.530747	1.854348
ltkp	.0603565	.0349671	1.73	0.095	-.0111593	.1318723
los	.0861285	.5095179	0.17	0.867	-.9559527	1.12821
lcons	-.0194171	.0380494	-0.51	0.614	-.0972369	.0584027
_cons	8.803911	5.126475	1.72	0.097	-1.680907	19.28873

Table. 2. 3b: OLS Estimation of Rent Equation with Lags (Paris)

lrr1	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lgdpr	-.4740031	.4259671	-1.11	0.275	-1.346557	.398551
le	.0236981	.7792188	0.03	0.976	-1.572459	1.619856
ltkp						
--.	.0446485	.0327035	1.37	0.183	-.0223415	.1116385
L1.	.0295113	.0317064	0.93	0.360	-.0354364	.094459
los	.062953	.4689851	0.13	0.894	-.8977195	1.023626
lcons						
L12.	.0503167	.0256531	1.96	0.060	-.0022313	.1028647
_cons	11.30204	4.700177	2.40	0.023	1.674167	20.92992

Table. 2. 3c: OLS Estimation of Yield Equation (Paris)

ly	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
li	.2409886	.0249435	9.66	0.000	.19078	.2911972
_cons	-2.222535	.1024082	-21.70	0.000	-2.428672	-2.016398

Table. 2. 3d: OLS Estimation of New Construction Equation without Lags (Paris)

lcons	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	-.7987912	1.82478	-0.44	0.669	-4.774645	3.177062
le	4.014771	7.161996	0.56	0.585	-11.58988	19.61942
li	-.2050757	.245801	-0.83	0.420	-.74063	.3304787
ldev	-.2235955	.1575053	-1.42	0.181	-.56677	.1195791
_cons	-28.06721	67.19269	-0.42	0.684	-174.4675	118.3331

Table. 2. 3e: OLS Estimation of New Construction Equation with Lags (Paris)

lcons	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	4.682157	2.341778	2.00	0.093	-1.047967	10.41228
le	.0247625	5.459346	0.00	0.997	-13.33378	13.3833
li	-.0203343	.2100279	-0.10	0.926	-.534254	.4935854
ldev						
L12.	-.1276414	.1299383	-0.98	0.364	-.4455889	.1903062
_cons	-23.52192	46.17345	-0.51	0.629	-136.5043	89.46045

Table. 2. 3f: OLS Estimation of Occupied Stock Equation without Lags (Paris)

los	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	.1063574	.1794904	0.59	0.564	-.2847186	.4974333
lcons	.0411402	.0311821	1.32	0.212	-.0267998	.1090802
li	-.0259907	.0149947	-1.73	0.109	-.0586613	.00668
ldev	.0216781	.0171982	1.26	0.231	-.0157937	.0591498
_cons	9.155769	1.268933	7.22	0.000	6.391001	11.92054

Table. 2. 3g: OLS Estimation of Occupied Stock Equation with Lags (Paris)

los	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	.5353862	.1144596	4.68	0.003	.2553137	.8154587
lcons						
L12.	.0489914	.0095221	5.15	0.002	.0256917	.072291
li	-.0083043	.0076735	-1.08	0.321	-.0270806	.010472
ldev						
L12.	.0107563	.0081415	1.32	0.235	-.0091653	.0306778
_cons	6.40995	.7134025	8.99	0.000	4.664317	8.155583

APP 2. 3. 2 3SLS (three-stage least squares) Estimation of Paris

Table. 2. 3h: 3SLS Estimation without Lags (Paris)

	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
lrr1						
lgdpr	-1.630087	1.013561	-1.61	0.108	-3.616631	.3564556
le	2.389925	1.548487	1.54	0.123	-.6450539	5.424904
ltkp	.007492	.0455791	0.16	0.869	-.0818414	.0968255
los	.4513891	.7133826	0.63	0.527	-.9468151	1.849593
lcons	.0137947	.0498668	0.28	0.782	-.0839424	.1115319
_cons	-.6615459	7.922862	-0.08	0.933	-16.19007	14.86698
ly						
li	.248323	.0266883	9.30	0.000	.1960148	.3006312
_cons	-2.202495	.1173514	-18.77	0.000	-2.432499	-1.97249
lcons						
lrr1	-1.868237	1.480907	-1.26	0.207	-4.770762	1.034287
le	6.4241	5.324296	1.21	0.228	-4.011329	16.85953
li	-.1147947	.1867592	-0.61	0.539	-.4808361	.2512467
ldev	-.2529852	.1288843	-1.96	0.050	-.5055937	-.0003767
_cons	-44.90519	50.11357	-0.90	0.370	-143.126	53.31561
los						
lrr1	.0805107	.0712971	1.13	0.259	-.0592292	.2202505
lcons	.0464026	.0121917	3.81	0.000	.0225073	.0702979
li	-.0262214	.009118	-2.88	0.004	-.0440924	-.0083504
ldev	.009463	.0067473	1.40	0.161	-.0037615	.0226876
_cons	9.359083	.500197	18.71	0.000	8.378715	10.33945

Table. 2. 3i: 3SLS Estimation with Lags (Paris)

