Vertical Sorting, Height Premiums and Productivity in Multi-Tenant Office Buildings

A study of Amsterdam, Rotterdam and The Hague.

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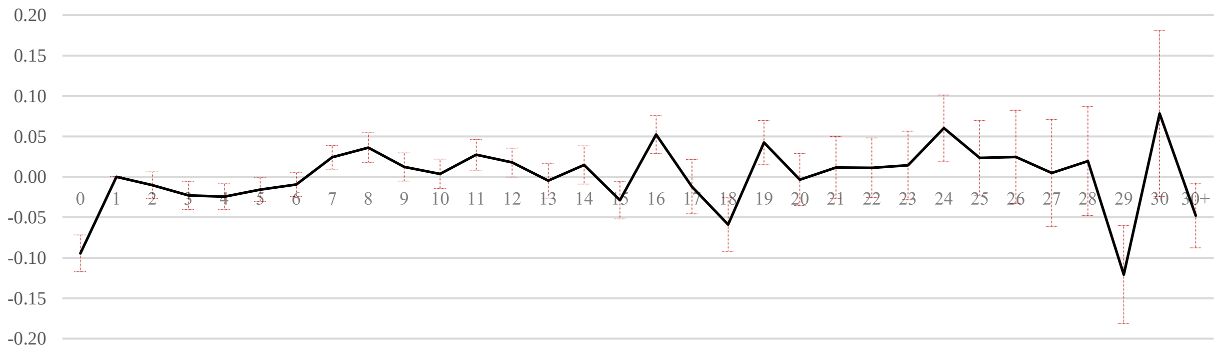
Executive Summary

As more people are moving towards urban environments, cities are under pressure and are becoming more dense. Cities are reaching their physical boundaries, limiting the possibilities for horizontal expansion. Solutions towards the problem of densification of cities such as tall buildings are becoming increasingly popular. The execution of the solutions require a vast economic understanding of these buildings. Existing urban economic literature revolving around this topic has mainly focussed on the horizontal scale of cities and buildings while largely ignoring the vertical aspects. In this study the vertical economics within tall buildings are further researched with an objective to shed light on the interrelationship between price premiums per floor level, vertical sorting through the willingness to pay for height of tenants and productivity measured by revenue per employee within tall buildings in Amsterdam, Rotterdam and The Hague. The topic of rent premiums and vertical sorting in connection to productivity is embryotic but there is room for improvement, especially through the analysis of different contexts. These factors have contributed to the following main question of this research: *What is the interrelationship between price premiums per floor level, vertical sorting and productivity of firms in multi-tenant office buildings in the three largest cities (Amsterdam, Rotterdam & The Hague) of the Netherlands?*

Based on a quantitative approach, supplemented with literature revolving around the determinants of building heights and floor heights of tenants, divided into the supply and demand of height a framework is made which is the basis and input for the empirical analysis of the three factors. Data is gathered for 1.311 rental transactions within multi-tenant, tall office buildings, divided between the three cities. Empirical analysis through linear multiple regression modelling is utilized to gain insights on the price premiums per floor, the vertical sorting of tenants based on their characteristics and the relationship between these two variables and productivity.

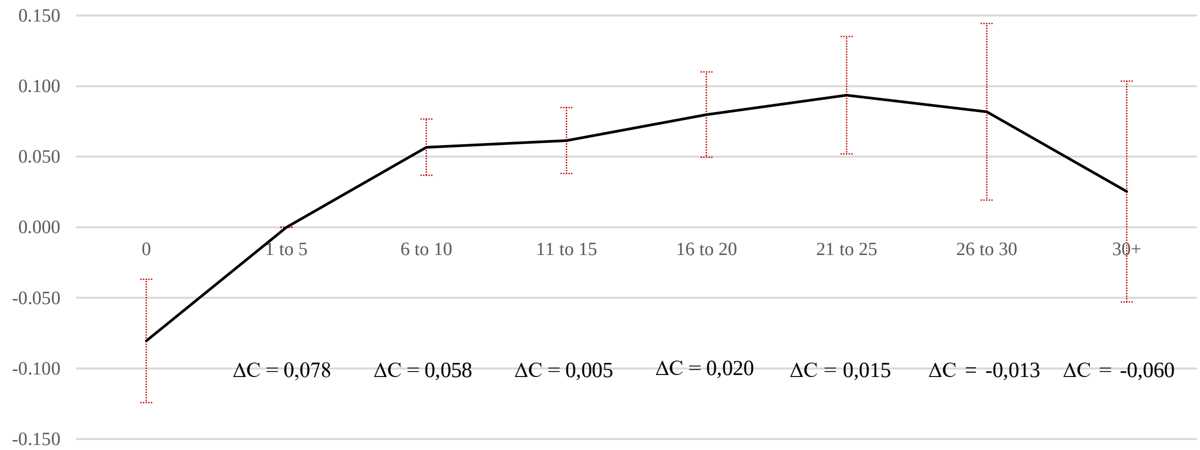
The main goal of this research is to expand the existing knowledge on the interrelationship of the three variables. Empirical analysis through several models results in a highly significant vertical price premium of 0,6% increase of transacted rental price per square meters for each consecutive floor level. In similar fashion a vertical price premium of 1,5% is found for each consecutive relative floor level. Both of these percentages indicate a strong relationship between both absolute and relative floor level height and willingness to pay for height effects such as view and status.

Figure A – Price premium coefficient per floor level



To identify the heights where these price premiums occur within a tall building, price premiums per floor level are plotted in figure A, indicating highly volatile and non-monotonic price premiums per floor in comparison to the 1st floor baseline. A dip between floor two and six can be seen confirming the literature's theory of a reduced willingness to pay for low level floors which hardly offer amenities such as view and status while accessibility decreases. A negative coefficient is observed on the ground floor which suggests the observed office sectors are not willing to pay more money for direct accessibility. As a significant pattern within figure A is difficult to observe, floor levels are grouped in brackets of 5. A non-monotonic trend is identified in figure B, suggesting a progressive trend up to floor level 25th, after which the trend becomes regressive.

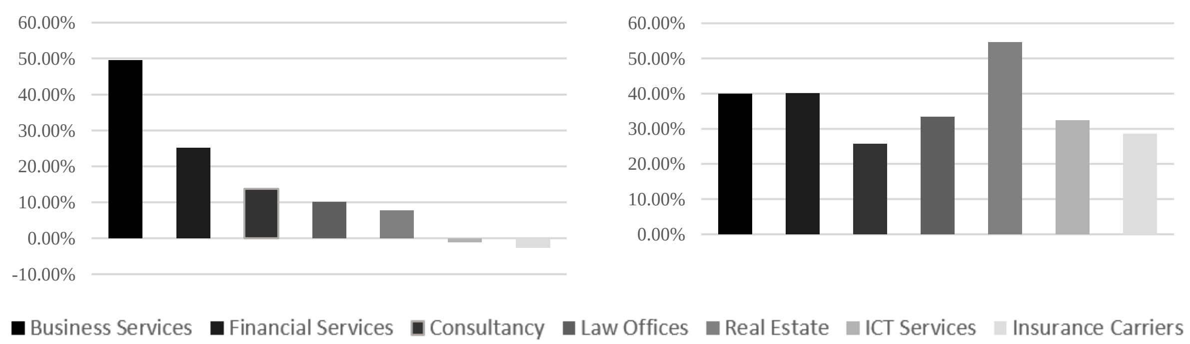
Figure B – Price premium coefficient per floor level bracket



The regressive pattern after floor 25 could indicate a turning point in terms of rent premiums where the trade-off between amenities and accessibility diminishes and the cost of transportation to the highest floors outweigh the benefits that view and status offer. Additionally, the highest floors within tall buildings hold significantly larger tenants in terms of floor space. Large tenants have a better negotiation position compared to smaller tenants due to their importance for within-building agglomeration effects. The coefficients in the highest floors of a building are to be treated with care due to the significantly lower sample sizes compared to other floor brackets.

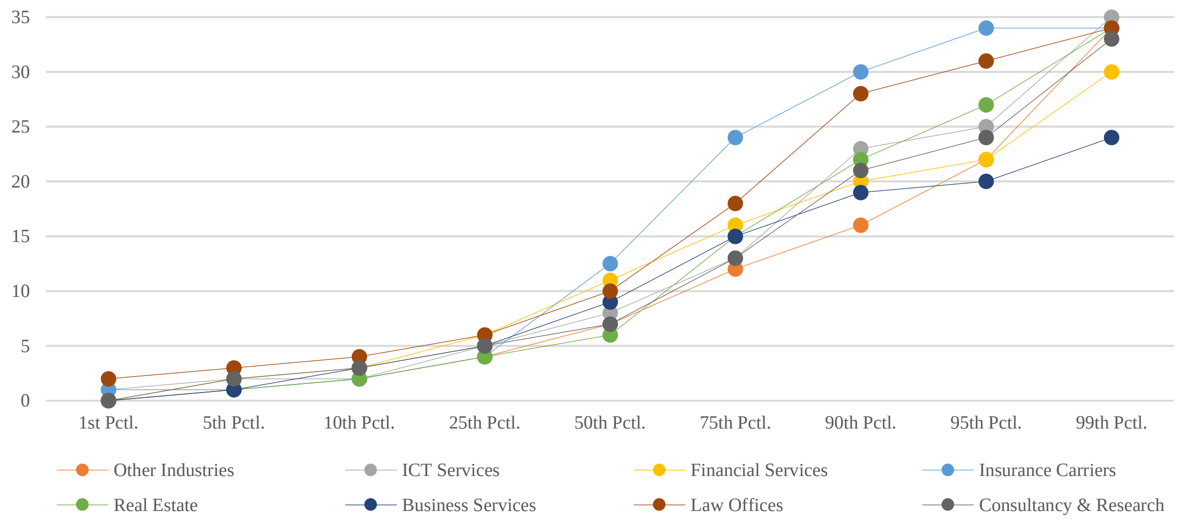
Figure C shows an overview of the percentage that a certain sector is willing to pay more to locate higher in terms of absolute and relative height respectively, in a building compared to the other industries baseline. The results indicate a difference between sectors ranging from 49,6% to -2,6% in terms of absolute height and 54,7% to 25,8% for relative height. All analysed industries are more willing to pay more for relative height while there are significant differences between sectors for absolute height. As the transaction samples are not divided evenly between sectors, the results should be treated with care.

Figure C - Sector comparison in terms of rent for highest floor and relative height respectively



Insurance carriers and law offices tend to locate higher within a building. Figure D illustrates the differences in floor levels per sector divided in percentiles, indicating the significant differences between insurance & law offices and the other analysed industries starting from the 50th and 75th percentile. A similar pattern where these two sectors differentiate themselves from the others is also seen when relative height is considered. An additional observation is concluded where ICT services, insurance carriers and law offices have no rental transaction on the ground floor whatsoever, indicating a search for privacy or status.

Figure D - Vertical location in terms of floor per sectors divided in percentiles



Finally, a significant, but not robust elasticity between the models is found between the floor levels and productivity, indicating that tenants who have more revenue per employee locate higher within a building. The observation where, as productivity increases by 1%, the floor level increases by 4,8%, is a confirmation of previous research and literature where firms who have a higher productivity value have an increased willingness to pay for height.

Preface

The master thesis presented within this document signals the end of the master track and my graduation from the TU Delft. This research is conducted within the Real Estate Management domain which is a part of the Management in the Built Environment master track and is the final assignment before I am able to receive the master's degree for which I have been working the past two years. A journey which started two and a half years ago in a pre-master track in a new to me city and an even newer academical environment.

The broad topic of this report, tall buildings, has been a general interest for me for as long as I can remember. The relatively low quantity of tall buildings in The Netherlands has maybe even been an extra driving force within this interest as I have hardly seen any actual, world renowned, tall buildings in real life. Starting from an interest and curiosity which I have had for as long as I can remember, has finally evolved into the final chapter of my educational career. This conclusion to this phase of my life with the topic of real estate is also the start of a professional career in the same field. A first taste of this new phase was the internship which helped me throughout this process.

A contribution is made to the topic of urban economics through this research, with a focus on tall buildings. A relatively new section within the vast body of knowledge of urban economics gave me the opportunity to find my own specific piece of interest and truly generate results which are applicable in real life. This aspect of applicability was one of my main motivators and interests as the data that was gathered and the results that are generated come from actual patterns which can be observed in real life. The two topics within this research, tall buildings and the economic functioning of the real estate world were perfectly combined with the statistical, quantitative, approach that I wanted to investigate further. The quantitative aspect of this research is something that I indicated to my first mentor from the very first moment the graduation process started. I wanted to do something with numbers. The little experience I have had with data and data analysis intrigued me to investigate and, more importantly, understand it further. If I look back at the start of the graduation process, at the daunting wall which was statistics and SPSS, I feel accomplished to understand a tiny margin of the field.

This accomplishment, however, is not only due to my own interest and work. I would first like to thank my first mentor, Ilir Nase, explicitly for not only guiding me throughout the graduation process but also for being open to questions. During the graduation process, he was always available to help me when I got stuck, especially by having several one on one sessions for a crash course on the applicable aspects of statistics. This was especially helpful as the past few months have been quite an endeavour, with the introduction of the COVID-19 virus during the graduation process. This event resulted in me having to do the internship from home after five weeks and the continuation of graduation from my ten square meter room at home. I would like to thanks my family, friends, roommates and loved ones for their support and interest during this dull period of sitting at home for months on end. Secondly, I would like to thanks my second mentor, Peter de Jong, for his guidance throughout the process but more importantly for his comments which made me zoom out from the detailed topic of my study. As I was working on the research I noticed my focus was only on the specific building types without grasping the entirety of the scope of the research. This helped me especially during the writing of my conclusions, discussion and recommendations for future research.

Finally I would like to thank my external mentors and colleagues at Cushman & Wakefield. During the few weeks I worked in the office I could really experience what the working life would file like after graduation. The involvement and interest of my colleagues and mentors specifically were really helpful. First I would like to thanks Bas Kamperman, who was my initial mentor during the first few weeks who helped me get settled and involved me into the day to day routine within the company. As Bas left Cushman & Wakefield two weeks before the COVID-19 virus forced the office to close, Mark Berlee became my external mentor. Despite not having the possibility to meet eye to eye, I would like to thanks Mark for his involvement and his willingness to help and connect to the right people within the company. This brings me to my final thanks, the research department within Cushman & Wakefield, Bas Hilgers and Nick van Assendelft, specifically. Thanks to the research department the data gathering process, which started as an impossible task within the timeframe, became possible by providing me with tools which sped up the data gathering process tremendously. Without these tools I would still be gathering the correct data as I am writing this, so to speak.

Daan Hinlopen
Duivendrecht, 2020

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Introduction

The introduction of this graduation research explains both the general topic of tall buildings and the economics behind these tall buildings. The first chapter explains the background as well as the different contexts of the topic. A general overview of the topic is then summarized into a problem statement from which the research questions can be formulated at the end of the chapter. Section 1.1 introduces the research with a background of the research topic which provides a context for the rest of the research. Section 1.2 then explains the different kinds of problems that are faced within the research topic. Section 1.3 goes into detail about the relevance of this research. This relevance is divided into scientific relevance and social relevance. Finally, in section 1.4 the main and sub questions as well as the hypotheses for this research are presented.

1.1 Background of tall buildings

Skyscrapers cannot only be considered tall buildings, these buildings, which combined, create a skyline of a city are symbols while also being works of art. These buildings are used as a means to announce the economic strength of a city throughout the world and to show the rest of the world what they are capable of (Barr J. , 2012). Liu, Rosenthal & Strange (2018) categorize them as small cities in terms of scale as the largest examples have the same square meters equivalent to a small town. However, this categorization cannot be made in terms of functionality and mobility. With a main entrance and vertical transportation through elevators a bottleneck is created that creates a lack of interactivity between different parts of a high-rise building.

These tall buildings all have an effect on a city because they reshape the skyline of a city (Ali & Al-Kodmany, 2012). In the current modern world, skyscrapers are becoming a familiar sight and are also seen as areas where rents are significantly higher (Koster, van Ommeren, & Rietveld, 2014). Tall buildings can be considered a strategic component in urban development for cities in the search for prestige and status to stakeholders which are influenced by economic cycles and regulations (Barr J. , 2012). This can be seen ever since the first tall buildings were being built, the building height has an importance for the builders that goes beyond the value of the building or the height of the lease contracts (Helsley & Strange, 2008). The exact height of these buildings is heavily influenced by the drive for status by these stakeholders such as investors, cities and developers. Not only the height of the building itself but also the relative height compared to other buildings seems to be important to skyscraper builders and developers. Building the tallest building created an additional value that was not connected to the standalone value as a real estate property (Helsley & Strange, 2008). Skyscraper builders react to building heights nearby or buildings built in recent history while starting up new developments by responding with a taller building (Barr J. , 2012).

When looking at the development of buildings in general a developer makes the calculation of expected income versus expenses in order to create a profit for their business in the end. Because of their size and complexity these tall buildings are of enormous subject to risks or political influences such as policies or restrictions. The development costs are vital in the equation of profit so therefore, understanding them is essential. Especially since the building cost per square meter floor area increases with 0.8% per floor level (De Jong, van Oss, & Wamelink, 2007). De Jong et al (2007) also conclude that, different compared to low-rise projects, the earning capacity of a high-rise project is directly related to the efficiency in which the floor plans are designed. This is, more specifically found in the relation between the gross floor area and the lettable floor area of a high-rise building. Tall buildings face challenges in the relation between the Gross Floor Area (GFA) and Lettable Floor Area (LFA) because the higher buildings go, the more GFA is needed for construction and installations, resulting in less LFA (Van Oss, 2007) which generates the income from a building. Also, when revenues are being considered in the equation these increasing building costs, therefore, need to be offset by an increase in income to make these expensive high-rise developments feasible in terms of profit. Nonetheless, the number of skyscrapers on a global level are growing at a significant rate. Business services has replaced the manufacturing industry as the primary business industry within cities (Liu, Rosenthal, & Strange, 2018).

1.1.1 Development context

The topic of urban agglomerations and urbanization is becoming more and more important as more than fifty percent of the world population lives in an urban environment such as cities (Glaeser & Gottlieb, 2009). This increasing number of people in our cities put pressure on these urban environments and cause them to become denser. The cities' density as a result of a growing world-, as well as urban population creates a certain pressure to accommodate these people in the existing urban environment. As cities have an optimal horizontal scale, expanding cities vertically by building taller buildings becomes a solution to maintain the limitations of expanding cities on a horizontal scale (Ali & Al-Kodmany, 2012) and therefore accommodate the people in a city. Housing an office in such a tall building also has benefits to the user due to agglomeration economies such as increased productivity (Buchanan, 2008).

The importance of tall buildings within our society is emphasized by Ali & Al-Kodmany (2012) by stating that they are becoming a more important part in our lives. Tall building design has shifted since the 1990s from an economic focus to a more sustainable and economic design focus. This resulted in a boom of high-rise buildings where eight out of ten skyscrapers have been built since the year 2000 (Emporis, n.d.). Nowadays, modern central business districts are known and are recognized by the presence of high-rise buildings with an office function. The presence of these buildings can, however, not be explained by existing urban economic models that focus on the horizontal aspect of a city (Koster, van Ommeren, & Rietveld, 2014).

1.1.2 Tall buildings in The Netherlands

Similar to the trends of urbanization as mentioned before, The Netherlands is also dealing with an increasing density in urban areas. More and more people are moving to large cities and the countries' population is growing. In an estimation a population growth of almost one million new Dutch citizens is expected in 2035 with almost

750.000 of those located in municipalities that have more than 100.000 inhabitants. Of these nearly one million citizens the largest growth is expected in the G4 (Amsterdam, Rotterdam, The Hague and Utrecht (CBS, 2016). Amsterdam is expected to become the first city in The Netherlands with one million inhabitants with an expected growth of twenty percent compared to 2019. The other three cities in the G4 are estimated to grow by 15-20% (RLTZ, 2019). Within these cities, the definition of tall buildings or high-rise is extremely contextual. In The Netherlands, there are numerous different definitions of high-rise buildings, however, the Dutch Building Code states that whenever a building is taller than 70 meters it checks the criteria of an high-rise building (Rijksoverheid, 2019). Additional to the height of a building the Dutch Building Code also states that whenever a building is required to have an elevator, which is above five floors, it can be considered high-rise. The importance of context for high-rise buildings is also stressed by the CTBUH (2019) as the surroundings of a building determine whether something can be called high rise. For instance, a building that is fourteen stories tall may not be tall in American cities such as New York or cities in Asia such as Hong Kong but might be considered tall in cities such as Amsterdam due to a difference in the norm of a city. Additionally, Amsterdam and Utrecht's city centres are restricted in terms of legislation. This also limits the construction of new high-rise buildings significantly. This is completely different in Rotterdam which is the only Dutch city with an 'American style' city centre with high-rise due to World War II bombings (Koster, van Ommeren, & Rietveld, 2014).