	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
lrr1						
lgdpr	.2607929	.3754843	0.69	0.487	-.4751427	.9967286
le	-.5685162	.46183	-1.23	0.218	-1.473686	.336654
ltkp						
--.	-.0183031	.012669	-1.44	0.149	-.043134	.0065277
L1.	-.0239839	.0133026	-1.80	0.071	-.0500566	.0020888
los	1.567762	.280803	5.58	0.000	1.017398	2.118126
lcons						
L12.	-.0689661	.0100605	-6.86	0.000	-.0886844	-.0492478
_cons	-6.638448	2.413102	-2.75	0.006	-11.36804	-1.908854
ly						
li	.241254	.0663678	3.64	0.000	.1111756	.3713324
_cons	-2.236387	.3156463	-7.09	0.000	-2.855042	-1.617732
lcons						
lrr1	4.77069	1.567921	3.04	0.002	1.69762	7.843759
le	2.306584	3.651385	0.63	0.528	-4.849998	9.463167
li	.0542242	.1432865	0.38	0.705	-.2266122	.3350605
ldev						
L12.	-.1080206	.087113	-1.24	0.215	-.278759	.0627178
_cons	-47.11811	30.92285	-1.52	0.128	-107.7258	13.48955
los						
lrr1	.5808395	.0788623	7.37	0.000	.4262722	.7354068
lcons						
L12.	.0451254	.0068752	6.56	0.000	.0316503	.0586006
li	-.0093351	.0055025	-1.70	0.090	-.0201199	.0014496
ldev						
L12.	.0060106	.0054249	1.11	0.268	-.004622	.0166433
_cons	6.156721	.4942362	12.46	0.000	5.188036	7.125406

APP 2.4 Frankfurt

APP 2. 4. 1 OLS Estimation of Frankfurt

Table. 2. 4a: OLS Estimation of Rent Equation without Lags (Frankfurt)

lrr1	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lgdpr	.1009961	.227766	0.44	0.660	-.3597041	.5616963
le	-1.504756	.4148272	-3.63	0.001	-2.343823	-.6656888
ltkp	.0340053	.0154599	2.20	0.034	.0027348	.0652759
los	.7616476	.390598	1.95	0.058	-.0284115	1.551707
lcons	-.0013605	.02931	-0.05	0.963	-.0606456	.0579246
_cons	13.68145	2.912032	4.70	0.000	7.791311	19.57159

Table. 2. 4b: OLS Estimation of Rent Equation with Lags (Frankfurt)

lrr1	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lgdpr	.1554876	.1745824	0.89	0.380	-.2015736	.5125488
le	-.2796807	.4226427	-0.66	0.513	-1.144082	.5847207
ltkp						
--.	.0061322	.0140563	0.44	0.666	-.0226161	.0348804
L1.	-.0003042	.0112313	-0.03	0.979	-.0232748	.0226663
los	-.0960665	.3237055	-0.30	0.769	-.7581186	.5659857
lcons						
L12.	-.0504537	.0168841	-2.99	0.006	-.0849855	-.0159218
_cons	8.358855	2.603163	3.21	0.003	3.034789	13.68292

Table. 2. 4c: OLS Estimation of Yield Equation (Frankfurt)

ly	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
li	.1196026	.0124636	9.60	0.000	.0945146	.1446905
_cons	-2.515665	.05745	-43.79	0.000	-2.631306	-2.400024

Table. 2. 4d: OLS Estimation of New Construction Equation without Lags (Frankfurt)

lcons	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	.0014929	2.307599	0.00	0.999	-4.983771	4.986757
le	-2.874023	4.107918	-0.70	0.496	-11.74864	6.000593
li	.15426	.1327058	1.16	0.266	-.1324335	.4409534
ldev	-.2021962	.0772355	-2.62	0.021	-.3690534	-.0353391
_cons	37.90516	44.33598	0.85	0.408	-57.8769	133.6872

Table. 2. 4e: OLS Estimation of New Construction Equation with Lags (Frankfurt)

lcons	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	.6901799	1.916893	0.36	0.731	-4.000288	5.380648
le	2.846239	3.256685	0.87	0.416	-5.122582	10.81506
li	.0220647	.10586	0.21	0.842	-.2369654	.2810948
ldev						
L12.	-.4318811	.1622765	-2.66	0.037	-.8289575	-.0348048
_cons	-26.44733	32.32204	-0.82	0.444	-105.5365	52.64185

Table. 2. 4f: OLS Estimation of Occupied Stock Equation without Lags (Frankfurt)

los	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	.0880348	.2070043	0.43	0.678	-.3591708	.5352405
lcons	.0002474	.0245038	0.01	0.992	-.05269	.0531847
li	-.0184734	.0090015	-2.05	0.061	-.03792	.0009732
ldev	-.0171124	.0081541	-2.10	0.056	-.0347284	.0005035
_cons	8.678533	1.310319	6.62	0.000	5.847761	11.5093

Table. 2. 4g: OLS Estimation of Occupied Stock Equation with Lags (Frankfurt)

los	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	.2100402	.090518	2.32	0.059	-.0114494	.4315297
lcons						
L12.	-.0718364	.0092267	-7.79	0.000	-.0944132	-.0492595
li	-.0126288	.0034836	-3.63	0.011	-.0211529	-.0041047
ldev						
L12.	-.0252845	.0074979	-3.37	0.015	-.0436312	-.0069378
_cons	8.432404	.5969475	14.13	0.000	6.971726	9.893082

APP 2. 4. 2 3SLS (three-stage least squares) Estimation of Frankfurt

Table. 2. 4h: 3SLS Estimation without Lags (Frankfurt)

	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
lrr1						
lgdpr	.4914145	.2044057	2.40	0.016	.0907867	.8920423
le	-.9890692	.605291	-1.63	0.102	-2.175418	.1972793
ltkp	.0109608	.01381	0.79	0.427	-.0161064	.0380279
los	-.0254512	.3458418	-0.07	0.941	-.7032886	.6523862
lcons	.0183982	.0210153	0.88	0.381	-.022791	.0595875
_cons	10.73876	3.638203	2.95	0.003	3.608016	17.86951
ly						
li	.1687255	.0269664	6.26	0.000	.1158724	.2215786
_cons	-2.281509	.138334	-16.49	0.000	-2.552639	-2.010379
lcons						
lrr1	1.220267	1.939116	0.63	0.529	-2.58033	5.020864
le	-4.215058	3.43481	-1.23	0.220	-10.94716	2.517047
li	.1119297	.1110985	1.01	0.314	-.1058193	.3296787
ldev	-.1883936	.0651178	-2.89	0.004	-.3160221	-.0607652
_cons	44.36464	37.06893	1.20	0.231	-28.28913	117.0184
los						
lrr1	.0962897	.151111	0.64	0.524	-.1998824	.3924619
lcons	-.0080083	.0180694	-0.44	0.658	-.0434237	.0274071
li	-.0225119	.0068668	-3.28	0.001	-.0359705	-.0090533
ldev	-.0115404	.0059292	-1.95	0.052	-.0231616	.0000807
_cons	8.628926	.9564159	9.02	0.000	6.754385	10.50347

Table. 2. 4i: 3SLS Estimation with Lags (Frankfurt)

	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
lrr1						
lgdpr	.3686585	.2672669	1.38	0.168	-.1551749	.8924919
le	-2.006631	.6389803	-3.14	0.002	-3.259009	-.7542526
ltkp						
--.	.0480432	.0179517	2.68	0.007	.0128585	.083228
L1.	.0722089	.0336035	2.15	0.032	.0063473	.1380705
los	1.006527	.4324619	2.33	0.020	.1589169	1.854136
lcons						
L12.	.1044179	.0348203	3.00	0.003	.0361713	.1726644
_cons	12.47096	6.139546	2.03	0.042	.4376712	24.50425
ly						
li	.1391198	.0574275	2.42	0.015	.026564	.2516755
_cons	-2.430363	.3156243	-7.70	0.000	-3.048975	-1.811751
lcons						
lrr1	2.175914	1.291407	1.68	0.092	-.3551974	4.707026
le	.6768266	2.216836	0.31	0.760	-3.668091	5.021745
li	-.0221441	.0713747	-0.31	0.756	-.1620358	.1177477
ldev						
L12.	-.3482802	.1155726	-3.01	0.003	-.5747983	-.1217621
_cons	-13.21557	22.30888	-0.59	0.554	-56.94018	30.50904
los						
lrr1	.2495464	.0614418	4.06	0.000	.1291227	.3699701
lcons						
L12.	-.0675572	.0062709	-10.77	0.000	-.079848	-.0552664
li	-.0129117	.0024705	-5.23	0.000	-.0177539	-.0080696
ldev						
L12.	-.0228714	.0053291	-4.29	0.000	-.0333163	-.0124264
_cons	8.151206	.4041549	20.17	0.000	7.359077	8.943336

APP 2.5 Amsterdam

APP 2. 5. 1 OLS Estimation of Amsterdam

Table. 2. 5a: OLS Estimation of Rent Equation without Lags (Amsterdam)

lrr1	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lgdpr	.9305201	.3361107	2.77	0.010	.2440905	1.61695
le	3.81287	1.240382	3.07	0.004	1.279673	6.346067
ltkp	-.0118172	.019126	-0.62	0.541	-.0508778	.0272433
los	-1.576377	.5193047	-3.04	0.005	-2.636939	-.5158154
lcons	.1028591	.0340623	3.02	0.005	.0332946	.1724236
_cons	-26.52783	12.54556	-2.11	0.043	-52.14928	-.9063691

Table. 2. 5b: OLS Estimation of Rent Equation with Lags (Amsterdam)

lrr1	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lgdpr	.0110459	.38935	0.03	0.978	-.7986517	.8207436
le	-5.932191	1.7268	-3.44	0.002	-9.523268	-2.341114
ltkp						
--.	.0153059	.0171915	0.89	0.383	-.0204458	.0510577
L1.	-.0163898	.0190993	-0.86	0.401	-.056109	.0233294
los	-.0562336	.7451543	-0.08	0.941	-1.605867	1.493399
lcons						
L12.	-.1889257	.0509978	-3.70	0.001	-.2949815	-.08287
_cons	60.73141	16.75906	3.62	0.002	25.87904	95.58379

Table. 2. 5c: OLS Estimation of Yield Equation (Amsterdam)

ly	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
li	.1528213	.0321398	4.75	0.000	.0880884	.2175543
_cons	-2.250318	.1416499	-15.89	0.000	-2.535615	-1.96502

Table. 2. 5d: OLS Estimation of New Construction Equation without Lags (Amsterdam)

lcons	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	.4834158	1.826913	0.26	0.798	-3.729453	4.696284
le	24.95683	9.941261	2.51	0.036	2.032237	47.88142
li	.5646897	.2828914	2.00	0.081	-.0876591	1.217038
ldev	.1349675	.1678784	0.80	0.445	-.2521608	.5220958
_cons	-221.1857	85.75544	-2.58	0.033	-418.9381	-23.43333