This difference in context even exists on a more national scale within The Netherlands. Different cities have different definition for what they would specify as high-rise. In Amsterdam, for instance, anything that is 30 meters or above or is twice the height of the buildings in the direct vicinity can be categorized as high-rise which are then divided into three categories of 30-60 meters, 60-100 meters and 100-150 meters (Gemeente Amsterdam, 2011). This is different in a city like The Hague where high-rise is categorized as a building which is above 50 meters tall (Gemeente Den Haag, 2017). Finally, the municipality of Rotterdam considers high-rise when a building is taller than 70 meters (Gemeente Rotterdam, 2011). These policy documents of the cities are subject to change while higher and higher buildings are being built in the three largest cities of The Netherlands. These major cities are choosing for high-rise buildings because of a shrinking supply of space. Cities are building more concentrated and denser but are also attempting to create landmarks for the skyline of the cities (NRC, 2018). In history, tall buildings were both competing in an urban environment for a regional competition in industry growth and a competition between the builders and developers of these tall buildings (Barr J. , 2013).

The policies within these cities differ in ambition for the amount and location of high-rise buildings. As Rotterdam aims to make the city centre more dense more and more tall buildings will be built to meet the increase in demands of dwellings within the city. The city strives to transform from a city with a single city centre to a more polycentric city with multiple areas of densification through high-rise (Gemeente Rotterdam, 2019). The approach to densification is also found within the policy documents of Amsterdam. A more intense use of land is a vital aspect of creating both a sustainably designed and economically strong city. Although high-rise is not the only method for intensification of land use, it is a very appropriate one. In the city, the areas next to major logistical hubs are designated to the development of high-rise (Gemeente Amsterdam, 2011). The Hague describes a similar approach where all high-rise is focussed around public transport hubs or near areas where amenities and services are clustered. This approach is used to meet the city's goal of connecting the skyline of The Hague to the quality of living within the city. High-rise in itself is not a goal that a city has on its own, but is a means to strategically use the available area in The Hague (Gemeente Den Haag, 2017).

In a more national context, eight out of the ten tallest buildings in The Netherlands are constructed after the year 2000 (The Skyscraper Centre, n.d.). In table 1.1, an overview of these buildings is shown.

	Building Name	City	Height (m)	Floors	Completion	Function
1	Maastoren	Rotterdam	164.8	44	2010	Office
2	Gebouw Delfste Poort 1	Rotterdam	151.4	41	1991	Office
3	De Rotterdam	Rotterdam	151.3	45	2013	Mixed use
4	Rembrandt Tower	Amsterdam	150	35	1995	Office
5	Millennium Tower	Rotterdam	149	34	2000	Mixed use
6	Ministerie van Binnenlandse Zaken	The Hague	146	37	2012	Office
6	Ministerie van Justitie	The Hague	146	37	2012	Office
8	Hoftoren	The Hague	141.9	29	2003	Office
9	World Port Center	Rotterdam	133.6	38	2001	Office
10	First Rotterdam	Rotterdam	128.2	32	2015	Office

Table 1.1 - Ten tallest buildings in The Netherlands (The Skyscraper Centre, n.d.)

The ten tallest buildings are all located in the three largest cities of The Netherlands. However, Rotterdam has significantly more tall buildings than The Hague and Rotterdam. This pattern also continues when all tall buildings in The Netherlands are considered. Rotterdam has significantly more tall buildings than Amsterdam, The Hague and the rest of The Netherlands. Fourteen percent of the tall building stock which is recorded by the Council of Tall Buildings and Urban Habitat (UCTBH) is over a hundred meters tall (Van Assendelft, 2017). 47% of these tall buildings over 40 meters are office buildings while 42% can be considered mostly residential buildings.

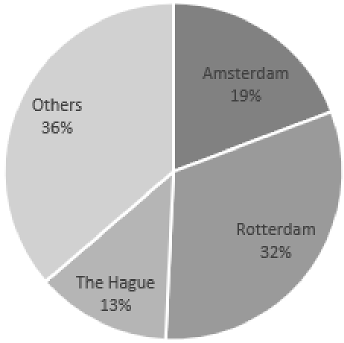

Figure 1.1 - Division of tall buildings (The Skyscraper Centre, n.d.)

1.2 Problem statement

Many different studies have been conducted on the benefits and downsides of building tall buildings and the reason why they are built by looking at not only their role as pieces of art and architecture, but also by focussing on tall building's technological, sustainable and evolving nature (Ali & Al-Kodmany, 2012). Within the topic of tall buildings, countless questions can be asked in order to understand tall buildings and the reasons behind tall buildings. This focus on tall buildings has come after decades of studies in horizontal patterns of developments in an urban area while the vertical patterns in these urban environments were mostly ignored. This shift from a horizontal to a vertical focus is illustrated in Van Assendelft (2017). Additionally, the increasing density of the cities due to agglomeration economies require a solution which stops the horizontal expansion of cities (Ali & Al-Kodmany, 2012). The increase in development of tall buildings is also influenced by the land scarcity created by the agglomeration and the increase in cost of land (Helsley & Strange, 2008).

Understanding the economics behind these tall buildings can give answers to problems that are stated in previous studies. The concept of price premiums, where rental or transaction prices increase per floor levels create a problem for developers as the cost increase per floor level, at some point, outweighs the income that can be gathered from a development. This balance could create buildings which are too tall in economic sense (Barr J. , 2012). These buildings that are not economically feasible because of their height could be the result where tall building builders or developers use these buildings to boost their egos in order to create an image of themselves and their corporations to the outside world (Helsley & Strange, 2008).

Recent studies by (Koster, van Ommeren, & Rietveld, 2014; van Assendelft, 2017; Liu, Rosenthal, & Strange, 2018; Nase, van Assendelft, & Remøy, 2019), however, indicate that the floor levels play a role in price premiums per floor level. The literature on these price premiums is emerging but still has limited observations and is limited in comparisons between these observations and contexts. Research within The Netherlands by Koster et al. (2014) has also shown that rent premiums increase by 4.0% per 10-meter increase of office building height. Research in the United States has resulted in a non-monotonic rent gradient which rises by 0.58% to 0.82% per floor level which increased up to 1.6-6.2% for stories higher than the 60th floor (Liu, Rosenthal, & Strange, 2018). The same researches have also researched the influence of productivity on vertical sorting. In this sense, productivity is defined as revenue per employee. Initial research that focussed on productivity concludes that, in fact, productivity does influence vertical sorting. More productive companies are more often located towards the top of a building while less productive companies are located lower in a building (Liu, Rosenthal, & Strange, 2018). These conclusions, however, are studied in a single context which limits the applicability of the results.

Regardless, these results all indicate that the theme of verticality is an interesting topic within urban economics. The subject of tall buildings within this topic of urban economics is also important as these buildings have a major role in urban environments and in a city's skyline because the functional lifespan of a building is over a hundred years (Van Assendelft, 2017). Literature focussed on agglomeration has proven that nearby employment in an area, in most cases, increase the productivity of a business as they are able to attract more skilled labour and participate in knowledge spill over. This literature, however, has only focussed on a horizontal scale, while leaving a gap on the vertical scale within buildings (Liu, Rosenthal, & Strange, 2018). The topic of rent premiums, vertical sorting in connection to productivity is embryotic but there is room for improvement, especially by researching different contexts and analysing these contexts with each other.

1.3 Relevance

The relevance of this research is divided into two different points of view. The scientific relevance offers insight in how the research fills a gap in existing knowledge while the social relevance section explains the benefits the outcomes of this research offer for the relevant stakeholders.

1.3.1 Scientific

The focus of this research is to gain more insight and improve the economic model theory of tall buildings with a goal of profit maximization for involved stakeholders. Through the identification of rent premiums, vertical sorting patterns and the relationship with tenant specific characteristics could yield benefits on both the demand and supply side of office space. Data on the vertical location is becoming more readily available which makes the data collection within this study possible. The focus on improving the economic model theory results in the scientific point of view becoming significantly more relevant compared to the social relevance of this study.

In previous research Koster et al. (2014) have identified that there is a relation between renters' willingness to pay (WTP) and the height of a building. This positive relation results in a 4% increase of price per square meter for every 10 meters of building height. This positive relation, however, might not only exist on a building height level but also on a floor height level where price premiums could be identified per floor level in a tall building. This research expands existing research by extending the existing knowledge on vertical sorting and rent premiums by increasing empirical data and researching a generalization of patterns within The Netherlands (Van Assendelft, 2017). This research, furthermore, expands current knowledge by investigating the height of floors with a relation to the height restrictions throughout different cities in The Netherlands. Current literature mostly focuses on the investigation for price premiums on building height (Koster, van Ommeren, & Rietveld, 2014) or price premiums and vertical sorting with a single context (Van Assendelft, 2017).

While horizontal patterns in urban contexts have been researched for several decades, the vertical workings of these urban patterns remain ignored on a larger scale (Liu, Rosenthal, & Strange, 2018). The understanding of different vertical height locations within high-rise building has room for improvement. Because of this, it is relatively unknown what sorts businesses into different locations of a building, how this affects rent levels (Liu, Rosenthal, & Strange, 2018) but also what and how there are differences between cities. Urban economics continue to grow into a vertical direction which asks for a better understanding of this vertical organization within office buildings (Liu, Rosenthal, & Strange, 2018). As the connection between productivity and location in tall buildings has been proven by Liu et al. (2018) in the context of the United States, more knowledge can be gathered to see whether these connections are reoccurring throughout the world.

1.3.2 Social

With more than fifty percent of the world's population living in urban environments, urbanization is becoming more common (Glaeser & Gottlieb, 2009). This urbanization with increasing city sizes as a result puts stress on the urban environment as they are becoming more and more dense. Cities in an already dense country such as The Netherlands are facing problems where expansion on a horizontal level is becoming increasingly difficult. Eight out of ten of the tallest buildings in The Netherlands are created in, or after, the year 2000 (The Skyscraper Centre, n.d.). These high-rise buildings could have positive effects but also create social concerns. By understanding tall buildings cities could be allowed to optimize the way that urban plots are used (De Jong, van Oss, & Wamelink, 2007). The research could prove to beneficial from a social perspective as the understand of supply of height could be translated to the high-rise visions of cities. Therefore, this research provides insights into the economics of tall buildings and their role within the existing and future urban environment. As economies are growing and evolving at a tremendous rate, the demand for knowledge on the organization on a vertical level within these urban areas and, more specifically, the office sector will grow (Liu, Rosenthal, & Strange, 2018).

1.4 Research questions

The main research question is derived from the problem statement which is presented in section 1.2. The relevance of the research is explained in section 1.3. These two sections together form the main objective of the research which is translated into the main research question. The main research question is as follows:

What is the interrelationship between price premiums per floor level, vertical sorting and productivity of firms in multi-tenant office buildings in the three largest cities (Amsterdam, Rotterdam & The Hague) of the Netherlands?

The following sub-questions are formulated to help answer the main question of this research:

- What are the determinants of building height?
- How can the interrelationship between productivity, price premium and vertical sorting per rental transaction be determined through a model?
- How do different the different tenant sectors affect vertical price premiums within the three cities?

1.5 Research focus and output

As can be seen in table 1.1, primarily office functions are shown as it indicates the focus of this study. The percentage of office functions within the tall building stock in The Netherlands is only slightly higher than residential functions, however, a focus is put on office functions. This focus is emphasized by studying the vertical sorting of tenants in depth while excluding external factors that could be brought in by different functions. As different functions have different reasons to locate within a building, the limitation to focus on a singular function is made to generate more accurate results. The available timeframe for the study also results in limited possibilities of analysis in terms of functions. As the possibility to gather data is limited to a single private source, which is explained in section 1.6, the choice to focus on a single building type is strengthened.

The main research output of this study is providing knowledge towards the field of economic of tall buildings which focuses on the behaviour of tenants in multi-tenant office buildings. The field is emerging but still demands more information, especially information from different contexts or cases. The goal of this research is to analyse tall buildings on a deeper level by researching the relationships between productivity and vertical sorting as well as rent premiums. Additionally, by analysing three different contexts more information and conclusions can be gathered that give insight in the applicability of the conclusions in different cities.

The deliverable of this research will be answers to the research questions with a quantitative focus. The database that will be expanded is also one of the main deliverables of this research. With this research extra knowledge will be created within the field of price premiums and vertical sorting. Additionally, the database that is created combines information that is relevant to the field and can be used for further analysis and research. The aim of this research is the improving of the theoretic economic model regarding tenants in tall buildings. Through the quantitative analysis on this topic, the theoretic economic model can be better understood and possibly improved in future research. The better understanding of the demand side of office space in tall buildings could also prove to be beneficial for cities in their policies and visions regarding high-rise. The output of this research is applicable both in a theoretical and a practical point of view. The knowledge gathered from this research can be used as starting points for future research while directly applicable information can be used by stakeholders that are involved in the creation of tall buildings.

1.6 Graduation company

The research for this thesis is performed at Cushman & Wakefield, primarily in the Amsterdam office. Cushman & Wakefield performs global real estate activities as a broker by providing various services to clients such as occupiers, investors, tenants and others. Cushman & Wakefield operates on a global level with around 53.000 employees and is the market leader in office transactions and valuations. The internship within the graduation period is undertaken in the Valuation & Advisory team.

1.7 Readers guide

The first chapter of this research presents an introduction to the topic of tall buildings and the problems that are relevant within the field of study and in practice. This background and problem statement is then translated into research questions. The scientific and social relevance as well as the research output are explained in this chapter. Chapter 2 sketches the theoretic framework which comes forth from the introduction. In this chapter prevalent theory is discussed and divided into a supply and demand of height section. Topics such as determinants for building height, rent premiums and vertical sorting are discussed in this chapter. The methodology of the research is presented in chapter 3 and covers the research approach, methods and phases that are used. The process of data collection, the design of the regression analysis and descriptive statistics are also discussed in the third chapter. The empirical analysis chapter, which is chapter 4, goes into depth on the results of the statistical analysis through the designed regression model. In the first part of the chapter the dataset analysis is discussed, followed by an in-depth multiple regression analysis. The results from these analysis are presented in chapter 5, supplemented with a conclusion and discussion. The limitations and recommendations towards further research is also presented in the final chapter.

1.8 Summary

In the introduction chapter to the research a context is presented on the topic of tall buildings. Section 1.1 illustrates a background of tall buildings on the largest possible scale. Within the section a more national context is also presented by looking at tall buildings in The Netherlands itself. Following the introduction on a global and national context, the problem statement is defined in section 1.2 which describes the exact challenges that are present within this field of study. As the number of tall buildings being built is steadily increasing, more knowledge is required to understand these buildings. Rent premiums per floor level are proven to be significant in previously conducted research, however these results are limited in terms of quantity and context. Section 1.3 shows both the scientific and social relevance of the study. As the study aims to improve the theoretic economic model of these tall buildings from a better understanding on the supply side of office space within these buildings, the study has a significant focus on scientific relevance. The research output in the form of a database and more insight and knowledge towards the improving of the existing theoretical economic model of tall buildings is described in section 1.5. Section 1.6 covers the graduation company of Cushman & Wakefield in Amsterdam while section 1.7 provides a readers guide towards the rest of the research.

2

Theoretic framework

The second chapter of this research goes into further detail about some of the aspects in the field of urban economics by looking at literature. The topics within this framework are divided into the categories of supply and demand of height. Section 2.1 of this research covers the literature on the supply of height and section 2.2 covers the demand of height. This is supplemented with a brief coverage of construction costs within tall buildings in section 2.3. Section 2.4 then presents a conclusion on the covered literature.

2.1 Supply of height

In the first part of the theoretic framework, the supply of height will be considered. Through literature by the likes of Helsey & Strange (2008); Barr (2010); Barr (2012); Barr (2013) an analysis is made on why tall buildings are built, and what factors contribute to the exact height and their height respective to other buildings.

2.1.1 General economics of the real estate markets

The real estate market is a unique one as it has characteristics such as being highly heterogeneous. The leading theory, the neoclassical theory for markets is characterized that transparency and provision of information are the key factors leading to a well-functioning market where prices are determined for goods and services by the equilibrium between supply and demand. This theory is based on the principle of a ‘perfect market’ which is characterized by being an open market with perfect competition combined with the unobstructed functioning of the specific market (Boots, 2014). The aforementioned characteristics confirm the peculiarities of the market when they are compared with the fundamentals for perfect market conditions.

The real estate market in general is both, an imperfect and in-efficient market due to various reasons. In a perfect market, products would have no differences between one and another. In the case of the real estate market this is significantly different as no object of real estate is the same. However, the real estate market is also peculiar as there are various sub-markets, such as offices or residential dwellings, which create a segmented structure (Boots, 2014). A lack of transparency is another factor leading to an imperfect market which also disrupts the market working in its optimum form (Boots, 2014) this transparency also leads to an in-efficient market as the information is not distributed symmetrically to the different actors in the market. This leads to one side of the market being more informed which results in a knowledge advantage towards one party (Barr N. , 2012). High transaction costs are a direct result to the asymmetric distribution of information as high costs are made to gain full-knowledge about the market (Boots, 2014). These factors lead to the real estate market being a product-differentiated market (DiPasquale & Wheaton, 1996) in which products are not frequently traded (Shapiro, Mackmin, & Sams, 2019).

Informational asymmetries, lack of information, costly acquisition of tenants and transaction cost are the main factors that contribute to the disruptions of the open-market real estate model (Van Assendelft, 2017).

The economics of verticality

As has been mentioned before in this study, the vertical patterns within commercial real estate have been largely ignored. As studies on horizontal patterns started with Alonso (1964), Mills (1967) and Muth (1969) through the monocentric city model, which is analysed in the next section. The pattern of vertical sorting is much less researched (Liu, Rosenthal, & Strange, 2018). However, as cities are becoming less and less flat due to factors such as urbanisation, the vertical dimension becomes more important (Westerhuis, 2018).

Liu et al. (2018) introduce these economics in verticality by treating each building as a city which is long and narrow. In the core of their model lies, firstly, the vertical transportation costs, which imply the costs that people make to access streets and secondly, the vertical amenities. Both increase as one moves up within a building. These costs made from the transportation within a building are significant as a tenant within a building typically waits about 22 minutes per day by waiting for an elevator (Liu, Rosenthal, & Strange, 2018) which result in major costs. These transportation costs, however, fits the analogy of Liu et al. (2018) by representing buildings as long, narrow cities. In these cities people usually also travel, but on a horizontal scale, which also bears transportation costs. In section 2.1.2 the determinants will be discussed which goes into more detail about the exact effects and results of the verticality of these buildings.

Monocentric city model

The monocentric city model is a model that is originally designed by Alonso (1964) and later adapted and expanded with features such as housing, transport and production by Mills (1967) and Muth (1969). It's importance, at the time, is expressed heavily as it is considered to be one of the most influential ideas about urban structures in a long period of time (Anas, Arnott, & Small, 1998). The model in itself is a descriptive model that shows the allocation of resources within a city and explains this in a more theoretical model (Kraus, 2006) while giving insights about the interaction between markets within a city (Liu, Rosenthal, & Strange, 2018). The output of this model is a degree of measurement in terms of centralization to compare different cities on an empirical level (Anas, Arnott, & Small, 1998).

The model assumes a circularly shaped city that is located on a site that is featureless, flat and empty. It also assumes that all employment within this city takes place at the very centre of this theoretical circle which is called the central business district (CBD). This CBD is seen as a single point within this city. The presented has inhabitants which are assumed to make one round trip per day towards the CBD where he works and receives wage. Finally, the further someone lives away from the CBD the greater the cost of commute towards this centre (Kraus, 2006). For businesses, the decision where to locate within such a city comes from a debate between a desire for location and the costs that are connected to the commute to this location. In these calculations, transportations costs, in terms of distance to a consumption market, are added to the production costs of a firm to determine the most profitable location a firm can get (Garza & Lizieri, 2016).