Table. 2. 5e: OLS Estimation of New Construction Equation with Lags (Amsterdam)

lcons	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	14.47118	29.798	0.49	0.675	-113.7393	142.6816
le	-15.19474	106.4317	-0.14	0.900	-473.1334	442.7439
li	1.477563	1.528308	0.97	0.436	-5.098217	8.053343
ldev						
L12.	-.5492529	.7437677	-0.74	0.537	-3.749427	2.650921
_cons	65.7911	794.2866	0.08	0.942	-3351.748	3483.331

Table. 2. 5f: OLS Estimation of Occupied Stock Equation without Lags (Amsterdam)

los	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	-.0010282	.0779683	-0.01	0.990	-.1808234	.178767
lcons	.0308461	.0115584	2.67	0.028	.0041923	.0574998
li	-.012283	.0120294	-1.02	0.337	-.0400229	.015457
ldev	-.0086408	.0071364	-1.21	0.261	-.0250975	.0078158
_cons	8.390057	.415551	20.19	0.000	7.431795	9.348319

Table. 2. 5g: OLS Estimation of Occupied Stock Equation with Lags (Amsterdam)

los	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	.4802896	.0088476	54.29	0.000	.4422216	.5183575
lcons						
L12.	.0364695	.0022148	16.47	0.004	.0269401	.0459989
li	-.0030381	.0030348	-1.00	0.422	-.0160958	.0100195
ldev						
L12.	-.0023326	.0013336	-1.75	0.222	-.0080706	.0034055
_cons	5.527022	.0501994	110.10	0.000	5.311031	5.743012

APP 2. 5. 2 3SLS (three-stage least squares) Estimation of Amsterdam

Table. 2. 5h: 3SLS Estimation without Lags (Amsterdam)

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lrr1						
lgdpr	2.267423	.2449537	9.26	0.000	1.787322	2.747523
le	6.573046	1.788679	3.67	0.000	3.067299	10.07879
ltkp	-.0854306	.0217436	-3.93	0.000	-.1280473	-.042814
los	-2.14005	.5423365	-3.95	0.000	-3.20301	-1.07709
lcons	.2212441	.030336	7.29	0.000	.1617866	.2807016
_cons	-62.65206	13.81566	-4.53	0.000	-89.73026	-35.57385
ly						
li	.1427207	.0342176	4.17	0.000	.0756553	.209786
_cons	-2.161638	.1577597	-13.70	0.000	-2.470841	-1.852434
lcons						
lrr1	3.742694	1.464279	2.56	0.011	.8727607	6.612627
le	-19.6155	11.58236	-1.69	0.090	-42.3165	3.085509
li	.5244078	.1655246	3.17	0.002	.1999855	.8488302
ldev	.3358741	.1167631	2.88	0.004	.1070227	.5647255
_cons	161.2378	104.1259	1.55	0.122	-42.8451	365.3208
los						
lrr1	-.1375367	.1018377	-1.35	0.177	-.3371348	.0620615
lcons	.0049003	.0165834	0.30	0.768	-.0276026	.0374032
li	-.0037026	.0143197	-0.26	0.796	-.0317688	.0243635
ldev	-.0045248	.0084393	-0.54	0.592	-.0210655	.0120158
_cons	9.329897	.5344695	17.46	0.000	8.282356	10.37744

APP 2.6 Milan

APP 2. 6. 1 OLS Estimation of Milan

Table. 2. 6a: OLS Estimation of Rent Equation without Lags (Milan)

lrr1	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lgdpr	-.6690527	.2416003	-2.77	0.009	-1.158147	-.1799586
le	1.801551	.4369916	4.12	0.000	.9169074	2.686194
ltkp	-.0005608	.0116275	-0.05	0.962	-.0240995	.0229779
los	-2.093752	.4341823	-4.82	0.000	-2.972708	-1.214796
lcons	.0348469	.0220817	1.58	0.123	-.0098552	.079549
_cons	15.99553	4.570481	3.50	0.001	6.743079	25.24799

Table. 2. 6b: OLS Estimation of Rent Equation with Lags (Milan)

lrr1	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lgdpr	-1.002988	.4799066	-2.09	0.046	-1.984508	-.0214693
le	2.143944	.5827095	3.68	0.001	.9521694	3.335719
ltkp						
--.	.0019369	.0136391	0.14	0.888	-.0259582	.0298319
L1.	.0221643	.0163598	1.35	0.186	-.0112953	.0556239
los	-1.718664	.6033491	-2.85	0.008	-2.952651	-.4846762
lcons						
L12.	.0012585	.0210893	0.06	0.953	-.0418739	.0443908
_cons	13.43626	5.199891	2.58	0.015	2.801287	24.07123

Table. 2. 6c: OLS Estimation of Yield Equation (Milan)

ly	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
li	.1608701	.0520221	3.09	0.003	.0560922	.265648
_cons	-2.496352	.1800161	-13.87	0.000	-2.858923	-2.133781