The model also assumes that rents increase when you get closer to the CBD and recline going outwards towards the suburbs (Geltner, Miller, Clayton, & Eichholtz, 2001). Additionally, the model assumes that all firms are all competing to get the most productive land within the CBD. The increased costs for these central sites are meant to be offset by productivity advantages (Rosen, 1978). The most central plots become even higher in value as high prices stimulate a more densely build plot. This results in developers bidding up the prices (Ahlfeldt & McMillen, 2015).

Since the time of the creation of the model there has been criticism on the functioning as the model as cities have become more and more polycentric, meaning that there is not just one city centre or even CBD in a city. Critics claim the model is outdated as it represents city from a different era. However, Kraus (2006) argues that, even in current time, there still lies value in the thoughts within this model. He argues that, even though, cities have changed drastically, there are still urban areas where this model is still directly applicable. Kraus also argues that in order to understand the polycentric cities, the monocentric city model is a good way to start to understand the economic forces that operate within these cities. Understanding these forces within monocentric cities is a crucial part of understanding the polycentric cities which could be more of this era (Kraus, 2006).

Cities such as New York and Hong Kong still resemble a more monocentric urban form, but most cities are losing the resemblance to the standard form and are shifting towards a polycentric form (Jennen & Brounen, 2009). Cities have been spreading out for many years which has resulted in decentralization and a more polycentric form. Multiple employment centres are created within a city which also result in different population distributions (Anas, Arnott, & Small, 1998). An important factor leading to this change in urban structure from monocentric to polycentric is due to a changing dynamic between firms. Technological innovations, deregulations and competition on a global scale have resulted in a change in the spatial organizations of businesses (Anas, Arnott, & Small, 1998).

2.1.2 Determinants for building height

One of the most iconic skyscrapers at the time it was build and today is The Empire State Building (ESB). With its pointy top it is similar to many other tall buildings as developers would use this shape to ensure their building was the tallest. During the time of the construction of the ESB, developers would have a competitive drive to be the tallest. The value of the building was no longer determined by the equation of profit minus costs, but more value would be given towards being the tallest building in both the world and its surrounding (Helsley & Strange, 2008)

However, this competitive atmosphere that was created also resulted in risks. This risk eventually gave the ESB the nickname *Empty State Building* as, at one point, it had 40 vacant floors during periods of economic downturn (Helsley & Strange, 2008). This drive, however, was also present during periods of economic upturn. Developers would start to look at buildings in their existing stock to see whether they could add floors to get back the title of having the tallest building. This battle towards this title would result in financial losses for developers which they were willing to accept as the profits no longer exceeded the costs. The United States held the title and image for building the tallest buildings for a long time. In the 1990s this title was lost to the Asian market. Towers kept getting taller in quest towards being the tallest where the current tallest building is 828 meters tall (Helsley & Strange, 2008). This trend has been continuing as the average height of the top 100 buildings has been increasing significantly over the period of 2001-2016 (Van Assendelft, 2017)

The average building height in 2001 was 286 meters while this grew by approximately 100 meters in 2016. However, as can be seen in the graph, the average height of buildings constructed each year over this period has not increased. The graph also does not show any global impacts that could impact the built meters in a specific year.

There are several aspects that determine the height of a building. The first height determinant in literature is the *status* aspect, which is discussed in the previous section. Tall buildings can be seen as a tool to signal strength in an economic sense of a developer, governmental entity or firm. This results into status becoming an important strategic aspect within the development of tall buildings (Barr J. , 2012). In one of the earliest studies concentrating on the subject, tall buildings and building height were merely seen as a way to *optimize profits* (Clark & Kingston, 1930).

In a more recent study, however, Barr (2010) argues that the height of a building is determined, essentially, by local and national economic factors, land use regulations and taxation. He emphasizes that the context around a building is important in the determination of building height. In his research in 2010 he finds no evidence that status or ego contribute to the drive of developers to build taller buildings. This concludes that his results support the theory of profit maximization. The quest towards receiving the status of building the tallest buildings is only the result of the combination of profit maximization and ego which does not happen unless the opportunity cost is low at that moment in time (Barr J. , 2010).

After this research Barr (2012) finds evidence that supports the status theory. The desire for status increased the height of buildings by fifteen floors on average. When opportunity costs are low, i.e. during times of economic growth, the drive towards being the tallest becomes significant. *Contextual factors* in the likes of land regulation and economic factors also have determine the height of a building. Additionally, builders also look at their direct surroundings and are influenced by the objects that are newly built in the direct vicinity of a new development (Barr J. , 2012).

Every city tends to have a different image in terms of building height due to these contextual, political and economic factors. Each city also responds in a different way to general economic events from the perspective of supply and demand. Cities like Amsterdam and Rotterdam are very different in terms of building height because they are influenced by these contextual factors (Van Assendelft, 2017).

Height can be seen as something that gives value to a developer or end-user while it can also be traded. Occupants, on the other hand see height as something that could give them a view or status. These two factors contribute to an increase in demand for offices that have these views or give status. This increase in demand, in turn increases the rental prices of these properties. In the end, a developer has to make a strategic decision where he finds a balance between the income that is projected from a building versus the costs he has to make to deliver these values (Barr J. , 2012).

2.1.3 Building height in economic theories

Literature regarding tall buildings and high-rise have been categorized into four different theoretical approaches by Garza & Lizieri (2016). Four categories can be made to separate height determinants for tall buildings (Garza & Lizieri, 2016): *Traditional microeconomic model, Game theoretic approach, Business cycles & Global cities*. The theories that the authors have summarized all analyse different researches conducted on the tall buildings and height determinants field.

The monocentric city model is a central feature within the traditional microeconomic model. Within this model, prices increase on real estate as someone travels further from the CBD. Prices increase towards the inner circles of the CBD as firms compete to be as close as possible to the centre. The scarcity of these locations and the number of demanding firms result in these price increases. Within the traditional microeconomic model, building height increases as the economic activity in such a city increases. Thus, resulting in the conclusion that the tallest buildings should stand in the cities with the most activity in an economical sense (Garza & Lizieri, 2016)

The game theoretic approach puts focus on the competitiveness between developers for building the tallest building in the world (Garza & Lizieri, 2016). The ego and status that developers seek is the main factor that contributes to the exact height of tall buildings. Developers are willing to accept more risk and even go beyond the feasibility point. This results in buildings becoming 'economically too tall' by exceeding the height which maximizes developer profit (Barr J. , 2012)

Helsey & Strange (2008) argue that the overinvestment, which is explained in the previous category, in these buildings that become the tallest in the world are a signal of business cycles which indicate global economic downturn.

In the last category within the article of Garza & Lizieri (2016), global cities are cities which are ahead in an economic sense by having the most skilled labour (Helsley & Strange, 2008). These global cities then tend to attract new, skilled labour in the same way that agglomeration has drawn people towards a city. The result of this is that developers are able to combine the most skilled labour and best resources on a global level. This, in turn, allows them to produce taller buildings faster and on a bigger scale.

2.2 Demand of height

The second part of this theoretic review looks at the other side of the literature. As opposed to the supply side, the demand side focuses on literature that researches why firms locate precisely where they do in tall buildings. Through analysis, with a focus on the articles by Koster et al. (2013); Liu et al. (2018) and Nase et al. (2018) an overview is presented of the literature focussed on the demand of height. The demand side of the topic of tall buildings focusses on analysing and estimating the willingness to pay (WTP) for a tenant for a higher location in a building. An additional focus is on the analysis of vertical sorting between the floors in a building in relation to different industry sectors (Nase, van Assendelft, & Remøy, 2018).

2.2.1 Rent premiums, vertical sorting and productivity

Within the topic of tall buildings, rent premiums, vertical sorting and productivity are less researched. These three following sections cover the literature and consensus on these topics.

Rent premiums

Liu et al. (2018) provide evidence in their research that premiums in rent on a vertical level are independent of employment within, or outside a building. Even though accessibility diminishes the higher you go in a building, rents increase approximately 0.58% per floor level (Liu, Rosenthal, & Strange, 2018). In The Netherlands, Koster et al. (2014) have conducted a similar research. While Liu et al. focus on floor level rent premiums, Koster et al. research building height premiums. They conclude that rental levels increase at about 4% per ten meters in building height which comes from an increase in productivity, views and landmark effects. Additionally, the WTP on the basis of building height has a nonlinear relation to rents (Koster, van Ommeren, & Rietveld, 2014). In a recent study, Van Assendelft (2017) focusses solely on the Amsterdam office sector and concludes a rent premium of 1.0% per consecutive floor in multi-tenant tall buildings which are attributed to the same view and landmark effect. These two factors are supplemented with the effect of exclusivity for the tallest of buildings (Van Assendelft, 2017).

Within-building agglomeration economies, the *landmark effect* and the *view effect* all contribute to the existence of rent premiums (Koster, van Ommeren, & Rietveld, 2014). However, the benefits of within-building agglomeration economies diminish significantly in height. As the effect of height on rents become less steep for buildings over 90 meters the assumption of less benefits of these within-building economics are confirmed (Koster, van Ommeren, & Rietveld, 2014). The combined landmark and view effect is 2.8-5.5% on rent premiums for a building that is five times taller than the height average of buildings. It is unlikely, however, that this effect is solely due to the views that these tall buildings create (Koster, van Ommeren, & Rietveld, 2014). This view effect is the likely the result of employees' values in their workplace. As visitors of a building would put less value in a view, employees who spend significant portions of their day in an office are more likely to appreciate these views (Liu, Rosenthal, & Strange, 2018). As a counterpoint to the view effect Koster et al. (2014) argue that if employees within a tall building place value in views there might be no building height effect, which they concluded, but only the presence of a floor height effect (Koster, van Ommeren, & Rietveld, 2014).

The landmark effect can be allocated to status. Although it is likely that small firms are less influenced by these effects. If large firms were to locate in tall buildings, they become easier to locate in a geographical sense and could attract investors and skilled employees more easily (Koster, van Ommeren, & Rietveld, 2014). While tenants are willing to pay price premiums to locate in a landmark due to the attention these buildings receive (Koster, van Ommeren, & Rietveld, 2014), it is likely that these effects only occur for the tallest buildings (Helsley & Strange, 2008). In a more recent study, Nase et al. (2018) are the first to decompose the vertical rent premiums in a quantitative manner. The vertical rent premium is composed of a view effect, which relates to 27% of the premium, 3% from industry-level differences and 70% from firm-level signalling and other factors.

Vertical sorting

In the theory of vertical sorting there is distinction between two types of tenants which put different values on different parts of tall buildings. Commercial tenants can be split up between retail focussed and office focussed tenants. While the retail tenants are more focussed on accessibility, office tenants put more emphasis on amenities within a building. The effect of these amenities on a firm's profit is high enough to compete against the negative aspects that come from locating higher in a building. Because of these factors, retail tenants are more likely to locate themselves in the lowest floors of a building while office tenants will position themselves higher up in a building (Liu, Rosenthal, & Strange, 2018).

Due to the fact that Liu et al. (2018) include retail tenants in their research, a price premium for locating on the ground floor is present. Thus, resulting in a non-monotonic rent gradient where rent prices decline for the lowest floors of the building, excluding the ground floor, and go up for higher floors (Liu, Rosenthal, & Strange, 2018). This is the result of the tension between amenity and access-oriented firms within commercial tenants. Connected to the tension between these types of tenants is the difference per sector. Sorting evidence shows that there are significant differences between industry types in where they tend to locate buildings. As law, consultancy and management firms tend to locate higher in a building, ICT firms show patterns in locating lower in a building (Nase, van Assendelft, & Remøy, 2018). These patterns are in line with vertical sorting conclusions by Liu et al. (2018) but should be interpreted carefully due to the limited sample size and height of buildings in the city of Amsterdam (Van Assendelft, 2017).

Vertical rent gradients have no relation to the direct context of a building as they are the result of a separate set of mechanisms. Agglomeration literature indicates that sharing skilled labour and sharing knowledge are key factors which result in productivity spill overs in close vicinities. The vertical rent gradients, however, are not related to the nearby employment and the size of this nearby employment (Liu, Rosenthal, & Strange, 2018).

Productivity

In the primary research on the concept of productivity in tall buildings, Liu et al. (2018) provide evidence that indicates that more productive industries tend to locate on higher floors in tall buildings. Thus, a positive correlation between revenue per worker and industry employment is present in this context. According to the authors, bigger firms in size also establish their headquarters on floor levels that are higher. These headquarters tend to locate higher as it provides amenities and status (Liu, Rosenthal, & Strange, 2018). This concept is linked by Nase et al. (2018) to the research on social power in relation to within-building location. Within this theory, people with more power within a company are located higher in a building as floor location signals power (Dorfman, Ben-Shahar, & Heller, 2017). This concept of individual social power within a building can be closely related to the status of a firm (Nase, van Assendelft, & Remøy, 2018). Liu et al. (2018) also argue that businesses realise cost reductions through the view and status effect as workers are willing to accept lower wages to work within these prestigious buildings. However, literature does not support this theory. Nase et al. (2018) argue that employee satisfaction and performance increases which increases productivity. This increased productivity then translates to larger profits and therefore a higher WTP by tenants.

A high location within a building is worth more to a tenant that is more productive. This pattern exists because of the view or status effect. These two aspects create value for a business as they appear to be important as employees' prerequisites or by showing productivity to customers. It is also implied that amenity focussed offices tend to locate higher in a building while access focussed businesses, such as retail, are mostly located on ground floor level (Liu, Rosenthal, & Strange, 2018). One exception can be found as ICT firms, who are the second highest ranking sector in terms of productivity, do not follow the pattern by locating higher in a building (Nase, van Assendelft, & Remøy, 2018).

While the principle of productivity-based sorting on a vertical location is embryotic, horizontal sorting on the basis of productivity is much more researched. Higher productivity firms tend to locate in clusters within postal codes and buildings (Liu, Rosenthal, & Strange, 2018). The more researched horizontal level shows these patterns in standard urban structure. An increase in employment densities within these clusters increases productivity as knowledge spill over through contacts with nearby businesses increases. As employment, wages, rents and productivity increases closer to a CBD, buildings tend to become higher as developers are pushed towards using a plot of land in a more intense way (Liu, Rosenthal, & Strange, 2018).

On a more internal level, employees who work within a tall building could be more productive, which is labelled within-building agglomeration economies. The density of employees within such a building creates the possibility for internal returns to grow. Additionally, firms could benefit from external returns that happen within a multi-tenant building due to knowledge spill overs between workers and contact through conversations between employees of different firms. These interactions between different types of tenants within a building could also lead to new combinations and innovations (Koster, van Ommeren, & Rietveld, 2014).

2.3 Construction costs

To create these tall buildings, the construction costs also need to be considered as they part of the equation to determine development profit. The capacity to make a profit on a tall building development is determined by the efficiency of floor plans and essentially the ratio between the Lettable Floor Area (LFA) and the Gross Floor Area (GFA) (De Jong, van Oss, & Wamelink, 2007). Similar as to income and rent increases as a building becomes taller, construction costs also increase by about eight percent per ten stories (Van Oss, 2007).

In a study where the rent premiums and building costs premium are compared, it is concluded that rent premiums increase more per floor level than building costs. This means that the increasing costs that a building makes are offset by the increase in rent levels (Van Assendelft, 2017).

This gap between income versus costs is important to developers and designers as this indicates the possibilities to give a building extra qualities and higher standards. This margin is also used to connect a building to the existing urban fabric (Van Assendelft, 2017). However, as has been mentioned before, at a certain point these buildings become economically too tall (Barr J. , 2012), resulting in the cost premium overtaking the rent premium. Understanding these building costs in tall buildings is essential as the quality of these buildings is the only reason tenants are willing to pay these rents (De Jong, van Oss, & Wamelink, 2007).

2.4 Summary

The second chapter of this research covers the existing literature on both the supply and demand side of height for tall buildings. While general economic principles on verticality and the monocentric city model are analysed in section 2.1.1, section 2.1.2 and 2.1.3 cover the literature on the reasons why tall buildings are built exactly as tall as they are. In depth, these sections analyse what factors contribute to these heights and from what economic literature these factors stem. Following the supply side theory, section 2.2.1 looks at the most important factors which contribute to why firms locate exactly where they do within tall buildings. Section 2.3 then covers a very brief overview on the role of construction costs within this balance of supply and demand.

As a conclusion, figure 2.1 represents the most important theories that are concluded through the theoretical framework of this research. This figure combines all theories by different authors to illustrate the mechanics of what is discussed in literature.

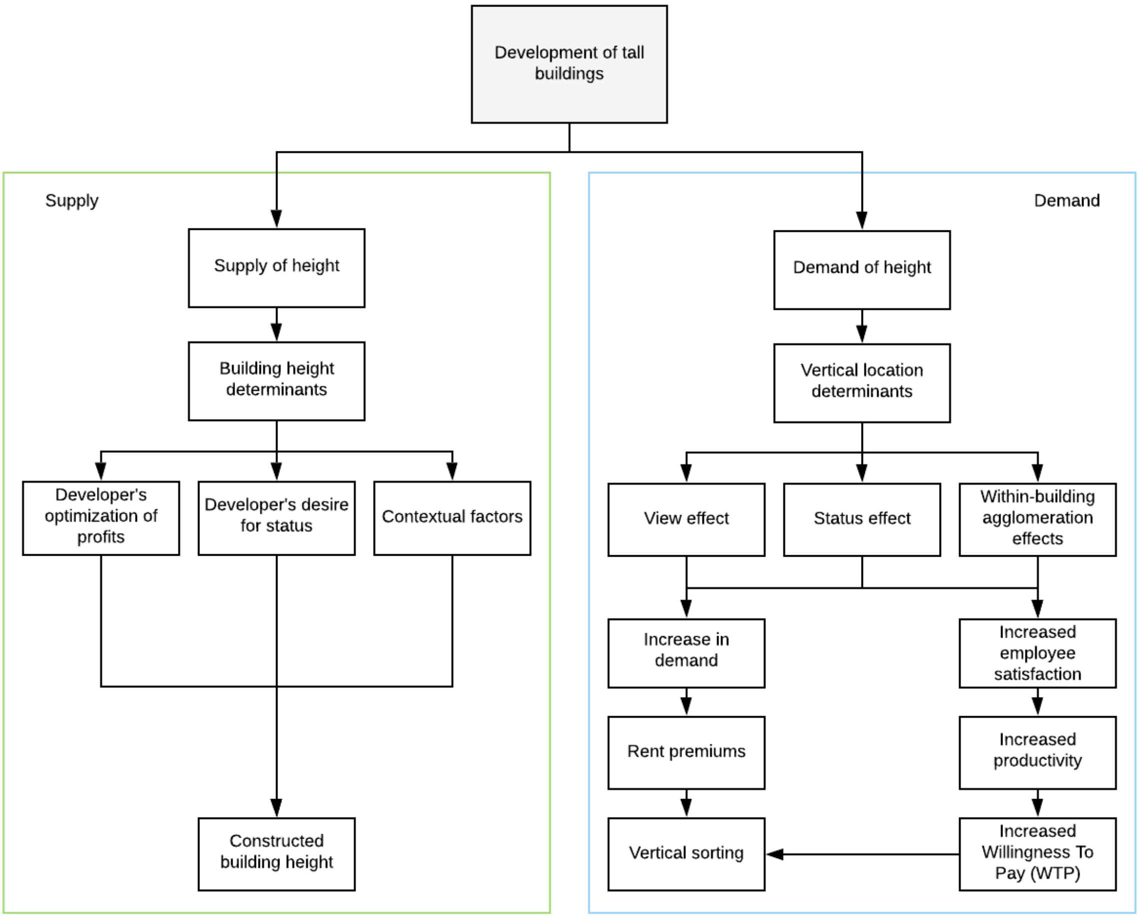

Figure 2.1 – Supply and demand of the development of tall buildings - Connections and associations between literature (Own illustration, based on Helsey & Strange (2007); de Jong et al. (2007); Barr (2010); Barr (2012); Koster et al. (2014); Garza & Lizieri (2016); van Assendelft (2017); Liu et al. (2018) and Nase et al. (2018)).

The framework starts with a division of supply and demand which stems from different focus points within literature. Within the monocentric city model an assumption is made that the best locations in terms of accessibility and productivity are found in the CBD. This assumption results in that rent values increase within these CBDs while they decrease the further a firm decides to locate outside the CBD. This principle is, however, influenced by the more modern principle of polycentrism within cities where multiple CBDs exist. These centres each influence the wave of rent levels within cities in their own way.

Building height of tall buildings is determined by three factors: the developers' *optimization of profits*, the developers' desire for *status* and *contextual* and regional factors such as zoning and regulations within a city. Height is a traded good that gives value to both developers and end-users. This balance between supply and demand results in a strategic decision by a developer on how tall he should build a building to deliver the values of tenants while also balancing income versus costs.

In literature there are four classifications of building height within economic theories: *traditional microeconomic model*, the *game theoretic approach*, *business cycles* and the *global cities* theory. These categorizations have helped understand and cluster different pieces of literature to see where each conclusion comes from.

On the demand side of height, the determination of a vertical location for a firm comes from three factors: the *view effect*, the *status* effect and *within-building agglomeration effects*. These three factors are associated with increased employee satisfaction as an employee puts value in the perks, such as view and status, in the building he works. This increased employee satisfaction then leads to increased productivity and therefore increased profits. This could result in a tenant having increased WTP for these perks to realise increased profits. The aforementioned perks, however, also increase demand for these tall office building locations. As height increases, the effect of view and status perks increases, which could result in price premiums per floor level. Depending on a firm's willingness to pay for these perks, they locate on a certain floor in a building. This determination of how valuable these perks are eventually result in vertical sorting of tenants.

3

Methodology

The third chapter of this research expands on, and explains the main research methods, the process of data collection and the design and use of descriptive statistics that are used throughout the study. Section 3.1 sets a rough outline on the research approach, the methods and the different key phases. In section 3.2 the data collection methods and statistical divisions are explained. Section 3.3 expands on the basics of the regression analysis and its design. Section 3.4 goes into more depth on the descriptive statistics while section 3.5 provides a summary to the chapter.

3.1 Research approach

A quantitative approach is used throughout this research in order to answer the main question that has been set. The quantitative approach, in this research, has been chosen as it able to explain phenomena through the collection of data in the form of numbers which are then analysed by the means of mathematical and statistical methods (Cresswell, 1994). This empirical approach is used to give a precise answer that generates results which are directly applicable, have concrete conclusions and can test hypotheses. The quantitative approach of this research is, however, not limited to descriptive statistics to answer hypotheses but uses the field of econometric modelling with a regression analysis (Knight & Ruddock, 2009). These methods are used in order to analyse the vertical location determinants divided in vertical sorting, productivity and price premiums which have been identified in the previous chapter through literature of Helsey & Strange (2007), Barr (2010), Barr (2012), Koster et al. (2014), Garza & Lizieri (2016), Van Assendelft (2017), Liu et al. (2018) and Nase et al. (2018) (see figure 2.1).

3.1.1 Research phases

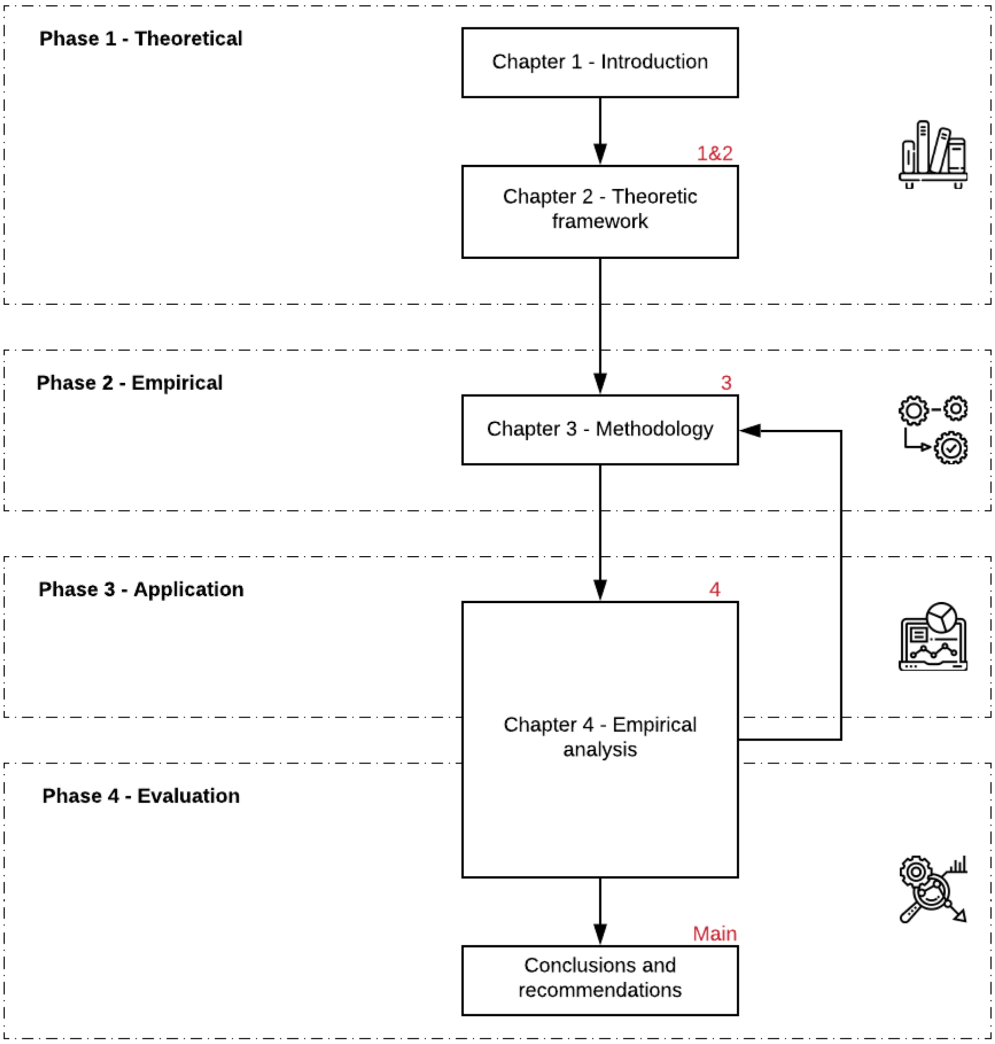

Figure 3.1 – Research phases

The goal of this study is to analyse the relations between productivity, floor levels, price premiums and the vertical sorting of tenants in multi-tenant office buildings. In order to analyse these patterns and, finally, to answer the main question of this research four phases (figure 3.1) have been identified to structure the methods and the process of the research. Each phase is vital within the entirety of the research as they support the process towards the final result. In the first phase, the theoretical phase, which is presented in chapter 1 and 2 of the research the problem is illustrated, and research questions are set. Additionally, this phase expands on this introduction by analysing the existing theory in depth and developing theoretical framework. The empirical phase, which is the second phase of this research, revolves around the design of the methodology, the regression model and the collection of all the available data towards a database for each of the three cities. This database is vital as it is the input for the third, application phase where the designed model is applied based on the gathered data. The application and empirical phase work closely together as feedback from the application phase needs to be adapted and implemented in the previous phase. Phase 4 serves as an evaluation phase where the models are used to analyse the interrelationship between rent premiums, vertical sorting and productivity in multi-tenant office buildings in the three largest cities of The Netherlands. Following this analysis, the differences and similarities between the different contexts are also studies in this phase.

Within these different phases and chapters seven objectives have been formulated, see table 3.1, which need to be completed before the research can move to the next phase. The table also shows what methods are to be used throughout each phase.

Research phases	Method	Objectives	Chapter	Sub-question
1 - Theoretical	Literature review	1 – Discover and analyse existing theoretical concepts revolving around tall buildings. 2 – Critically study the existing body of knowledge to identify gaps.	1 & 2	1 & 2
2 - Empirical	Data collection Database creation Model design Variable identification	3 – To develop an empirical regression model on the basis of variables that are identified through literature. 4 – Gather data from various sources in a combined database.	3	3
3 - Application	Model application	5 – Application of the designed regression model in each identified area to determine rent premiums and vertical sorting.	4	3
4 - Evaluation	Figures Outcome analysis	6 – The use of the model to assess the interrelationship between rent premiums, vertical sorting and productivity 7 – To analyse the differences between each context in order to find differences and similarities.	4 & 5	4

Table 3.1 Objectives and methods per phase (Own illustration)

3.2 Data collection

The data collection phase is a vital part of the research process as this information is the foundation of the rest of the research. In this chapter the data filtering process and the sources of data are described.

3.2.1 Data filtering

The first step towards a database of rental transactions is the selection of relevant buildings for this research. To collect these objects certain parameters must be met in order to be useful towards the objective of this research. Figure 3.2 shows the flowchart that is used in order to select the final building list for which buildings meet the criteria of the research. The data selection starts in the three selected cities of Amsterdam, Rotterdam and The Hague. Based on these parameters the office and multi-use function buildings are filtered. Following this selection all buildings above forty meters are selected. Finally, in this research only multi-tenant office buildings are considered as the patterns between different tenants on different levels in a building will be analysed.

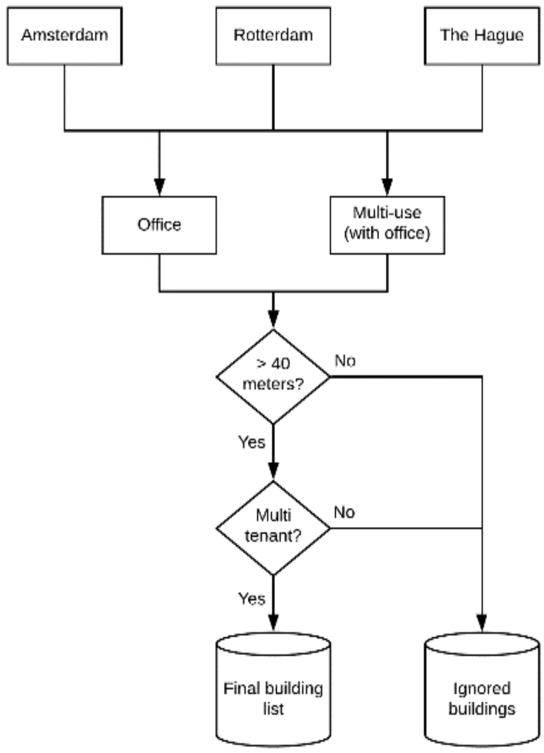

Figure 3.2 – Flowchart final building list

The object list data is initially acquired from public data provider Emporis.com. As a starting point Emporis provides technical information per building on a global level. This data source is considered to be the most complete, publicly available source for technical information such as building height. Previously conducted research which form the basis of this research area such as Barr (2012) and Ahlfeldt & McMillen (2015) have used this data source to good extend.

Following the flowchart, the filters are set upon office buildings in Amsterdam, Rotterdam and The Hague. Additionally, Emporis offers the possibility to exclude any buildings below a certain building height, in this case 40 meters is used. While looking at the three different cities within this study, each city defines high-rise differently. In Amsterdam high-rise is defined as building which are 30 meters or higher (Gemeente Amsterdam, 2011). Rotterdam considers buildings taller than 70 meters high-rise (Gemeente Rotterdam, 2019) while this is 50 meters for The Hague (Gemeente Den Haag, 2017). In the national guideline of the building decree the threshold is 70 meters as well (Gemeente Den Haag, 2017). Since there are different definitions and the differences between the cities are significant, a uniform measurement defined by Emporis is used in order to compare the results between different cities.

Emporis, however, does not provide information whether an object has multiple tenants. However, due to the availability of data and necessary tenant information the final building list is reduced further. Only the buildings that match reported market transactions and buildings that have been valued. The final building list represent the objects that match the criteria and have accessible rent rolls and contracts within the available data sources. Based on the previously described criteria, table 3.2 shows an overview of the final building list before, and after the criteria of multi-tenancy. In Amsterdam 82,9% of the multi-tenant tall building stock is represented in the study. 70,0% and 66,7% of the multi-tenant building stock is represented in the study in Rotterdam and The Hague respectively. Resulting in an overall representation of 76,3% through the three cities. An overview of the objects that meet the criteria is presented in appendix I.

	Tall office buildings	Multi-tenant buildings	Final building list	Percentage of tall building stock
Amsterdam	76	41	34	82,9%
Rotterdam	57	30	21	70,0%
The Hague	36	9	6	66,7%
Total	169	80	61	76,3%

Table 3.2 Object per city (Own illustration)

As can be seen in the table above, Amsterdam has the most tall office buildings, followed by Rotterdam and The Hague. A significant difference can also be observed between the amount of multi-tenant office buildings. The Hague has significantly less multi-tenant office buildings compared to the other cities. In figure 3.3, 3.4 and 3.5 a map is shown for each city. The location for each tall building are gathered from the public source of Emporis.

Figure 3.3 – Object locations Amsterdam (Batchgeo, n.d.)

Figure 3.4 – Object locations Rotterdam (Batchgeo, n.d.)

Figure 3.5 – Object locations The Hague (Batchgeo, n.d.)

Indicator	Amsterdam			Rotterdam			The Hague			Overall		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Height (m)	40,00	150,00	72,87	40,96	164,75	90,86	53,65	127,75	76,82	40	164,75	80,18
# Floors	10	36	19	10	44	23	14	26	19	10	44	20
# Tenants	3	219	18	3	197	30	4	39	14	3	219	21
# Elevators	2	13	5	4	28	10	3	19	9	2	28	8
# Parking places	40	914	253	80	1.094	410	0	925	351	0	1.094	338
GFA	7.418	93.423	28.348	12.703	114.695	37.670	21.191	73.748	39.231	7.418	114.695	35.083
LFA	4.515	74.768	22.859	10.728	100.455	32.218	18.560	62.600	32.656	4.515	100.455	29.224
GFA/LFA Ratio	1,07	1,64	1,24	1,02	1,38	1,18	1,14	1,53	1.22	1,02	1,64	1,21
Construction year	1960	2017	1998	1952	2016	1989	1975	2010	1995	1952	2017	1994
EI	0,74	1,80	1,09	0,71	1,40	0,97	1,14	1,54	1,34	0,71	1,80	1,13
Distance to station	55,93	3.314	747	50	1.385	420	155	838	631	50	3.314	599
Distance to highway	289	4.428	1.643	476	4.803	3.007	352	2.298	1.437	289	4.803	2.029

Table 3.3 – Key indicators overview (Own illustration)

Table 3.3 presents an overview on the key indicators on the building samples for each city, combined with the overall min, max and mean indicators of the three cities combined. The average height of the buildings in Amsterdam is 72,87 meters while this is 90,86 in Rotterdam and 76,82 in The Hague. Rotterdam also has the highest number of average floors of 23 compared to 19 in Amsterdam and 19 in The Hague. Another noticeable feature in the sample is that Amsterdam has a significantly newer tall building stock compared to Rotterdam and The Hague. Whilst in Amsterdam roughly 74% of the tall buildings are constructed after the year 2000, this number is significantly lower in the other cities. In Rotterdam only 29% of the buildings above 40 meters are constructed after 2000 and in The Hague this number is 43%. This indicates that Amsterdam has had a significant impulse of high-rise buildings in the past twenty years compared to the other cities. In the table another interesting indicator is the number of tenants which range from 3 to 219 tenants.

Once the objects have been identified which fit the parameters of this research, the next step is to gather as many rental transactions as possible. At the end of the data collection period, a rental transaction database for each of the three cities is created. Figure 3.6 illustrates the rental transaction data gathering process. In order to complete the data, five primary sources are used. Within Cushman & Wakefield, tenancy agreements, rent rolls and a transaction database are used as the main input. However, not all this information is complete. Face rent rented m², lease start and end date, floor levels, the use and tenant name need to be present within a rental transaction in order to be useful within this research. All transactions that do not cover these criteria are discarded. In order to complement the database towards the objective of analysing the interrelationship between price premiums, vertical sorting and productivity, additional data is required. Tenant information for each individual tenant is gathered and paired with each rental transaction from the Company.info source. Tenant revenue, number of employees and a SBI-Code is added to each transaction. Together with the existing database of Amsterdam up to 2016, this data is the basis of the final rental transaction database for each city.

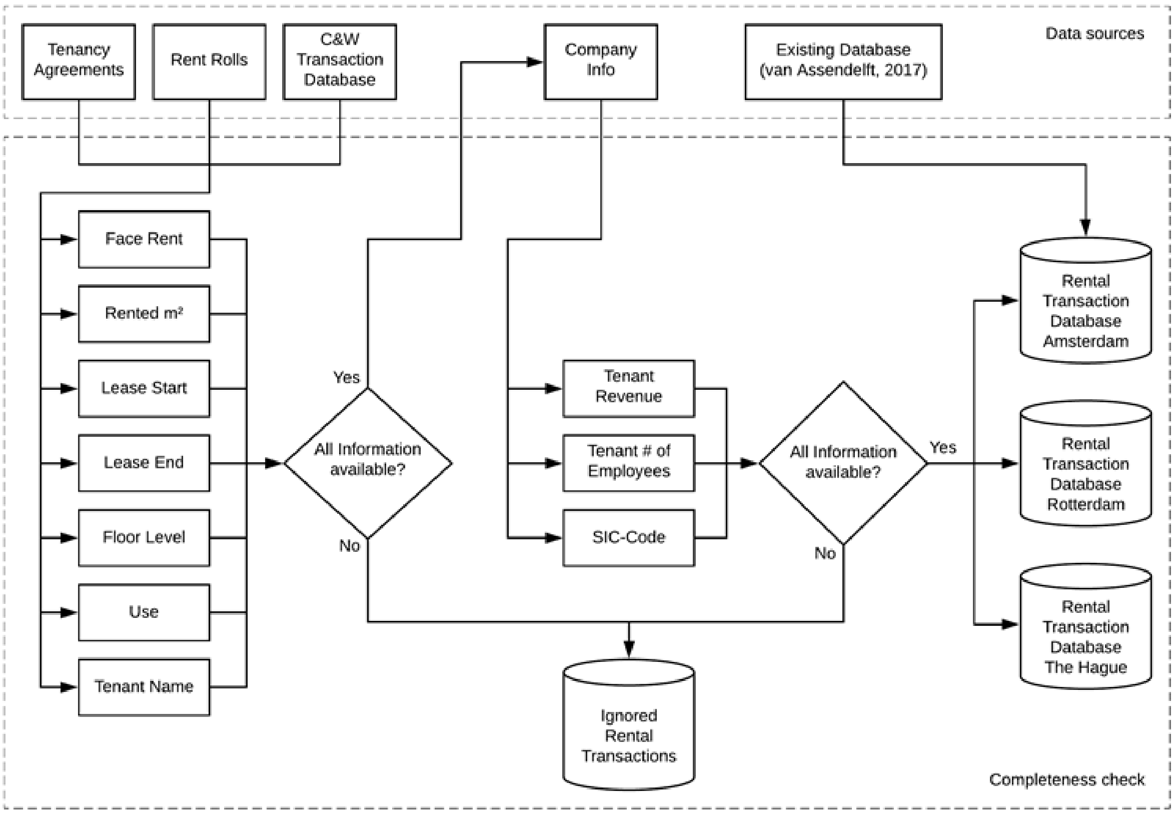

Figure 3.6 - Data gathering process (Own illustration)

The rough transaction database consists of 1.311 individual rental transactions. 168 (13%) of these rental transactions come from tenancy agreements, while 1.009 (77%) are gathered from rent rolls and 128 (10%) are obtained from the Cushman & Wakefield rental transaction database.

All rental transactions within the database are supplemented with tenant characteristics to analyse the interrelationship between productivity in terms of revenue per employee, rent premiums and vertical sorting. For all 1.311 transactions, the tenant's Chamber of Commerce number, total assets, total revenue, total employee number and SBI-code is identified through the source of Company.info. Within the source the registration of all companies' employees and revenues are not identical. As the source shows all affiliations with other parent companies and subsidiaries, the location of registration of all relevant information is identified. As a guideline, the overarching parent company for each tenant is used to gather the tenant data to create a dataset which is as accurate as possible.

3.2.2 Data sources

As is explained in the previous paragraph two types of databases are created which are linked in terms of property characteristics. The first database type are the specific objects which meet the criteria of this research and the second database are rental transactions within these buildings between the year 2000 and 2019. The process of data filtering is explained in section 3.2.1. In this section the sources of the data are explained in greater detail.

Existing database

The existing database created by van Assendelft (2017) is a primary source of information in the context of Amsterdam for this research. The research resulting from this database studies the price premiums and vertical sorting of industry sectors in multi-tenant office buildings in Amsterdam. This particular database is used as a starting point for the development of the databases for the other two cities. The gathered information within this source covers all rental transactions within tall, multi-tenant office buildings stretching over the time period of 2000-2016 (Van Assendelft, 2017). This source is supplemented with gathered information through other sources for the period 2017-2019.