Table. 2. 6d: OLS Estimation of New Construction Equation without Lags (Milan)

lcons	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	4.436462	2.821069	1.57	0.135	-1.543937	10.41686
le	6.715903	4.025284	1.67	0.115	-1.817318	15.24912
li	-.2190089	.2188984	-1.00	0.332	-.6830528	.2450351
ldev	-.0431253	.0552312	-0.78	0.446	-.1602101	.0739596
_cons	-89.93704	37.91517	-2.37	0.031	-170.3136	-9.560473

Table. 2. 6e: OLS Estimation of New Construction Equation with Lags (Milan)

lcons	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	-5.619418	7.596764	-0.74	0.481	-23.13759	11.89875
le	8.674569	2.727675	3.18	0.013	2.384539	14.9646
li	.5198206	.2603665	2.00	0.081	-.0805855	1.120227
ldev						
L12.	.0905244	.0474337	1.91	0.093	-.0188579	.1999066
_cons	-44.54163	56.1457	-0.79	0.450	-174.0138	84.93058

Table. 2. 6f: OLS Estimation of Occupied Stock Equation without Lags (Milan)

los	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	.0197298	.112557	0.18	0.863	-.2188804	.2583401
lcons	-.009724	.0086869	-1.12	0.279	-.0281394	.0086914
li	-.0165911	.008175	-2.03	0.059	-.0339213	.0007391
ldev	.0026515	.0020801	1.27	0.221	-.0017581	.0070611
_cons	9.158775	.7076322	12.94	0.000	7.658661	10.65889

Table. 2. 6g: OLS Estimation of Occupied Stock Equation with Lags (Milan)

los	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
lrr1	-.1805068	.131805	-1.37	0.208	-.4844496	.1234359
lcons						
L12.	.0049738	.0027363	1.82	0.107	-.0013361	.0112837
li	-.0027343	.004993	-0.55	0.599	-.0142482	.0087795
ldev						
L12.	.0008906	.0008128	1.10	0.305	-.0009837	.0027648
_cons	10.37328	.8347169	12.43	0.000	8.448424	12.29815

APP 2. 6. 2 3SLS (three-stage least squares) Estimation of Milan

Table. 2. 6h: 3SLS Estimation without Lags (Milan)

	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
lrr1						
lgdpr	-1.70008	.3898795	-4.36	0.000	-2.464229	-.9359298
le	1.480693	.4890609	3.03	0.002	.5221515	2.439235
ltkp	.0128506	.0133931	0.96	0.337	-.0133994	.0391006
los	.2857981	.7693711	0.37	0.710	-1.222142	1.793738
lcons	.1093843	.035513	3.08	0.002	.0397802	.1789884
_cons	9.800365	5.835311	1.68	0.093	-1.636633	21.23736
ly						
li	.2872127	.067764	4.24	0.000	.1543978	.4200276
_cons	-2.081985	.2332467	-8.93	0.000	-2.53914	-1.62483
lcons						
lrr1	5.285926	2.220899	2.38	0.017	.9330448	9.638807
le	2.624668	2.907991	0.90	0.367	-3.074889	8.324225
li	-.3074808	.1747731	-1.76	0.079	-.6500298	.0350681
ldev	-.0214868	.0434715	-0.49	0.621	-.1066893	.0637158
_cons	-54.58391	28.00615	-1.95	0.051	-109.475	.3071343
los						
lrr1	-.0591742	.0817443	-0.72	0.469	-.2193901	.1010417
lcons	-.0091104	.005908	-1.54	0.123	-.02069	.0024692
li	-.0137873	.0061301	-2.25	0.025	-.025802	-.0017726
ldev	.0027983	.0015097	1.85	0.064	-.0001607	.0057572
_cons	9.657663	.5162952	18.71	0.000	8.645743	10.66958

Table. 2. 6i: 3SLS Estimation with Lags (Milan)

	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
lrr1						
lgdpr	-.3994385	.1141886	-3.50	0.000	-.6232441	-.175633
le	.3183226	.1205619	2.64	0.008	.0820256	.5546196
ltkp						
--.	.0071833	.003219	2.23	0.026	.0008742	.0134923
L1.	.0115252	.0040757	2.83	0.005	.0035369	.0195135
los	-2.108182	.3505859	-6.01	0.000	-2.795318	-1.421046
lcons						
L12.	-.0006356	.0057366	-0.11	0.912	-.0118791	.0106079
_cons	27.65041	3.565027	7.76	0.000	20.66309	34.63774
ly						
li	.0505207	.1826119	0.28	0.782	-.3073921	.4084334
_cons	-2.837771	.7255397	-3.91	0.000	-4.259803	-1.415739
lcons						
lrr1	-3.550562	5.734443	-0.62	0.536	-14.78986	7.688739
le	7.874133	1.674969	4.70	0.000	4.591254	11.15701
li	.4466827	.1984681	2.25	0.024	.0576924	.835673
ldev						
L12.	.0798325	.0357113	2.24	0.025	.0098397	.1498253
_cons	-49.63942	40.43494	-1.23	0.220	-128.8904	29.6116
los						
lrr1	-.2537271	.0929634	-2.73	0.006	-.4359321	-.0715222
lcons						
L12.	.0055463	.0016711	3.32	0.001	.0022711	.0088216
li	-.0024233	.0033537	-0.72	0.470	-.0089964	.0041498
ldev						
L12.	.0007392	.000595	1.24	0.214	-.000427	.0019054
_cons	10.82697	.5871095	18.44	0.000	9.676258	11.97769

APP 2.7 Madrid

APP 2. 7. 1 OLS Estimation of Madrid

Table. 2. 7a: OLS Estimation of Rent Equation without Lags (Madrid)

lrr1	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lgdpr	-.7922259	.5047618	-1.57	0.125	-1.814063	.2296109
le	3.461397	.3275586	10.57	0.000	2.798289	4.124505
ltkp	-.01303	.0302295	-0.43	0.669	-.0742264	.0481663
los	.7103932	.8616513	0.82	0.415	-1.033929	2.454715
lcons	.0280503	.0370421	0.76	0.454	-.0469374	.1030381
_cons	-25.36186	4.258149	-5.96	0.000	-33.98204	-16.74169

Table. 2. 7b: OLS Estimation of Rent Equation with Lags (Madrid)

lrr1	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lgdpr	.7629964	.487445	1.57	0.128	-.2339406	1.759933
le	1.500163	.4634366	3.24	0.003	.5523291	2.447998
ltkp						
--.	-.0186117	.0286065	-0.65	0.520	-.0771185	.0398951
L1.	-.0142086	.0296337	-0.48	0.635	-.0748163	.046399
los	1.793992	.9171293	1.96	0.060	-.0817482	3.669732
lcons						
L12.	.1410646	.0462232	3.05	0.005	.0465275	.2356016
_cons	-36.07908	6.980727	-5.17	0.000	-50.35627	-21.80189

Table. 2. 7c: OLS Estimation of Yield Equation (Madrid)

ly	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
li	.3405486	.0416527	8.18	0.000	.2566558	.4244413
_cons	-1.788396	.1499146	-11.93	0.000	-2.090339	-1.486452

Table. 2. 7d: OLS Estimation of New Construction Equation without Lags (Madrid)

lcons	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	3.282783	2.672046	1.23	0.236	-2.35474	8.920307
le	-5.646383	5.832626	-0.97	0.347	-17.95215	6.659381
li	.4778706	.1150294	4.15	0.001	.2351798	.7205613
ldev	-.0385003	.0747391	-0.52	0.613	-.1961861	.1191855
_cons	43.54155	42.68861	1.02	0.322	-46.52355	133.6066

Table. 2. 7e: OLS Estimation of New Construction Equation with Lags (Madrid)

lcons	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	-1.010008	.5875735	-1.72	0.120	-2.339192	.3191752
le	4.403702	1.97041	2.23	0.052	-.0536757	8.86108
li	.3430126	.1626016	2.11	0.064	-.0248179	.7108431
ldev						
L12.	-.3029014	.0828166	-3.66	0.005	-.4902454	-.1155573
_cons	-29.67238	16.13333	-1.84	0.099	-66.16851	6.823746

Table. 2. 7f: OLS Estimation of Occupied Stock Equation without Lags (Madrid)

los	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	.2059363	.03375	6.10	0.000	.13473	.2771426
lcons	.0033221	.010059	0.33	0.745	-.0179005	.0245447
li	-.0291651	.0065374	-4.46	0.000	-.0429577	-.0153725
ldev	.0075751	.0031652	2.39	0.029	.0008972	.0142531
_cons	8.231288	.1868577	44.05	0.000	7.837053	8.625523

Table. 2. 7g: OLS Estimation of Occupied Stock Equation with Lags (Madrid)

los	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lrr1	.1003704	.0204183	4.92	0.001	.0541809	.1465599
lcons						
L12.	-.0400079	.0076409	-5.24	0.001	-.0572928	-.0227231
li	-.0086046	.0100839	-0.85	0.416	-.0314158	.0142067
ldev						
L12.	.0101205	.0053632	1.89	0.092	-.0020119	.0222529
_cons	9.148966	.1315182	69.56	0.000	8.851451	9.44648

APP 2. 7. 2 3SLS (three-stage least squares) Estimation of Madrid

Table. 2. 7h: 3SLS Estimation without Lags (Madrid)

	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
lrr1						
lgdpr	.5107278	.2369271	2.16	0.031	.0463591	.9750965
le	1.478617	.1817443	8.14	0.000	1.122405	1.83483
ltkp	.0102339	.0115297	0.89	0.375	-.0123639	.0328317
los	.2089263	.3602821	0.58	0.562	-.4972136	.9150662
lcons	.03555	.0121577	2.92	0.003	.0117214	.0593787
_cons	-17.19697	1.729358	-9.94	0.000	-20.58645	-13.8075
ly						
li	.3776704	.0487598	7.75	0.000	.2821029	.4732379
_cons	-1.654138	.1830256	-9.04	0.000	-2.012861	-1.295414
lcons						
lrr1	5.494656	2.246184	2.45	0.014	1.092216	9.897096
le	-10.87108	4.927734	-2.21	0.027	-20.52926	-1.212895
li	.5011235	.0987675	5.07	0.000	.3075427	.6947043
ldev	-.0564674	.0623505	-0.91	0.365	-.1786723	.0657374
_cons	82.14084	36.16933	2.27	0.023	11.25025	153.0314
los						
lrr1	.2010298	.0295844	6.80	0.000	.1430455	.2590141
lcons	.0041056	.0088077	0.47	0.641	-.0131572	.0213684
li	-.0297686	.0057209	-5.20	0.000	-.0409814	-.0185559
ldev	.0071187	.0027641	2.58	0.010	.0017011	.0125363
_cons	8.254917	.1639053	50.36	0.000	7.933669	8.576166