Cushman & Wakefield

Through a graduation internship within Cushman & Wakefield most of the necessary data is gathered. Cushman & Wakefield (C&W) is a real estate consultant that operates on a global level by creating sustainable value for its clients (Cushman & Wakefield, 2020). The three main sources of rental transactions within the company, which are explained in the previous section, are available within the company as they are used as input in valuation assignments that the company has completed since 2000. This source provided unique and rich data concerning face rents, square meters and lease terms while also providing information regarding the floor level tenants were operating from.

Strabo

All possible sources of information are used in order to fill the databases as much as possible. Through the internship at Cushman & Wakefield access to Strabo, which is a consultant specialized in Real Estate information, and their Vastgoed Transactie Informatie Systeem (VTIS, translates to Real Estate Transaction Information System) database (Strabo, 2020). This database offers rental transaction data of rental transactions within The Netherlands since 1985. This database is often used as a starting point to find objects but is also used as input into the rental transaction database itself. However, the VTIS database does not offer information on floor levels per rental transaction and is therefore supplemented with fieldwork to gather the necessary information.

Company.info

The data that is gathered through this source is an essential extension of this study. Company.info transforms data into relevant information about companies (Company.info, 2020). As can be seen in the flowchart regarding the rental transaction database this source is used to gather information such as tenant revenue, tenant employee numbers and SBI-codes. This source is used in a combination with data from the Dutch Chamber of Commerce where additional information regarding companies is gathered.

Kadaster & Basisregistratie Adressen en Gebouwen (BAG)

The BAG and Kadaster (translation: cadastre) provide building characteristic information such as construction year, parcel area, functions and the square meters of these specific functions. This information is provided by Dutch municipalities, provinces and the Dutch land registry. The necessary information is mostly publicly available through the BAG-viewer which provides the aforementioned information per address.

Emporis

The website of Emporis is used as a provider of technical information such as building height and floor levels. The map of Emporis serves as the starting point to the gathering of objects that meet the criteria for building height, floor levels and location. Through these filters the final building database is collected with their respective heights and floor levels and added to the object database.

Energy Performance

This source is used as additional input for the object database as it provides information on the energy performance of each specific building. For each building, when available, an energy performance rating has been gathered from ep-online.nl, which is connected to the specific energy label of a building. Energy labels range from A+++ to G, where G is the poorest energy performance and A+++ is the best performing building.

BREEAM score

As a complimentary source, the BREEAM (Building Research Establishment Environmental Assessment Method) scores, which indicate how sustainable a building is, are added to the database. The Dutch Green Building Council manages and distributes these scores.

Actueel Hoogtebestand Nederland (AHN)

This source is used in combination with BAG 3D to establish the heights of the buildings in the object database. The AHN (translation: Current Height Database Netherlands) provides the height of all terrain, buildings and other objects in The Netherlands through a map. This source is used as a check for building height which are gathered from different sources in order to ensure that the data is as precise as possible.

3.2.3 Submarket division

In the maps below the submarket divisions per city are depicted. The submarkets within this research are slightly different compared to the submarkets that are labelled by Cushman & Wakefield. Because certain submarkets have very limited transaction data, submarkets have been combined. The combining of these submarkets does not result in different results as they are physically close to each other and therefore share characteristics which result in similar rent values. For example, the region of Zuidelijke IJoevers (Southern IJ banks) is combined with the city centre submarket. The Riekerpolder submarket has been combined with West-Axis for similar reasons. Figure 3.7 shows the submarket division for Amsterdam.

The submarket division for Rotterdam within Cushman & Wakefield is more scattered, which results in very little samples per submarket. This could result in insignificant results per submarket, therefore certain submarkets have been combined depending on their physical location and distance to other submarkets. For instance, the submarket Kralingen has been combined with City Centre as their average rental prices per square meter are similar, 217 and 208 euros per square meter respectively. The Kralingen submarket only entailed 12 rental transactions, and therefore for the purpose of this study have been combined. The final division per submarket is shown in figure 3.8.

As the The Hague object list is very limited, and due to similar reasons as Rotterdam, certain submarket within the city centre region are combined. Additionally, originally the Zurichtoren is located within the city centre submarket. However, this would lead to four transactions within a single submarket. As rental levels are relatively similar between the City Centre and Haagse Hout submarket, the Zurichtoren is added to the Haagse Hout submarket. This results in the final submarkets of Haagse Hout and Laak as is depicted in figure 3.9.

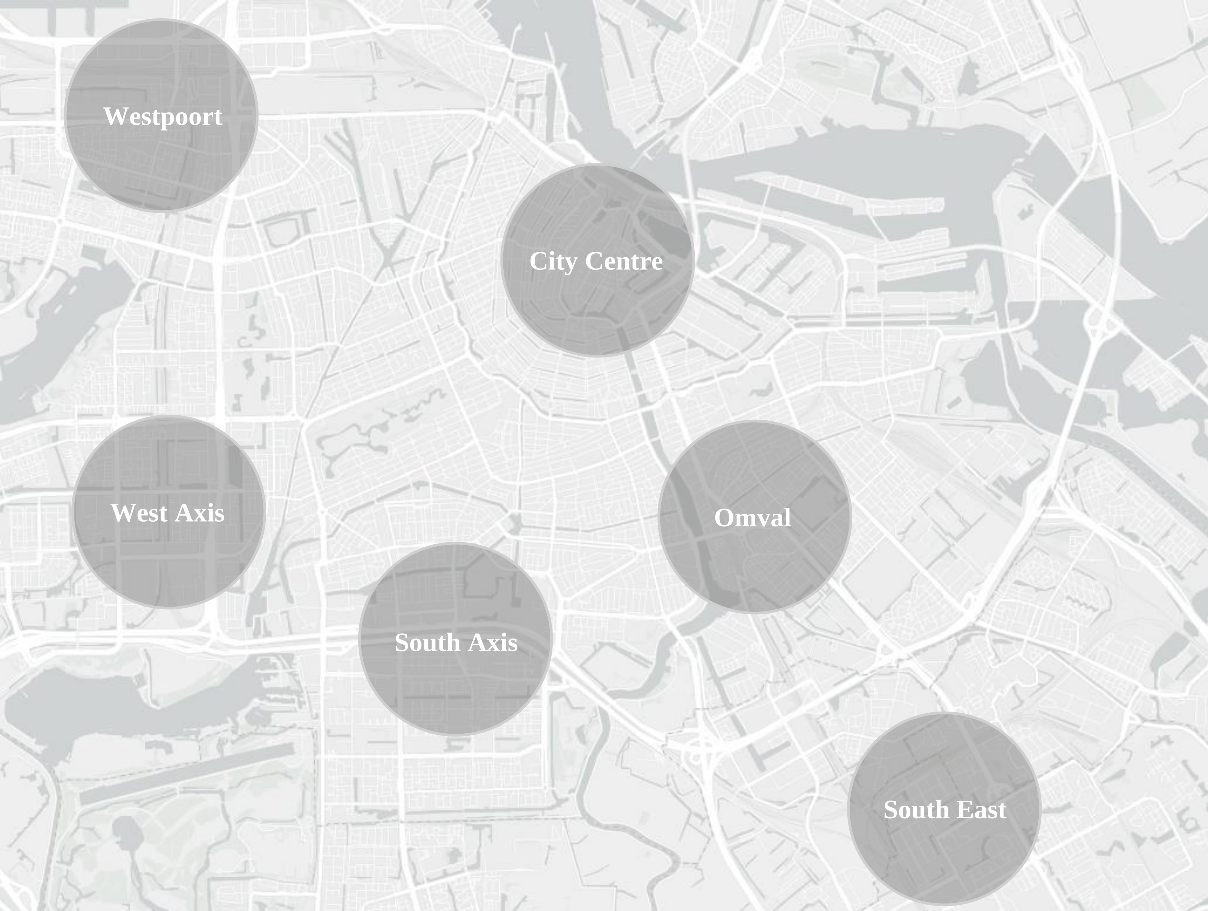

Figure 3.7 – Submarket division overview Amsterdam (Own illustration)

Figure 3.8 – Submarket division overview Rotterdam (Own illustration)

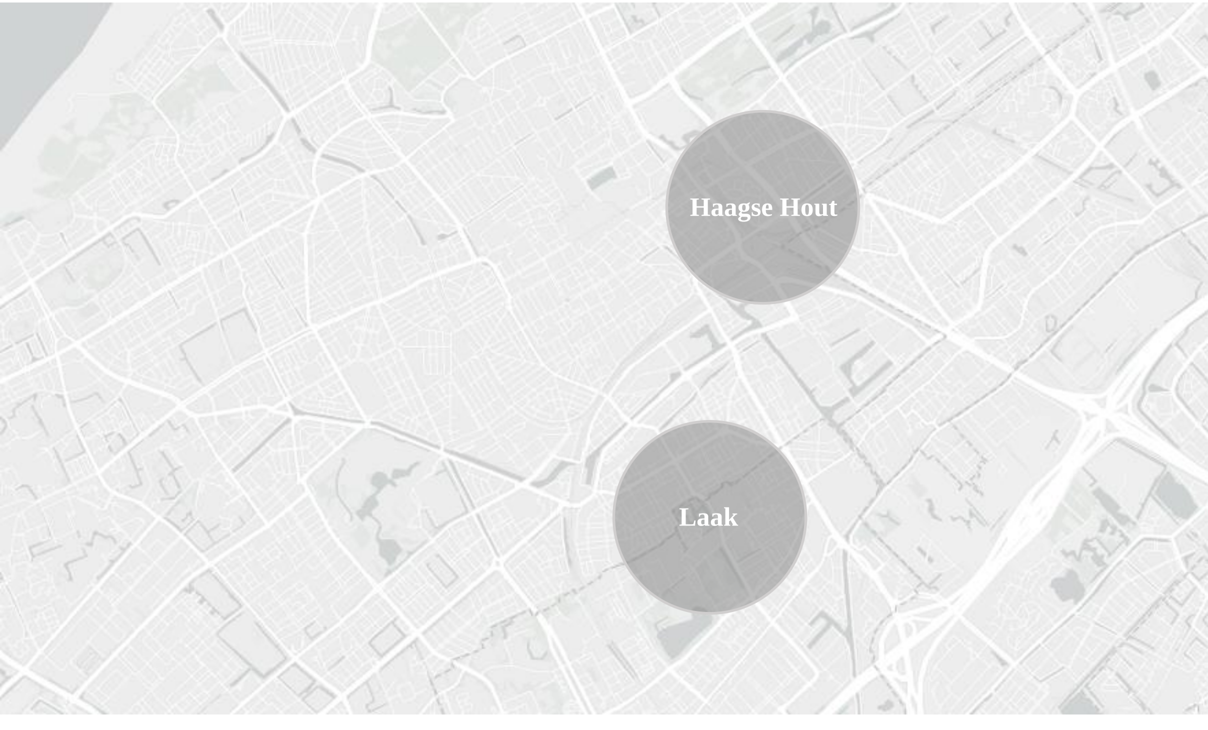

Figure 3.9 – Submarket division overview The Hague (Own illustration)

Table 3.4 presents the average rent levels per submarket as described above as well as the minimum and maximum of the rental transactions within the six submarkets of Amsterdam between the year 2000 and 2019. For each sub market the mean real rent figures as well as the Ln rent values. The real figures are presented purely as indicative numbers within this chapter. The real figures are not used as input in the models and the empirical analysis of the research. As can be seen in the table the South Axis submarket is significantly more populated than other sub markets. The highest mean rents can also be found in this submarket with an average of EUR 305,80, followed by a close EUR 286,90 in the Omval submarket. The lowest average rent is registered in Westpoort with an average of EUR 166,00. The six different submarkets result in an average of EUR 274,60 rent per square meter per year.

Submarket Amsterdam	#	%	RentSqm Mean*	LnRentSqm Min	LnRentSqm Max	LnRentSqm Mean
City Centre	49	8%	230,6	4,99	5,65	5,43
Omval	57	9%	286,9	4,74	5,99	5,61
South Axis	423	65%	305,8	3,69	6,11	5,66
West Axis	17	3%	176,7	4,38	5,52	5,09
Westpoort	42	6%	166,0	4,82	5,27	5,11
South East	56	9%	175,9	4,70	5,79	5,16
Total/Average	645	100%	274,6	4,55	5,72	5,34

Table 3.4 – Key figures submarkets Amsterdam

As can be seen in the graph in figure 3.10, there is limited information in Amsterdam after the year 2016. This, however, does not mean that no rental transactions have taken place within the other submarkets. During the data gathering process within Amsterdam numerous objects and transactions were found after 2016 that did not have sufficient data to add to the database.

In the graph a similar pattern can be seen as in the table above. The South Axis submarkets holds the highest rent levels on average over the period of 2000-2019. The submarket with the second highest rent levels is the Omval. Occasionally the rent levels of this submarket exceed the South Axis market. This, however, can be attributed to the limited amount of objects that are in the Omval market. A shift in rent levels within a single building can significantly influence the mean rent levels in the submarket. As the South Axis holds more objects and transactions the development of this line can be seen as more significant.

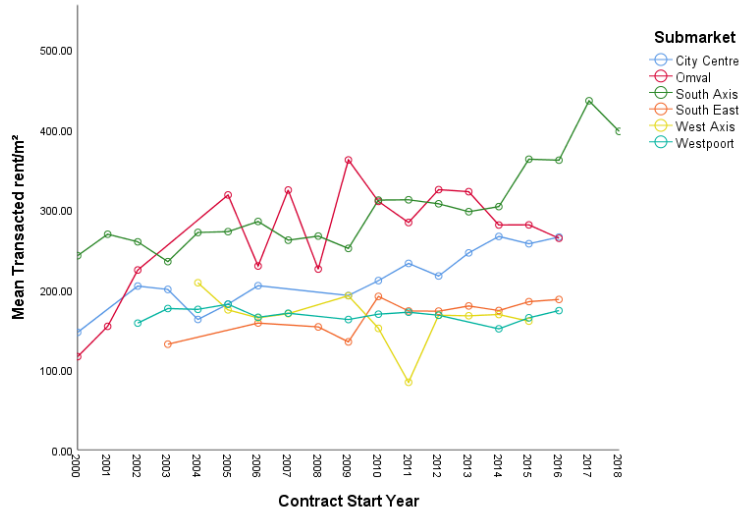

Figure 3.10 – Mean Transacted rent/m² per Amsterdam submarket

This large amount of transactions within the South Axis submarket, especially between the years 2000-2016 also shows a rather not volatile line while the Omval trends are rather volatile per year. Another interesting observation is the gradual increasing trend of the City Centre as well as the South East submarket. The remaining submarkets show rather stable trends.

The city of Rotterdam is divided into three submarkets. Table 3.5 shows these three different markets and indicates that the Kop van Zuid market holds the highest rent levels in the city with an average of EUR 202,60. The close second of the City Centre submarket holds an average rent level of EUR 206,90 while Delfshaven realises an average rent of EUR 164,10. The average rent is EUR 202,60 which is significantly lower compared to Amsterdam.

Submarket Rotterdam	#	%	RentSqm Mean	LnRentSqm Min	LnRentSqm Max	LnRentSqm Mean
City Centre	488	80%	206,9	4,13	5,70	5,30
Delfshaven	61	10%	164,1	4,68	5,38	5,08
Kop van Zuid	41	7%	208,5	5,07	5,52	5,34
Total	590	100%	202,6	4,13	5,70	5,28

Table 3.5 – Key figures submarkets Rotterdam

The closeness of the average rent levels in the table above between the City Centre and Kop van Zuid can also be seen in the graph in figure 3.11. Throughout the years the sub market with the highest rent levels is traded between the two. However, as the City Centre submarket holds significantly more rental transactions (500 versus 42 respectively) it is less volatile and more representative.

As the Delfshaven submarket only entails a single object, the trend line is very volatile. Additionally, there were hardly any rental transactions until 2012. This is the year that the Rotterdam Science Tower within the Delfshaven market is renovated and used with a primary office function. The rent levels within this area are significantly lower compared to the other two markets, as can be seen in the graph.

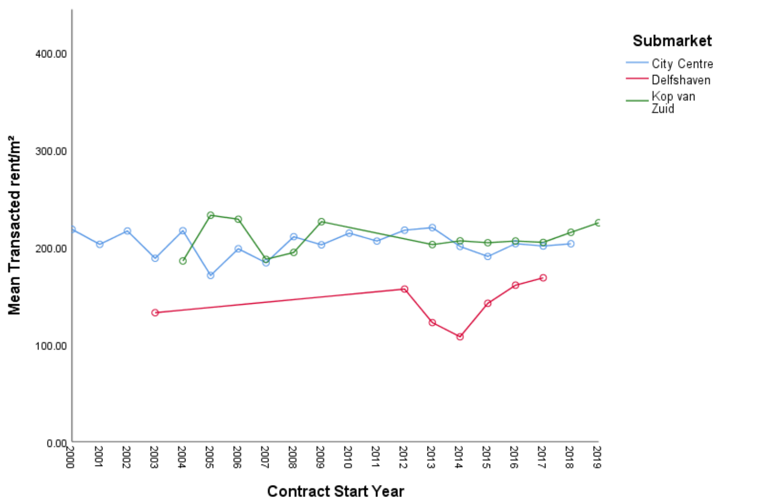

Figure 3.11 – Mean Transacted rent/m^2 per Rotterdam submarket

The high-rise within the city of Rotterdam has also been expanding into different areas. While the city's high-rise was rather monocentric and primarily took place within the City Centre, in 2004 the Kop van Zuid market appeared in the graph.

Within the research, The Hague is divided into two submarkets. In combination with figure 3.9 and 3.12 the city shows monocentric characteristics in terms of high-rise within the city. Most high-rise is clustered around one area while this is different in Rotterdam and Amsterdam. Table 3.6 shows that Haagse Hout, however, is the submarket where most high-rise is situated, conforming the concentration of high-rise. Haagse Hout also has a significantly higher rent per square meter mean of EUR 219,0 compared to the EUR 150,36 of Laak. On average rent levels of EUR 214,51 are realised in The Hague which is higher than Rotterdam's rent levels but still significantly lower compared to Amsterdam.

Submarket The Hague	**#**	**%**	**RentSqm Mean**	**LnRentSqm Min**	**LnRentSqm Max**	**LnRentSqm Mean**
Haagse Hout	71	93%	219,0	4,73	6,13	5,43
Laak	5	7%	150,36	4,85	5,12	5,01
Total	76	100%	214,51	4,73	6,13	5,40

Table 3.6 – Key figures submarkets The Hague

As can be seen in figure 3.12, the trend line is very different compared to Amsterdam and Rotterdam which could be allocated to the fact that the number of transactions is much lower compared to the other cities. Regardless of the smaller database the higher Haagse Hout's rents can be seen in the graph throughout the years. However, more interesting in this graph is the decline in office rents near 2008 and 2009 which is within the financial crisis. Even after this period this trend has been continuing up to 2016. After this period, recovery can be seen to the office rents in Haagse Hout but the rent levels are still lower compared to the ten years before.

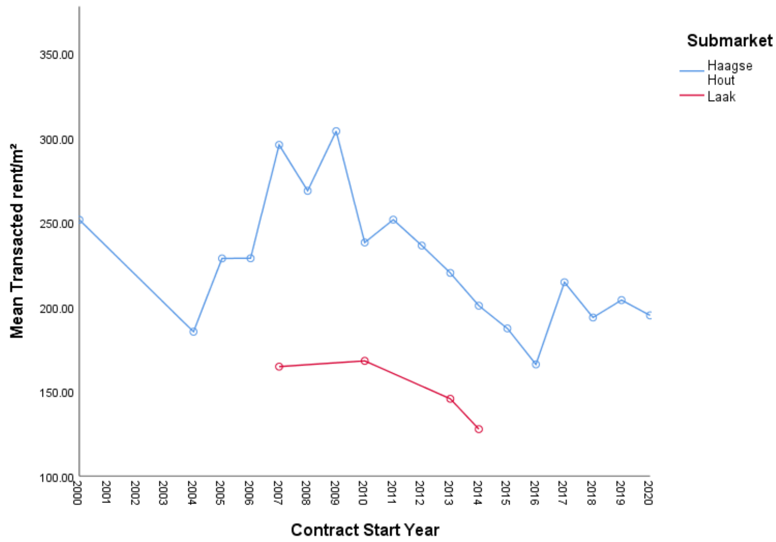

Figure 3.12 - Mean Transacted rent/m^2 per The Hague submarket

3.2.4 Tenant division

The SBI (Standaard Bedrijfs Indeling) is a code system which categorizes businesses and sectors (Kamer van Koophandel, 2019). This code is used during registration with the Dutch Chamber of Commerce (Kamer van Koophandel) and is therefore allocated to every firm within the database. The selection of industry sectors and SBI codes originates from previously conducted research by Liu et al. (2016) and Van Assendelft (2017) where FIRE and business services SBI codes are used to analyse how these tenants operate within tall buildings. The final division is depicted in table 3.7.

Industry Sector Name	SBI	SBI Description
ICT Services	62	Activities regarding information technology services
	63	Activities regarding information services
Financial Services	64	Activities regarding financial Institutions
	66	Activities regarding other financial services
Insurance Carriers	65	Activities regarding insurance and pension funds
Real Estate	68	Activities regarding the renting and trading of real estate
	81	Activities regarding facility management and maintenance
Business Services	73	Activities regarding advertisements and market research
	77	Activities regarding the renting leasing of cars, consumer goods and machines
	78	Activities regarding job placement services
	79	Activities regarding travel agency services
Law Offices	69.1	Activities regarding legal services
Consultancy, research & specialised services	69.2	Activities regarding accountancy, consultancy and administrative services
	71	Activities regarding architecture, engineering and technical design & consultancy services
	72	Activities regarding research and development services
	74	Activities regarding industrial design, photography and translation services

Table 3.7 – Tenant division per industry sector and SBI-code (Kamer van Koophandel, 2019)

3.3 Regression analysis

This section provides an explanation on the design of the regression and both the independent and dependent variables which are used as input within this analysis.

3.3.1 Regression design

A regression model is, simply put, based on the linear formula which is shown in equation 1. This linear formula represents a statistical regression analysis to assess the relationship between dependent and independent variables (Field, 2013). As can be seen in the equation the outcome is influenced by a model which represents the entered data in combination with an error range. The error within this linear equation represents the difference between an outcome which is predicted and the values that are observed in a model (Field, 2013).

$$Outcome_i = Model_i + Error_i \tag{1}$$

A linear regression model can be made with many independent variables, but also with a singular predictor. A regression analysis predicts a straight, linear, line and a simple linear regression with one predictor can be used to plot the best matching straight line based on the data that is used as input in the model. Equation 2 shows an example of a simple regression with a single predictor in combination with the aforementioned error.

$$y_i = (\beta_0 + \beta_1 X_i) + \varepsilon_i \qquad (2)$$

Equation one and two are similar, however the second equation is more defined. The first change is that the outcome is illustrated as y_i. The $Model_i$ is also transformed into a more defined formula. The first aspect that has changed is that the slope of the straight line is defined as β and the single point where the line crosses the vertical axis of the graph. The point where the line intersects the y-axis is called intercept y-axis and is illustrated in the equation as β_0. The second aspect that has changed within the model is that the first regression coefficient is added to the equation, depicted as X_i. This coefficient shows how the magnitude of the interrelationship between the independent variable β_1 and the dependent variable y_i is (Field, 2013).

In this research it can be assumed that the dependent variable of rent value is not determined by a single independent variable but is influenced by a more complex number of variables which each influence the outcome in their own way. Analysing these different independent variables and the weight of their influence on the dependent variable is part of the objective of this research. To achieve this objective, a multiple regression analysis is implemented which changes the model from a singular independent variable as can be seen in equation 2, to a multiple regression model as is depicted in equation 3. Through this equation the impact of the independent variables on the rent values can be studied (Slade, 2000).

$$y_i = (\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_n X_n) + \varepsilon_i \qquad (3)$$

As is depicted in equation 3 the number of predictors in a multiple regression are, in theory, infinite. However, having too many predictors could result in the model becoming overfit. An overfit model would result in a significant decrease in the prediction power of the regression model as the variables make little contribution. Additionally, the variables could correlate among each other, which also results in a decrease in prediction power (Field, 2013). To determine the number of variables and samples are necessary a rule of thumb is used where 8 times the number of variables is needed for each variable (Green, 1991). According to Field (2013) ten to fifteen samples are required per variable. The interrelation between rent values, vertical location and productivity is the subject of this study. Therefore, it assumes that floor levels and tenant characteristics influence the dependent variable. Within this research the log-linear approach is used. This is argued to be the more preferred method over linear, reciprocal, logarithmic and semi-log (Slade, 2000). The final multiple regression equation is adapted from previously conducted research such as Koster et al. (2014) and Nase et al. (2018). The result of the adaptation of the equation is the formula that is presented in equation 4. B_0-β_7 represent the coefficients that are determined based on the variables which are explained in table 3.8.

$$Tr_i = (\beta_0 + \beta_1 Fl_i + \beta_2 B_i + \beta_3 L_i + \beta_4 Tra_{i+} + \beta_5 P_i + \beta_6 C_{i+} + \beta_7 D_i + \beta_8 T_i) + \varepsilon_i \qquad (4)$$

Variable	Description
Tr_i	Transaction rent per square meter per year (Price adjusted to 2019)
Fl_i	Number of floors
B_i	Building specific variables
L_i	Location variables
Tra_i	Transaction specific variables
P_i	Tenant characteristic variables
C_i	Tenant class dummy
D_i	Submarket dummy
T_i	Time specific parameter
ε_i	Error term

Table 3.8 – Variable description

In order to analyse the interrelationships and answer the relevant questions which are presented in the previous sections of this study, the statistical software SPSS Statistics is used. By operationalizing the presented equation within this software, the R^2 can be determined. The sample is used in combination with the R^2 to determine how much variation in the dependent variable of transaction rent per square meter per year can be connected to the regression model. The potential loss of shortage of data is covered by using the adjusted R^2 which executes the same procedure but covers the entire population, rather than the gathered sample. By using the adjusted R^2, the extent of the predictive power that the model has can be determined. This is then used to compare the different outcomes that the model gives (Field, 2013).

However, before all the samples can be applied to the model, the data is first checked for outliers and multicollinearity. Outliers are possible points of data which can significantly change the mean of a variable and therefore give unrealistic results (Field, 2013). The description and detection of outliers is explained in greater detail in section 3.4.

3.3.2 Dependent variables

As this study is focussed on rent premiums per floor level within multi-tenant office buildings within Amsterdam, Rotterdam and The Hague it is natural that the dependent variable for this research is the amount of rent paid per square meter of office floor space. However, there are two different types of rent levels per square meter which can be considered as dependent variables. First, headline or face rents are considered as the dependent variable. These are all the contract rents which can be found in tenancy agreements and rent rolls. However, the office market stabilizes itself in an artificial manner by handing out incentives to tenants (Boots, 2014). These are described as real rents. Within real rents, the headline rents are corrected with incentives which are different for each tenant, resulting in a more accurate rent level in an ideal scenario. However, this ideal scenario is very difficult to analyse as information about incentives is not always accurate or obtainable. The second dependent variable, highest floor of a transaction, is used to analyse vertical sorting. The transformed form of the highest floor variable is used to find the elasticity between the independent and dependent variables. In the table below, the number of samples for each dependent variable is presented.

Variable	Type	Variable description	#	Source
LnRentSqm	Ln	Headline rent per square meter LFA (excluding incentives & service costs and price adjusted to 2019) (2015=100)	1.311	Rent Rolls Tenancy Agreements C&W Database
LnHighestFloor	Ln	Highest Floor that a tenant occupies within a building	1.311	Rent Rolls Tenancy Agreements C&W Database

Table 3.9 – Dependent variables

Within the database the rental price per square meter exclusively consists of office square meters and therefore excludes the rents tenants pay for parking spaces, storage units and service costs. The final sample of 1.311 rental transactions consist of tenancy agreements within multi-tenant office buildings, above forty meters tall within the cities of Amsterdam, Rotterdam and The Hague between the year 2000 and 2019. As can be seen in the table, all rental values have been adjusted for inflation through yearly CPI (Consumer Price Index) values. This results in rental values which are inflated to 2019 price levels by using 2015 as a base reference. Therefore, all monetary values covering rents are expressed as year 2019 Euros. Both the dependent and some independent variables have also been transformed according to a Ln Log transformation to increase the interpretability of the results.

3.3.3 Independent variables

Similar to the dependent variable table, the table below presents all the independent variables that are gathered from previously conducted research. The table also shows the whether the variable serves a Linear, Log or Dummy purpose. Dummy variables are included to control for fixed effects and are indicated with either a 1 or a 0, indicating whether it is a yes or a no. The sign of a variable shows the expected direction of the interrelationship that a variable will have. Additionally, a description per variable is presented in combination with the source where the variable is gathered.

Variable	Type	Sign	Variable description	Source
Object # Floors	Linear	+	Number of floors in a building, excluding basement	Emporis + C&W
Object # Tenants	Linear	+	Number of tenants within a building	C&W
Highest Floor Level	Linear	+	Highest Floor of a transaction	C&W
Relative Floor Level	Linear	+	Relative floor of a transaction	C&W
LnLFA	Ln	-	Total LFA in a rental agreement	C&W
LeaseTerm	Linear	+	The total lease term of a rental agreement	C&W
LnDistStat	Ln	-	Distance to the nearest train station by foot	C&W
LnDistHigh	Ln	-	Distance to the nearest highway exit/entry by car	C&W
LnAgeSinceRenov	Ln	-	Building age since construction of a building	BAG
# Elevators	Linear	+	The number of elevators within a building	C&W
# Parking	Linear	+	The number of parking spots within a building	C&W
Penthouse	Dummy	+	Dummy to select whether it is the highest floor	C&W
Multiple Floor Tenant	Dummy	+	Dummy to select whether tenant occupies > 1 floor	C&W
LnTenEmployees	Ln	+	The number of employees a company has nationwide	Company.info
LnRevenue/Employee	Ln	+	The ratio between revenue and employee numbers	Company.info
LnTotalAssets/Employee	Ln	+	The ratio between total assets and employee numbers	Company.info
Tenant Sector Dummies	Dummy	+	Dummy to select tenant sectors	Company.info
Time Fixed Effects	Dummy	+	Dummy to select transacted year	C&W
Space Fixed Effects	Dummy	+	Dummy to select submarkets	C&W
Submarket	Dummy	+	Dummy to select submarket (1 = yes, 0 = no)	C&W

Table 3.10 – Independent variables

3.4 Transaction overview

In this section an overview and statistical analysis is presented on the gathered samples of rental transactions. First, an overview of is presented of the transactions and key figures, which is followed by descriptive statistics and a brief statistical analysis on outliers within the samples of the different cities.

3.4.1 Transaction analysis

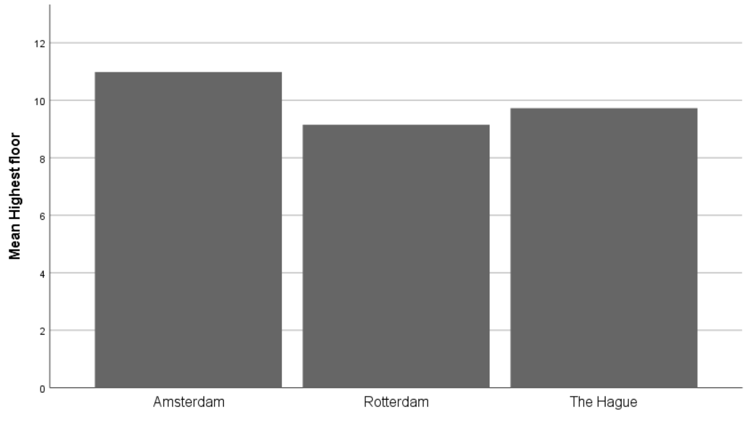

Figure 3.13 – Mean Highest Floor per city

This section which analyses several interesting aspects of the deployed database starts with an analysis of the initial differences between the three cities. In figure 3.13 the mean highest floor level is categorized per city to observe which city holds the highest average floor levels within the transaction database. The difference per city is marginal and hovers between the 9th and the 11th floor level. Amsterdam clearly holds the highest average floor level, followed by The Hague. The average transaction in Rotterdam takes place on the lowest floor level. While the Amsterdam and Rotterdam database holds a significant amount of transactions, the results of The Hague should be treated with care.

Office surface area

In this research no distinction is made between the surface area of rental transactions. In a previously conducted research by Boots (2014) and Ziermans, Dröes & Koppels (2016) rental transactions larger than 500 m^2 are used in models. However, Koster et al. (2014) argue that in the Dutch context all lease transactions surpassing 50 m^2 can be used as samples within a database. In a recent study by Van Assendelft (2017) the difference in rent levels between rental transactions with a surface area between 200 and 500 m^2 and rental transactions larger than 500 m^2 are analysed. This analysis results in marginal differences with a mean of 1,13%. Additionally, starting from 2013 an increasing pattern in rent levels for smaller floor areas is identified while larger floor areas decrease (Van Assendelft, 2017). However, as it is possible the multi-tenant office market is different in Rotterdam and The Hague compared to Amsterdam no threshold for office space is used. Within the models differences in office surface area are tested to analyse the differences between 0 m^2, 200 m^2 and 500 m^2 thresholds.

Mean rents per year

The average rent values per square meter per submarket are shown in section 3.2.3. Figure 3.14 shows an overview of average rent levels with 95% confidence interval error bars. These interval bars indicate the accuracy of the data points per year, indicating that the confidence in certain years is significantly lower compared to other years. No patterns can immediately be recognized within the graph. However, major lows in terms of rent levels can be seen in 2003 and 2017 while the period in between shows relatively stable rent levels. As most data points in the final database are focussed within this period of time, it also shows the smallest confidence interval bars. This indicates that the rent levels near the start and end of the graph can be uncertain. Throughout the graph the mean transacted rent/m² lies between roughly EUR 200 and EUR 250 per year.

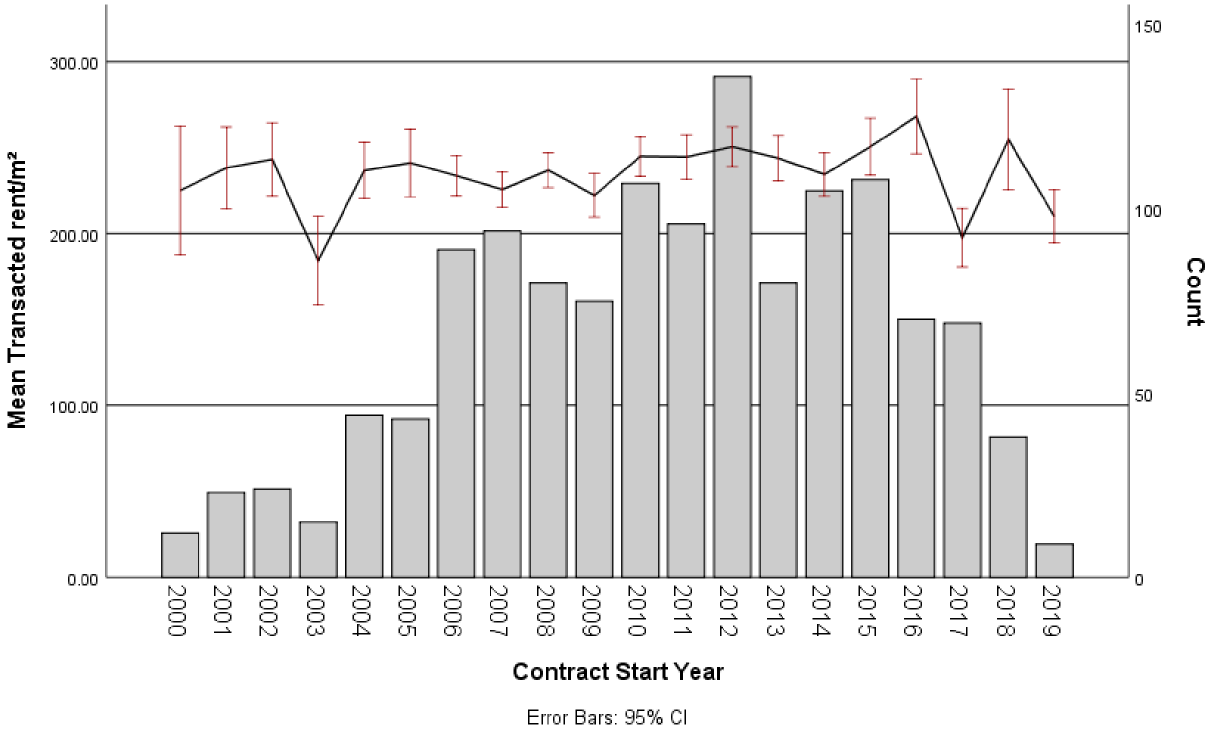

Figure 3.14 – Mean transacted rent / m² per contract start year

Mean rents per tenant sector

Table 3.11 below shows the categorization and transacted rent / m² key figures per analysed sector in the final database. The amount of samples N is shown alongside the percentage as well as the mean, standard deviation, minimum and maximum of these categories. The significant differences in terms of transaction samples is immediately recognizable. There are also significant differences between mean rents per sector ranging from roughly EUR 260 and EUR 220.

Tenant sectors	N	%	Mean	Std.Dev.	Minimum	Maximum
ICT Services (SBI 62 & 63)	79	3.01%	236.16	67.49	101.09	413.90
Financial Services (SBI 64 & 66)	264	10.39%	235.78	66.94	104.04	451.35
Insurance Carriers (SBI 65)	342	15.01%	261.50	63.65	127.70	434.32
Real Estate (SBI 68 & 81)	107	5.53%	220.40	67.70	106.16	441.38
Business Services (SBI 73, 77, 78 & 79)	18	0.98%	256.01	70.55	122.18	430.16
Law Offices (SBI 69.1)	79	4.36%	246.81	61.706	118.30	407.16
Consultancy, research & specialised services (SBI 69.2, 71, 72 & 74)	365	21.07%	220.32	61.60	104.16	469.91
Other industries	57	4.17%	254.03	77.09	145.60	478.34
Total	1310	100.00%				

Table 3.11 – Transacted rent figures per tenant sector

Figure 3.15 and figure 3.16 show the differences in terms of transacted rent / m^2 when they are categorized per city and sector. The trend of Amsterdam having the highest rent levels can also be seen in the both graphs while Rotterdam and The Hague are relatively close to each other. The differences, however, in the range of mean transacted rents are an interesting occurrence in figure 3.16. While there are enormous differences in transacted rents between the cities within the Insurance Carriers sector, the difference in Business Services or Financial Services is significantly smaller. This could mean that certain industries could be willing to pay more to locate within a certain city compared to other industries. In the second graph, in Amsterdam, the Insurance Carrier firms pay the most rent, closely followed by the Real Estate and Law offices. However, this order is not directly applicable to Rotterdam as well as The Hague. While the insurance carrier firms in Amsterdam pay the most amount of rent, the insurance firms in The Hague pay close to average. In Rotterdam the financial services sector pays the highest amount of rent while the business services do the same in The Hague. Within these two graphs the significant differences per sector and each city can be seen. The interrelationships between these rent levels and industry sectors will be further analysed in chapter 4.

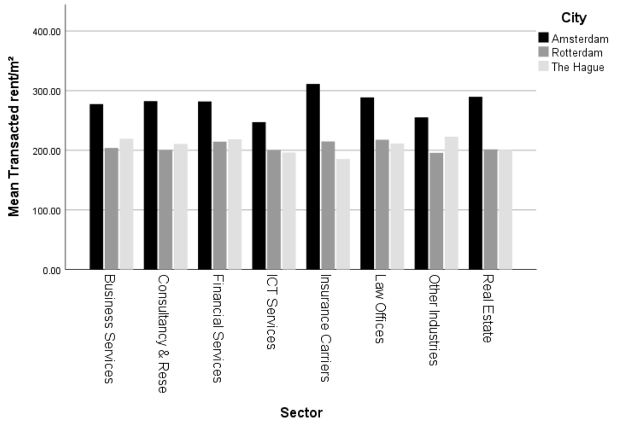

Figure 3.15 – Mean transacted rent/m^2 per sector

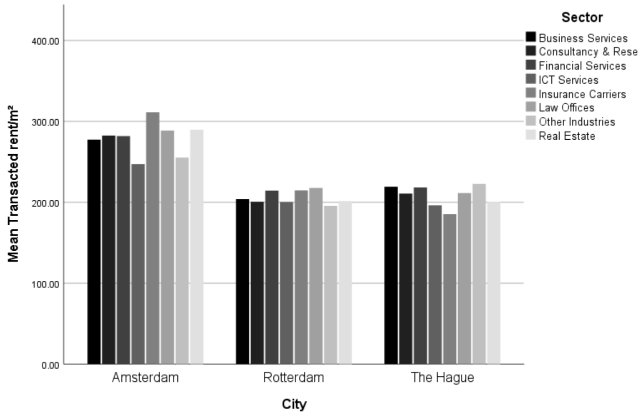

Figure 3.16 – Mean transacted rent/m^2 per city

3.4.2 Descriptive statistics

In order to get an overview of the available data, a descriptive statistics summary is made in table 3.12. The sample amount, mean, standard deviation, minimum, maximum, skewness and Kurtosis are presented for each variable.