Table. 2. 7i: 3SLS Estimation with Lags (Madrid)

	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
lrr1						
lgdpr	.7163208	.7976286	0.90	0.369	-.8470027	2.279644
le	.7699032	.9614595	0.80	0.423	-1.114523	2.654329
ltkp						
--.	-.0776908	.0369472	-2.10	0.035	-.1501059	-.0052757
L1.	-.0753045	.0486348	-1.55	0.122	-.1706271	.020018
los	5.227481	1.178922	4.43	0.000	2.916837	7.538126
lcons						
L12.	.2943578	.0551644	5.34	0.000	.1862377	.402478
_cons	-61.51609	8.007684	-7.68	0.000	-77.21086	-45.82132
ly						
li	.462961	.2073511	2.23	0.026	.0565602	.8693618
_cons	-1.238832	.8541026	-1.45	0.147	-2.912842	.4351787
lcons						
lrr1	-1.055811	.4177123	-2.53	0.011	-1.874512	-.23711
le	4.453877	1.314398	3.39	0.001	1.877705	7.03005
li	.3392732	.1246433	2.72	0.006	.0949768	.5835696
ldev						
L12.	-.2853864	.0645323	-4.42	0.000	-.4118673	-.1589055
_cons	-29.97831	10.76215	-2.79	0.005	-51.07174	-8.884885
los						
lrr1	.1109611	.0151221	7.34	0.000	.0813223	.1406
lcons						
L12.	-.0432705	.0050862	-8.51	0.000	-.0532393	-.0333016
li	-.0046985	.0067005	-0.70	0.483	-.0178313	.0084343
ldev						
L12.	.0058248	.0035512	1.64	0.101	-.0011354	.0127849
_cons	9.136625	.0965073	94.67	0.000	8.947474	9.325776

Appendix 3 Summary of Outputs and Notations in the Four Subsectors (Chapter 5)

APP 3.1 User (Occupier) Sebsector

Hypothesis 1: In the first quadrant, real rent is positively (+) affected by real GDP, employment, take-up ratio, and negatively (-) influenced by new construction and occupied stock.

(1) Function of occupier subsector (non-lag): lrr = f (lgdpr, le, ltkpr, los, lcons, lrr (t-1))
, where lrr: log of real rent; lgdpr: log of real Gross Domestic Product; le: log of employment; ltkpr: log of take-up ratio; lcons: log of new construction; lrr (t-1): log of real rent at the time period (t-1)

Table. 3.1a: Occupier subsector (non-lag)

	OLS	GLS	Panel FE	Panel RE	GMM	SUR (3SLS)
lgdpr	0.612***	0.543***	0.209***	0.231***	0.056***	0.640***
le	0.198***	0.169***	2.188***	1.580***	0.025***	0.187***
ltkpr	0.087***	0.085***	-0.003	0.002***	0.121***	0.072***
lcons	0.070***	0.111***	0.049***	0.056***	-0.018***	0.080***
los	-0.419***	-0.374***	-1.148***	-0.759***	0.006	-0.436***
lrr (t-1)					0.918***	
constant	-0.321	-0.196	-0.792	-5.742	-0.484	-0.411
Adjusted R^2	0.816		0.328	0.392		0.793
F-statistic	245.10***	1751.2***	46.68***			
Wald Chi^2				197.30***	11082***	612.87***
No. of samples	276	276	276	276	276	154

(2) Function of occupier subsector (lag): lrr = f (lgdpr, le, ltkpr (t-1), los, lcons, lrr (t-1))
, where lrr: log of real rent; lgdpr: log of real Gross Domestic Product; le: log of employment; ltkpr (t-1): log of take-up ratio at time period (t-1); lcons (t-12): log of new construction at time period (t-12); lrr (t-1): log of real rent at the time period (t-1)

Table. 3.1b: Occupier subsector (lag)

	OLS	GLS	Panel FE	Panel RE	GMM	SUR (3SLS)
lgdpr	0.649***	0.618***	0.164*	0.649***	0.081***	0.723***
le	0.199***	0.199***	1.767***	0.199***	0.028	0.145**
ltkpr	0.092***	0.105***	-0.010	0.092***	0.013**	0.099**
ltkpr (t-1)	0.081***	0.061***	-0.004	0.082***	0.008	-0.002
lcons (t-12)	0.028*	0.028*	-0.007***	0.027*	-0.002	0.022
los	-0.464***	-0.478***	-0.801***	-0.464***	-0.035***	-0.468***
lrr (t-1)					0.884***	
constant	-0.572	-3.580	-5.945	-0.572	-0.334	1.066
Adjusted R^2	0.859		0.289	0.862		0.810
F-statistic	223.48***		21.92***			
Wald Chi^2		2436.6***		1340.9***	11082***	479.40***
No. of samples	221	221	221	221	221	99

APP 3.2 Investment Subsector

Hypothesis 2: In the second quadrant, yield (capitalisation rate) is positively (+) affected by the interest rate.