While this table provides an accurate overview of the total transaction database, appendix III gives insight into the descriptive statistics which are separated for each city. Additionally, several other variables are shown in the appendix which made no contribution to the rest of the study. In the table above the mean face rent of EUR 239 can be seen. All monetary values are corrected for inflation to 2019 euros with 2015 as the base year.

The average number of floors throughout the database is just above 20 while the average number of tenants is close to 97. The significant differences in range between the independent variables is also worth noting. While the range for number of floors, logically, is rather small, the difference between the maximum and minimum of lettable floor area (LFA) is quite significant. This wide range of floor space in the transaction database also results in a standard deviation which is rather large. The skewness and kurtosis values also show bigger numbers compared to some other continuous independent variables. As the skewness value is positive, the normality plot for this variable is shifted to the left (Field, 2013). This means that there are significantly more smaller transactions compared to large transactions. If a normality plot of a certain variable is evenly distributed, the kurtosis value would be zero. The closer to zero, the more normal the distribution is. The value of 41,82 for the LFA variable indicates that the distribution is more pointy, rather than flat in the centre (Field, 2013).

Variable	N	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis
Headline rent / m^2	1311	238.71	66.89	101.09	478.34	0.601	-0.177
Ln. Headline rent / m^2	1311	5.44	0.28	4.62	6.17	0.012	-0.504
Number of floors	1311	20.10	7.74	10	44	0.732	0.394
Number of tenants	1311	96.83	85.658	2	219	0.310	-1.696
Transaction area (LFA)	1311	1006.49	2129.49	25.00	24.359.12	5.630	41.817
Distance to nearest station	1311	373.02	398.53	50.50	3.313.86	2.581	10.045
Distance to nearest highway	1311	2315.12	1022.06	288.65	1.022.06	0.525	0.189
Total term of lease	1222	6.1060	3.49	0.35	21.01	0.982	1.095
Years since last renovation	1311	29.58	19.28	2.00	68.00	0.794	-0.243
Number of elevators	1311	11.34	6.08	2	28	0.589	-0.454
Number of parking spots	1311	489.16	265.87	0	1094	0.252	-0.802
Number of employees of a tenant	739	4546.39	21345.80	1	300000	9.282	109.157
Ln Assets/Employee	732	12.64	1.94	8.96	19.52	0.994	0.785
Ln Revenue/Employee	419	12.74	1.35	9.27	17.34	0.965	0.969
Highest floor	1311	10.08	7.26	0	44	1.307	2.160
Relative floor	1311	0.50	0.26	0.00	1.00	0.015	-0.997
Penthouse Effect	1311	0.01	0.113	0	1	8.616	72.352
Single floor tenants	1311	0.85	0.356	0	1	-1.975	1.905
Multiple floor tenants	1311	0.15	0.356	0	1	1.975	1.905
Ground Floor	1311	0.05	0.216	0	1	4.191	15.584
Floor 1 to 5	1311	0.32	0.467	0	1	0.770	-1.410
Floor 6 to 10	1311	0.34	0.475	0	1	0.656	-1.572
Floor 11 to 15	1311	0.21	0.410	0	1	1.398	-0.045
Floor 16 to 20	1311	0.11	0.309	0	1	2.548	4.499
Floor 21 to 25	1311	0.06	0.235	0	1	3.756	12.126
Floor 26 to 30	1311	0.02	0.147	0	1	6.503	40.353
Floor 30+	1311	0.02	0.131	0	1	7.355	52.178
ICT Services	1311	0.08	0.274	0	1	3.058	7.365
Financial Services	1311	0.26	0.439	0	1	1.089	-0.815
Insurance Carriers	1311	0.01	0.116	0	1	8.364	68.056
Real Estate	1311	0.04	0.204	0	1	4.480	18.102
Business Services	1311	0.06	0.238	0	1	3.698	11.696
Law Offices	1311	0.06	0.238	0	1	3.698	11.696
Consultancy & Research	1311	0.20	0.401	0	1	1.490	0.220
Other industries	1311	0.28	0.448	0	1	0.993	-1.016
Year Dummy 2000	1311	0.01	0.095	0	1	10.316	104.579
Year Dummy 2001	1311	0.02	0.131	0	1	7.355	52.178
Year Dummy 2002	1311	0.02	0.131	0	1	7.355	52.178
Year Dummy 2003	1311	0.01	0.106	0	1	9.194	82.665
Year Dummy 2004	1311	0.03	0.178	0	1	5.250	25.601
Year Dummy 2005	1311	0.03	0.178	0	1	5.250	25.601
Year Dummy 2006	1311	0.07	0.252	0	1	3.438	9.834
Year Dummy 2007	1311	0.07	0.257	0	1	3.345	9.202
Year Dummy 2008	1311	0.06	0.240	0	1	3.670	11.488
Year Dummy 2009	1311	0.06	0.232	0	1	3.816	12.580
Year Dummy 2010	1311	0.08	0.274	0	1	3.058	7.365
Year Dummy 2011	1311	0.07	0.261	0	1	3.279	8.763
Year Dummy 2012	1311	0.10	0.305	0	1	2.601	4.771
Year Dummy 2013	1311	0.06	0.238	0	1	3.698	11.696
Year Dummy 2014	1311	0.08	0.272	0	1	3.096	7.597
Year Dummy 2015	1311	0.08	0.275	0	1	3.040	7.252
Year Dummy 2016	1311	0.05	0.225	0	1	3.976	13.828
Year Dummy 2017	1311	0.05	0.219	0	1	4.116	14.963
Year Dummy 2018	1311	0.03	0.168	0	1	5.619	29.621
Year Dummy 2019	1311	0.01	0.083	0	1	11.954	141.105
Rotterdam City Centre	1311	0.37	0.484	0	1	0.528	-1.724
Rotterdam Delfshaven	1311	0.05	0.211	0	1	4.309	16.592
Rotterdam Kop van Zuid	1311	0.03	0.174	0	1	5.390	27.091
Amsterdam Omval	1311	0.04	0.204	0	1	4.480	18.102
Amsterdam South-Axis	1311	0.32	0.468	0	1	0.758	-1.427
Amsterdam South-East	1311	0.04	0.202	0	1	4.526	18.513
Amsterdam Westpoort	1311	0.03	0.176	0	1	5.319	26.329
Amsterdam City Centre	1311	0.04	0.190	0	1	4.881	21.861
Amsterdam West-Axis	1311	0.01	0.113	0	1	8.616	72.352
The Hague Laak	1311	0.00	0.062	0	1	16.112	257.992
The Hague Haagse Hout	1311	0.05	0.226	0	1	3.943	13.564

Table 3.12 – Descriptive statistics independent and dependent variables

3.4.3 Outliers

As is described in previous sections, the dataset is analyzed for outliers. The identification of possible outliers within the dataset of each city is done through boxplot diagrams and scatterplots. All values which are presented as extreme outliers, marked with a star, within a boxplots are values that are different in comparison with the rest of the dataset on a significant level. The threshold for what is considered an outlier is three standard deviations (Field, 2013). As the dependent variables within this research are the most important, boxplots are made to identify possible outliers within the variables. Figure 3.17 shows an example of a boxplot diagram analyzing the Ln Transacted Rent/m^2 dependent variable, indicating several outliers. Within the deployed database only the extreme outliers are removed as they could significantly alter the results of the study. In this case transaction number 583 is removed as it is expected to be caused by a human error. By generating a scatterplot, on the same dependent variable, which can be seen in figure 3.18 the deployed dataset can be observed categorized per contract year. Through this scatterplot the outliers can be seen visually. Transaction number 583 can be identified quickly as it is the most significant outlier in year 2009.

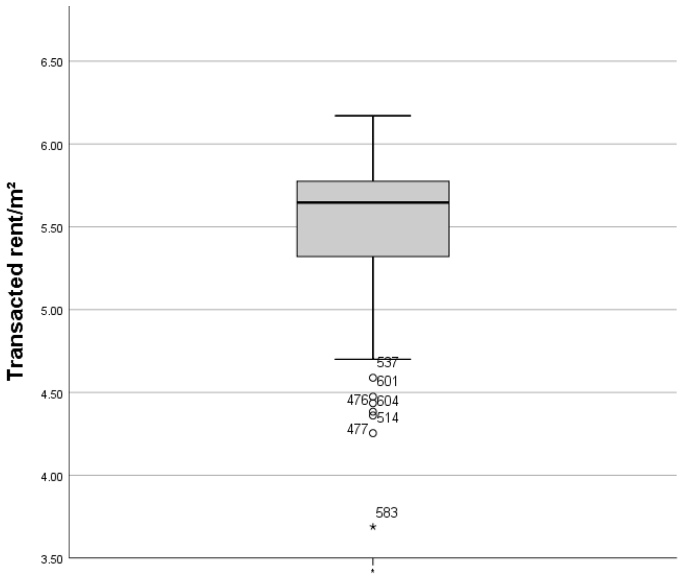

Figure 3.17 - Outliers Ln transacted rent/m^2

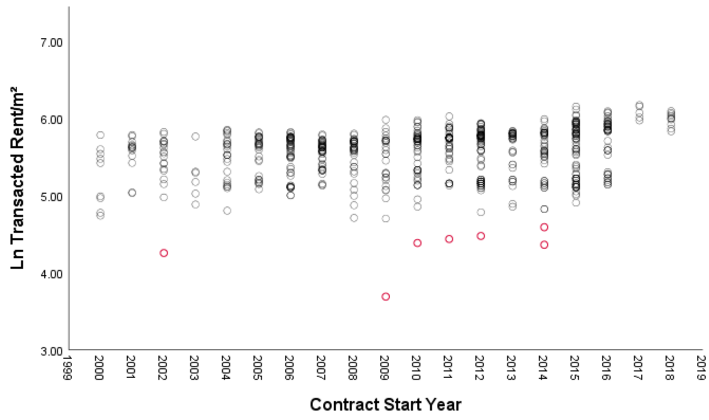

Figure 3.18 – Scatterplot Ln Transacted rent/m^2 per year

Outliers of all important variables are analyzed, however, these are not reported within this study as they are not as important as the dependent variables. Appendix IV shows a brief overview of several other boxplot graphs, divided per city. Figure 3.19 shows the boxplot for the second dependent variable, Ln Highest Floor. Transaction located on the ground floor are identified as outliers but are logically not removed as they are vital within the study.

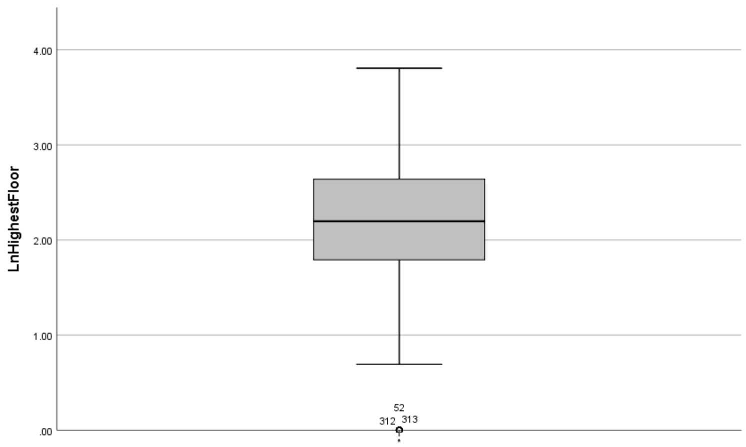

Figure 1.19 – Outliers Ln Highest Floor

3.5 Summary

The third chapter of this study describes the methodology of the research. This methodology section covers the research approach, data collection, model design and a brief analysis on descriptive statistics and the process of fine-tuning the database. The first section of this chapter introduces the quantitative research method alongside the proposed theoretical, empirical, application and evaluation research phases of the study. Section 3.2 goes into detail about the selection of data. Through the identification of multi-tenant tall buildings and eventually the individual rental transactions, the final database is created. Section 3.3 first explains the design of the regression model based on statistical principles and sources. As an extension of the rough regression design, the dependent variable of transacted rent / m^2 per year in 2019 euros is defined. The multiple regression model formula is then supplemented with predictors in the form of independent variables. Section 3.4 offers a brief insight in some of the data analysis procedures as well as the descriptive statistics and the identification of outliers within the database. This section, combined, is the foundation for the empirical analysis chapter of this research.

4

Empirical analysis

Chapter four focuses on the empirical analysis which is the basis for the conclusions and recommendations in the next chapter. In the first section of this chapter the process towards, and the final multiple regression model is presented. Section 4.2 expands on the analysis of the discovered rent premiums through each significant variable. Section 4.3 focuses on the analysis between the interrelationship and the role of tenant characteristics and the sorting of tenants on price premiums per floor and finally section 4.4 provides a summary.

4.1 Multiple regression model

As discussed in the methodology section, multiple regression modelling is utilized to analyse the relationship between rent premiums, vertical sorting and the productivity in the shape of revenue / employee. Within the models the variables from section 3.3.3 are used as input as independent variables while the face rental price per square meter per year deflated to 2019 euros is used as the dependent variable. Within the model the independent variables, as well as fixed effects are used to analyse differences between outputs. The fixed effects in the form of floor level, time and submarket are used to strengthen the model and increase to what extent the variance of the variables can be used to explain the variance of the dependent variable. The final result of the multiple regression modelling is shown in the two tables on the next two pages.

The tables below show the output of ten different multiple regression model. The analysis of these models, in majority, consider the dependent variable of transacted, or face rent, divided by the square meters of the rented space expressed in 2019 euros in log form. Different models are constructed to test various relationships between the independent and dependent variables within the study. This results in ten models which each deploy a different combination of variables. Seven of the constructed models analyse the transacted rent / m^2 while three models are deployed to test the implication of the predictors on vertical sorting within multi-tenant tall office buildings. Throughout this section of the report only coefficients above the 95% level are analysed, which translates to a t-value > 2. Different control variables, in the form of time and space fixed effects through dummy variables are deployed. Within the model, baselines are used for the dummy variables to allow an analysis and comparison to the baseline. For both the time and space fixed effects a singular categorical dummy variable is excluded as input for the model to function as the baseline of the model. The baseline dummy that is used to control for time fixed effects is the year 2000 while the submarket South-Axis is selected as the baseline for spatial fixed effects. This allows the comparison of the reported coefficients to the year 2000 and the South-Axis area.

** = 99% confidence interval	Model 1 (Baseline Model)			Model 2			Model 3			Model 4			Model 5		
* = 95% confidence interval	**Coefficient**	**t-value**	**VIF**	**Coefficient**	**t-value**	**VIF**	**Coefficient**	**t-value**	**VIF**	**Coefficient**	**t-value**	**VIF**	**Coefficient**	**t-value**	**VIF**
Constant	5,745**	38,920		5,707**	39,436		5,650**	40,649		5,669**	38,449		5,401**	26,610	
Object # Floors	0,007**	7,133	2,939	0,007**	7,845	2,960	0,007**	8,257	2,681	0,010**	12,251	2,273	0,006**	5,241	3,400
Object # Tenants	0,001**	12,224	6,198	0,001**	11,731	6,257	0,001**	11,593	6,106	0,001**	12,296	6,197	0,001**	9,305	6,449
Highest Floor Level	0,006**	7,774	1,924	0,018**	9,802	10,607	0,006**	7,662	1,862				0,006**	5,654	2,186
Highest Floor Squared				-0,0004**	-7,099	11,505									
Relative Floor Level										0,149**	8,448	1,182			
Ln Surface Area	-0,007	-1,487	2,542	-0,006	-1,273	2,545	-0,004	-0,832	2,335	-0,006	-1,235	2,541	-0,006	-0,887	3,049
Lease Term	0,003	1,600	2,209	0,004*	2,046	2,217				0,003	1,613	2,209	0,003	1,405	2,320
Ln Distance to Station	-0,001	-0,116	4,748	-0,007	-0,701	4,780	0,001	0,104	4,614	-0,003	-0,275	4,711	0,037**	2,866	4,294
Ln Distance to Highway	-0,015	-0,970	3,780	-0,018	-1,161	3,782	-0,011	-0,751	3,742	-0,015	-0,945	3,779	0,0005	0,024	3,644
Ln Age since Renovation	-0,110**	-9,478	4,657	-0,116**	-10,137	4,679	-0,083**	-7,881	4,070	-0,112**	-9,631	4,658	-0,101**	-7,392	4,206
Elevators #	0,003**	2,670	3,459	0,005**	3,711	3,531	0,004**	3,237	3,386	0,004**	2,785	3,460	0,004*	2,218	3,351
Parking Spots	-0,0002**	-6,133	3,911	-0,0002**	-5,216	3,988	-0,0002**	-7,091	3,888	-0,0002**	-6,120	3,907	-0,0002**	4,411	3,885
Penthouse Effect	-0,008	-0,201	1,107	0,008	0,204	1,110	0,002	0,045	1,106	-0,022	-0,537	1,118	0,005	0,107	1,172
Multiple Floor Tenant	0,030	1,872	1,835	0,023	1,455	1,842	0,029	1,914	1,756	0,028	1,733	1,838	0,017	0,852	2,038
ICT Services	0,040*	2,246	1,279	0,040*	2,292	1,279	0,036*	2,140	1,276	0,037*	2,129	1,281	0,041	1,812	1,346
Financial Services	0,035**	2,875	1,626	0,029*	2,440	1,633	0,032**	2,689	1,619	0,033**	2,686	1,631	0,038*	2,331	1,607
Insurance Carriers	0,041	1,118	1,107	0,059	1,643	1,112	0,043	1,167	1,099	0,046	1,272	1,105	0,040	0,921	1,244
Real Estate	0,050*	2,191	1,194	0,054*	2,381	1,195	0,037	1,683	1,191	0,052*	2,264	1,195	0,038	0,977	1,195
Business Services	0,043*	2,271	1,207	0,034	1,824	1,213	0,043*	2,285	1,197	0,040	2,093	1,209	0,064**	2,691	1,290
Law Offices	0,038	1,999	1,257	0,035	1,836	1,258	0,039*	2,053	1,236	0,038	1,979	1,257	0,021	0,880	1,360
Consultancy Services	0,035**	2,780	1,478	0,036	2,891	1,478	0,035**	2,841	1,462	0,034**	2,723	1,479	0,039*	2,354	1,467
Ln Tenant Employees													-0,005	-1,856	1,593
Ln Tenant Asset/Employee													0,002	0,575	1,325
Ln Tenant Revenue/Employee															
Dependent variable	Ln Transacted Rent / m²			Ln Transacted Rent / m²			Ln Transacted Rent / m²			Ln Transacted Rent / m²			Ln Transacted Rent / m²		
N	1.223			1.223			1.311			1.223			679		
k	49			50			48			49			51		
Nk-ratio	24,96			24,46			27,31			24,96			13,31		
Time Fixed Effects (Trans. Year)	Yes (19)			Yes (19)			Yes (19)			Yes (19)			Yes (19)		
Space Fixed Effects (Submarket)	Yes (10)			Yes (10)			Yes (10)			Yes (10)			Yes (10)		
R^2	0,730			0,741			0,726			0,732			0,758		
Adjusted R^2	0,719			0,730			0,716			0,722			0,739		
Standard Error Estimate	0,14672			0,14373			0,14815			0,14608			0,14054		