Function of investment subsector: ly = f (li, ly (t-1))
, where ly: log of yield; li: log of interest rate; ly: log of yield at time period (t-1)

Table. 3.2: Investment subsector

	OLS	GLS	Panel FE	Panel RE	GMM	SUR (3SLS), non-lag	SUR (3SLS), lag
li	0.139***	0.135***	0.187***	0.185***	0.030***	0.154***	0.062**
ly (t-1)					0.936***		
constant	-2.519	-2.532	-2.330	-2.339	-0.082	-2.482	-2.891
Adjusted R^2	0.239		0.241	0.241		0.277	0.066
F-statistic	104.76***		243.39***				
Wald Chi^2		137.28***		238.42***	8925.8***	58.10***	4.74**
No. of samples	332	332	332	332	332	154	99

APP 3.3 Development Subsector - Flow

Hypothesis 3: In the third quadrant, the amount of new construction is positively (+) affected by rent, employment, development permit, and negatively (-) influenced by the interest rate.

(1) Function of development subsector (flow, non-lag): lcons = f (lrr, le, li, ldev, lcons (t-1))
, where lcons: new construction; lrr: lagged real rent; le: lagged employment; li: lagged interest rate; ldev: lagged development permit; lcons (t-1): new construction at time period (t-1)

Table. 3.3a: Development subsector (flow, non-lag)

	OLS	GLS	Panel FE	Panel RE	GMM	SUR (3SLS)
lrr	0.427***	0.483***	2.969***	1.310***	0.203	0.707***
le	0.314*	0.319*	-0.818	0.032	-0.020	0.254
li	0.600	0.090	0.1690	0.082	-0.044	0.066
ldev	0.223***	0.114***	0.013	0.069	-0.053*	0.239***
lcons (t-1)					0.900***	
constant	-0.670	-0.605	-4.375	-2.721	-0.541	-1.900
Adjusted R^2	0.227		0.076	0.136		0.266
F-statistic	13.68***		8.01***			
Wald Chi^2		55.72***		26.03***	502.70***	71.19***
No. of samples	174	174	174	174	174	154

(2) Function of development subsector (flow, lag): lcons = f (lrr, le, li, ldev (t-12), lcons (t-1))
, where lcons: log of new construction; lrr: log of real rent; le: log of employment; li: log of interest rate; ldev: log of development permit at time period (t-12); lcons (t-1): log of new construction at time period (t-1)

Table. 3.3b Development subsector (flow, lag)

	OLS	GLS	Panel FE	Panel RE	GMM	SUR (3SLS)
lrr	0.275*	-0.105	0.093	0.788**	-0.068	0.496***
le	0.545***	0.843***	5.989***	0.703**	0.272	0.321**
li	-0.143	-0.062	0.019	-0.237***	-0.0003	-0.122
ldev (t-12)	0.116**	-0.061	-0.127***	-0.086*	-0.005	0.147***
lcons (t-1)					0.821***	
constant	-2.683	-2.387	-55.283	-7.091	-1.281	-1.840
Adjusted R^2	0.190		0.141	0.124		0.629
F-statistic	8.16***		13.12***			
Wald Chi^2		25.79***		37.66***	502.70***	38.83***
No. of samples	123	123	123	123	123	99

APP 3.4 Development Subsector - Stock

Hypothesis 4: Occupied stock is negatively (-) affected by real rent and interest rates, and positively (+) influenced by new construction and development permits.

(1) Function of development subsector (stock, non-lag): los = f (lrr, lcons, li, ldev, los (t-1))
, where los: logged occupied stock; lrr: log of real rent ; lcons: log of new construction; li: log of interest rate; ldev: log of development permit; los (t-1): logged occupied stock at time period (t-1)

Table. 3.4a Development subsector (stock, non-lag)

	OLS	GLS	Panel FE	Panel RE	GMM	SUR (3SLS)
lrr	-0.276***	-0.403***	0.165***	0.164***	0.011***	-0.552***
li	-0.004	-0.013*	-0.044***	-0.044***	-0.003**	-0.022
lcons	0.191***	0.056	-0.006*	-0.006*	-0.004***	0.239***
ldev	0.136***	0.015	0.004*	0.004*	0.001	0.145***
los (t-1)					1.002***	
constant	9.349	11.332	7.989	8.081	-0.076	10.772
Adjusted R^2	0.319		0.018	0.016		0.333
F-statistic	21.45***		57.90***			
Wald Chi^2		25.79***		187.32***	197948***	176.44***
No. of samples	176	176	176	176	176	154

(2) Function of development subsector (stock, lag): los = f (lrr, lcons (t-12), li, ldev (t-12), los (t-1))
, where los: logged occupied stock; lrr: log of real rent; lcons (t-12): log of new construction at time period (t-12); li: log of interest rate; ldev (t-12): log of development permit at time period (t-12); los (t-1): logged occupied stock at time period (t-1)

Table. 3.4b Development subsector (stock, lag)

	OLS	GLS	Panel FE	Panel RE	GMM	SUR (3SLS)
lrr	-0.210**	-0.399***	0.223***	0.222***	0.006**	-0.391***
li	-0.002	-0.006	-0.034***	-0.035***	-0.0003	-0.001
lcons (t-12)	0.128***	-0.013	-0.005*	-0.005	0.0005	0.122***
ldev (t-12)	0.148***	0.006	-0.019	-0.002	-0.0002	0.137***
los (t-1)					1.003***	
constant	9.273	11.768	7.659	7.768	-0.069	10.533
Adjusted R^2	0.267		0.047	0.005		0.417
F-statistic	11.55***		43.35***			
Wald Chi^2		2436.6***		132.59***	215301***	78.31***
No. of samples	117	117	117	117	117	99