** = 99% confidence interval	Model 6			Model 7			Model 8 (Baseline Model)			Model 9			Model 10		
* = 95% confidence interval	**Coefficient**	**t-value**	**VIF**	**Coefficient**	**t-value**	**VIF**	**Coefficient**	**t-value**	**VIF**	**Coefficient**	**t-value**	**VIF**	**Coefficient**	**t-value**	**VIF**
Constant	5,569**	20,882		5,650**	35,495		1,933**	9,906		1,379**	4,020		0,946*	2,103	
Object # Floors	0,005**	3,278	4,218	0,004**	3,238	3,561									
Object # Tenants	0,001**	3,439	9,124	0,001**	4,911	8,616									
Highest Floor Level	0,006**	4,060	2,746	0,006**	6,543	2,016									
Highest Floor Squared															
Relative Floor Level															
Ln Surface Area	0,001	0,059	2,589	-0,005	-0,650	2,329									
Lease Term	0,005	1,804	2,353	0,003	1,644	1,967									
Ln Distance to Station	0,010	0,570	4,769	-0,018	-1,650	4,262									
Ln Distance to Highway	-0,024	-0,941	3,329	0,004	0,226	3,299									
Ln Age since Renovation	-0,067**	-3,643	4,159	-0,088**	-6,829	3,800									
Elevators #	0,001	0,671	3,806	0,004**	2,709	3,106									
Parking Spots	-0,0000	-1,203	5,035	-0,0000*	-2,158	5,057									
Penthouse Effect	0,058	1,098	1,255	-0,008	-0,193	1,122									
Multiple Floor Tenant	-0,021	-0,833	2,328	0,023	1,280	2,060	0,181**	3,266	1,177	0,171*	2,407	1,336	0,294**	3,703	1,361
ICT Services	0,060	1,707	1,452	0,052*	2,257	1,287	0,181*	2,425	1,249	0,136	1,455	1,267	0,368**	2,732	1,277
Financial Services	0,043*	2,126	1,702	0,035*	2,423	1,682	0,273**	5,261	1,560	0,187**	2,723	1,529	0,136	1,685	1,628
Insurance Carriers	0,066	1,521	1,284	0,067	1,622	1,129	0,282	1,728	1,082	0,247	1,256	1,202	0,057	0,314	1,230
Real Estate	0,059	1,038	1,297	0,044	1,786	1,237	-0,004	-0,045	1,182	-0,175	-1,060	1,168	-0,110	-0,514	1,2416
Business Services	0,033	0,791	1,369	0,061*	2,405	1,204	0,225**	2,704	1,171	0,184	1,775	1,239	-0,121	-0,737	1,289
Law Offices	-0,021	-0,466	1,347	0,050*	2,283	1,298	0,403**	4,801	1,198	0,437**	4,202	1,273	0,407*	2,161	1,243
Consultancy Services	0,041	1,719	1,544	0,030	1,919	1,462	0,158**	2,899	1,439	0,113	1,568	1,409	-0,026	-0,272	1,468
Ln Tenant Employees	-0,011**	-3,015	1,361							-0,0004	-0,035	1,312	0,007	0,503	1,249
Ln Tenant Asset/Employee										0,028*	2,069	1,253			
Ln Tenant Revenue/Employee	0,001	0,172	1,303										0,048*	2,027	1,206
Dependent variable	Ln Transacted Rent / m²			Ln Transacted Rent / m²			Ln Highest Floor			Ln Highest Floor			Ln Highest Floor		
N	387			886 (LFA > 200 m²)			1.311			732			419		
k	51			49			37			38			38		
Nk-ratio	7,59			18,08			35,43			19,26			11,03		
Time Fixed Effects (Trans. Year)	Yes (19)			Yes (19)			Yes (19)			Yes (19)			Yes (19)		
Space Fixed Effects (Submarket)	Yes (10)			Yes (10)			Yes (10)			Yes (10)			Yes (10)		
R^2	0,777			0,744			0,173			0,211			0,346		
Adjusted R^2	0,744			0,730			0,149			0,166			0,279		
Standard Error Estimate	0,14007			0,14833			0,66108			0,64120			0,59960		

4.2 Analysis of the rental price premium

As the main question of this study revolves around identifying and analysing the interrelationship between rent premiums, vertical sorting and tenant characteristic values such as productivity. One of the key variables of rent premiums in analysed in this section on the basis of the tables on the previous pages.

The rent premiums, which is denoted as 'Highest Floor Level', remain significant throughout the models at a $p<0{,}01$ level. The coefficient in the baseline model of 0,6% also remains stable throughout the different tested models. The display of the coefficient indicates that tenants are willing to pay 0,6% more rent to locate one floor higher within a multi-tenant tall office buildings within these three cities, *ceteris paribus*. Within the baseline model, the rental price premium is identified by controlling for both time and space fixed effects in the form of transaction year and submarkets respectively. The coefficients for the baseline model are shown in appendix VII.

Although the coefficient value remains stable throughout the models, the controlling for different predictors is required to analyse the robustness of the results. In comparison to previous work by Van Assendelft (2017) and Nase et al. (2018), lease term is used as a control variable within the baseline model. Model 3 tests and concludes that the exclusion of lease term from the multiple regression analysis does not yield different results in terms of price premiums within the deployed dataset. By removing the variable, however, the R^2 and adjusted-R^2 reduce from 0,730 and 0,719 to 0,726 and 0,716 respectively, indicating a loss of explanatory power in the third model while the variance nearly remains the same. The stable coefficient of 0,6% indicates that the result is relatively robust. Within the study by Van Assendelft (2017), an average price premium of 1,0% is concluded, which is 0,4% higher than the coefficient that is concluded in this study. This indicates that the inclusion of Rotterdam and The Hague lowers the price premium per floor coefficient, the individual differences between each city requires further research.

In model 2 a new independent variable is deployed, highest floor squared. Due to the high correlation with highest floor variable (VIF > 10), which can be explained as the former is derived from the latter, the coefficient of the latter changes and provides inaccurate results. The function of this model is to identify the sign of the relationship between highest floor and floor squared. As can be seen in the table the coefficient for highest floor squared is negative, indicating a decline of transacted price / m^2 at the upper percentiles rather than a continuously increasing positive relationship between highest floor and transacted rental price / m^2. This decline of price premium can directly be seen in figure 4.1.

When model 5 and 6, where the variances are tested including additional tenant characteristics an increase in explanatory power, compared to the baseline model, in adjusted-R^2 is shown of 0,020 and 0,025 respectively. Although this indicates an increase in robustness and explanation of the variances within the model, the two models have some flaws. Model 5 and 6 carry an Nk-ratio of 13,31 and 7,59 respectively, indicating a significantly reduced strength of the model compared to the 24,96 in the baseline model. The explanation for these losses in these ratios are the reduction of N due to limited observations within tenant characteristics. Model 5 includes 679 valid transactions based on tenant assets per employee while model 6 considers 387 transactions including the revenue per employee variable valid. Due to limitations of the data source for tenant characteristics, which are discussed in section 5.2, the two models increase in explanatory power, on paper, but reduce in trustworthiness due to the low Nk-ratio.

As is discussed in section 3.4.1, the original threshold of 200 m^2 of office space is not directly utilized within the database as the Rotterdam and The Hague office market could differ from a floor area size perspective. To account for this threshold, model 7 shows the coefficient once the samples with LFA < 200 m^2 are excluded from the linear model. This exclusion results in a loss of 337 transactions, indicating a significant size of the Rotterdam and The Hague office transactions are of relatively low size. Due to the loss of N, the Nk-ratio decreases to a respectable level of 18,08 and increases in terms of explanatory power to an adjusted-R^2 of 0,730 compared to the 0,719 of the baseline model. This increase indicates that the accuracy of the price premiums per floors coefficient increases once the lower-end transactions are excluded. A similar test for LFA > 500 m^2 transactions results in a significant loss in explanatory power, alongside a large variance between R^2 and adjusted-R^2 and a high standard error of the estimate. This indicates the model becomes more inaccurate once the 669 transactions which are below 500 m^2 are excluded, therefore this model is not used within the study.

Model 4 considers the second variable, within the analysis of the aforementioned interrelationship, of relative floor height. This independent variable can be used to analyse the vertical sorting of tenants in section 4.3, but also the identification of the percentage tenants are willing to pay more to move up a relative floor value. This relative floor value is directly related to the 'status effect' of section 2.4 while the highest floor is connected to the 'view effect'. Within model 4 a coefficient of 0,149 can be seen. However, as this variable is considered on a scale from 0-1 rather than a 0-100 two zeroes need to be added, resulting in a 1,5% increase in willingness to pay per tenth of a relative floor level. The model has a slightly higher explanatory value with an R^2 0,732 and adjusted R^2 of 0,722. Thus represents a more robust model compared to the baseline.

The third major finding from literature is the 'within-building agglomeration effects' which are covered through the inclusion of the independent variable of number of tenants within a building. Throughout the models this results in a positive sign and coefficient of 0,1%, indicating tenants are willing to pay 0,1% more rent for each additional tenant within a building. These results are identical in comparison with previously conducted research by Van Assendelft (2017).

To gain a better understanding of how the rent premium behaves throughout a building the coefficient for each respective floor is analysed through the model in appendix VI. Within this model, highest floor and fixed effects are excluded while a fixed effect dummy for each floor is added with a baseline of the 1st floor. By comparing each respective coefficient to the baseline a rent premium graph is plotted which can be seen in figure 4.1.

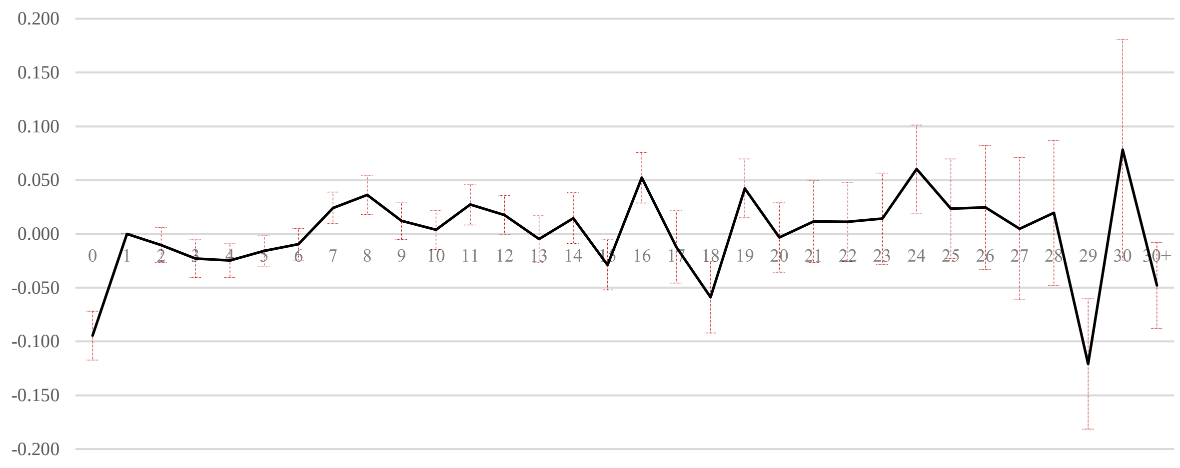

Figure 4.1 – Rent premium coefficient per floor

Each coefficient variable as presented in the appendix VI table is, first, corrected based on the exp.(β)-1 formula as it provides more accurate results. An example of such a coefficient correction can be seen in table 4.1. This table, however, shows the results of a correction on a separate dummy variable. All dummy variables throughout the study are corrected in a similar fashion.

By looking at the graph a similar pattern as previously conducted research can be seen where there is a drop-off in rent premiums and rent levels after the ground floor and first floor of a building due to accessibility restrictions and hardly any additional amenity benefits. The ground floor shows a negative coefficient, indicating a negative rent premium for the ground floor. This negative rent premium is a contrasting finding compared to studies conducted by Van Assendelft (2017) and Liu et al. (2018). The former study indicates a similar rent premium for the ground floor as the first to fifth floor in a research which is conducted in a similar context. The latter research concludes in a highly positive price premium for the ground floor. These results, however, are gathered from a different context as retail transactions are included and the gathered data concerns taller buildings in the United States. Up to floor 12 a marginal increase in rent premiums can be identified in comparison to the baseline of the first floor. However, patterns start to become more vague as the floor levels increase. Significant spikes in both positive and negative direction occur without a significant pattern. As figure 4.2 illustrates, transactions per floor level significantly decrease as floor levels go up. This effect results in large interval bars indicating low accuracy of the coefficient. Due to the low transaction numbers, the high floors are susceptible to degrees of error and could indicate inaccurate values.

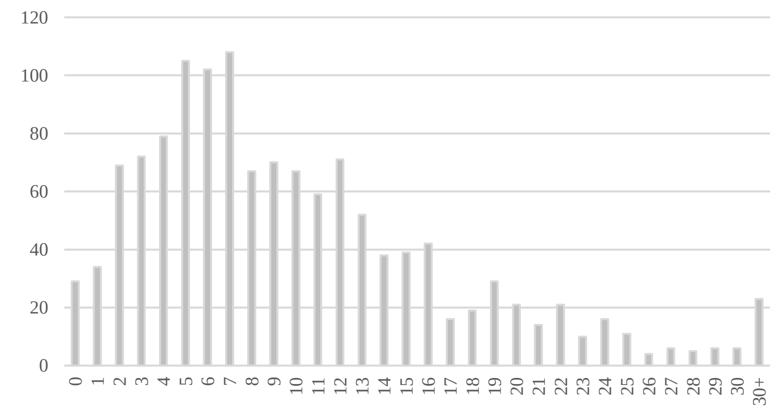

Figure 4.2 – N transactions per floor

By looking at a the floor with the largest deviation from 0 specifically, which is floor 29, another possible explanation can be identified on why the coefficient is negative. In floor 29 specifically, large transactions take place with an average around 4.500 m^2. Larger transactions tend to have lower rent levels and in combination with low samples for that specific floor, skewed information could be portrayed.

As the confidence interval bars increase significantly per floor level it becomes difficult to gather results in the form of patterns from figure 4.1. To gain a better understanding in what patterns occur within the higher floor of multi-tenant office buildings within the three cities, floor level dummies are categorized into brackets of five floors as can be seen in table 4.1. A separate multiple regression model is run which includes a dummy variable for each respective floor bracket. The outcomes concerning the coefficients of this model can be seen in the table as well. Following the model, each respective coefficient value is corrected according to the aforementioned formula. By implementing a baseline of floor dummy 1 to 5 a graph can be plotted which provides a better insight in to floor level price premiums brackets and its development throughout a building. The plotted graph can be seen in figure 4.3.

Dummy Variable	**Coefficient correction**	
	c	**g**
Ground Floor	-0,080	-0,077
Floor 6 to 10	0,057	0,058
Floor 11 to 15	0,061	0,063
Floor 16 to 20	0,080	0,083
Floor 21 to 25	0,094	0,098
Floor 26 to 30	0,082	0,085
Floor 30 +	0,039	0,026

Table 4.1 – Dummy coefficient corrections

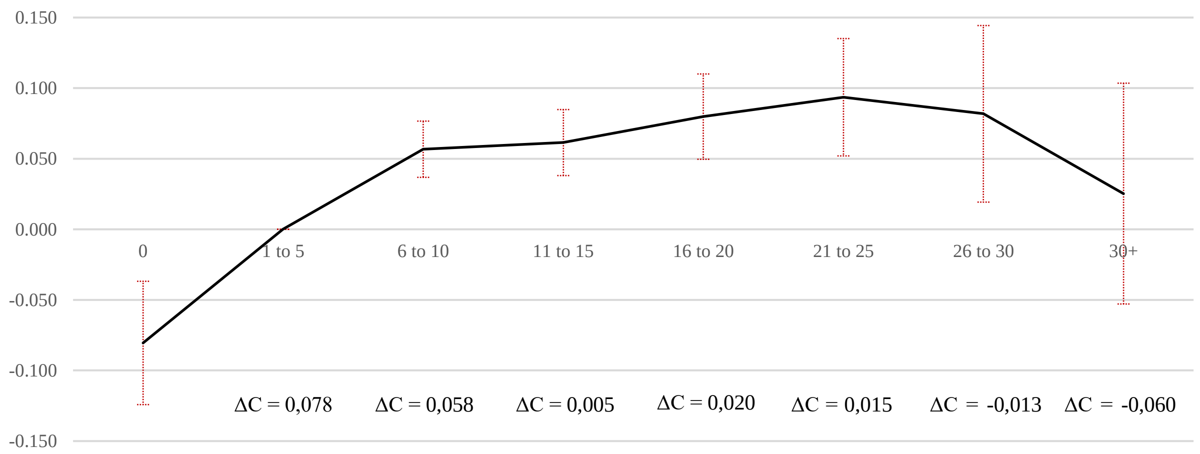

Figure 4.3 – Rent premium coefficient per floor bracket

In turn, this graph offers more insight into what occurs on higher levels of office floors in terms of price premiums. A deviation between -7,7% for the ground floor and 9,8% for floor 21 to 25 can be seen in comparison to the baseline. The values of the line in the graph depicts the coefficient compared to the baseline but does not give insights into the differences between each respective floor. The graph also depicts ΔC, indicating the difference between coefficients between two brackets and thus the percentage increase between two floors. With bracket 1 to 5 as a baseline, a negative coefficient can be seen for the ground floor, indicating lower rents in bracket. As office space tends to be amenity oriented rather than access oriented such as the retail market, this is an expected result. From the ground floor to bracket 1 to 5 a 7,8% in price premiums is identified. Together with a 5,8% increase between 1-5 and 6-10 these are the steepest differences between floor levels. Above ten floors the ΔC variable decreases with a 0,5%, 2,0% and 1,5% increase respectively. Beyond the 25th floor level ΔC becomes negative, indicating a decline in price premiums, with a value of -1,3% and -6,0% for the highest two floor brackets.

These results are in contrast with previous studies by Van Assendelft (2017) and Nase et al. (2018) who conclude a monotonic, progressive rent premium graph. The regressive trend starting in the higher floor levels seems to be caused primarily by the Rotterdam transactions as can be seen in appendix X. Price premiums in Rotterdam rise much faster in the lower floors and then decline after floor 16 to 20 while the highest price premiums in Amsterdam are found after this floor bracket.

Three possible explanations are offered for the decline in price premiums at the highest two floor dummy brackets. As can be seen in figure 4.3, the confidence intervals increase gradually as one moves up in floor level brackets. The explanation of these high confidence interval bars can be seen in figure 4.4 where the number of transactions per floor bracket are shown. This graph mimics the reverse of the confidence interval bar pattern. While the amount of transaction per floor decreases, the size of the confidence interval bars increase. The limited samples within the 26-30 and 30+ bracket are a possible explanation of the decrease in rent premiums in the higher floors. The results within figure 4.3, therefore, need to be treated with care.

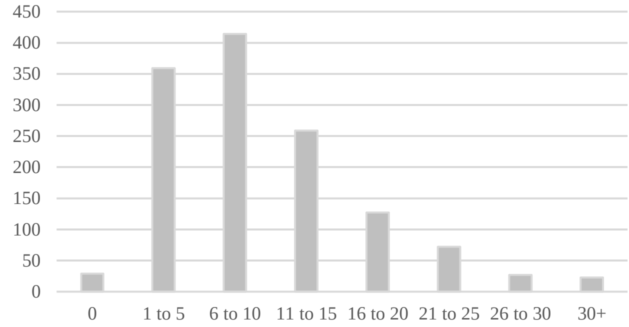

Figure 4.4 – N transactions per floor bracket

The second possible explanation for the decreasing rent premiums is the trade-off between access and amenity for tenants. As described in previous research the patterns within tall buildings are a reflection between the benefits that verticality offers and the benefits that accessibility offer. As floors become gradually higher, the accessibility of office space reduces while amenities increase. A possible explanation for the decrease in these rent premiums is a shift in a trade-off between these two factors. Possibly, amenities offer diminishing values once floor height increases while accessibility reduces linearly. This could result in a shifting point near floor 25 in the Dutch office market where the benefits no longer outweigh the accessibility limitations.

The final possible explanation for the reducing price premiums in the upper floors is the presence of large tenants in the upper floors of a building in terms of floor space. Large tenants are more willing to move in to higher floors due to possible status effects. Large tenants within a certain object could be able to negotiate lower rental prices due to their importance for the success of a building as they are able to provide value to other tenants within a building through externalities (Liu, Rosenthal, & Strange, 2017). To analyse whether this large tenant effect could provide an explanation for the decrease in premium a crosstab is made between average transaction size per floor bracket. This crosstab analysis is translated to the graph in figure 4.5. Immediately a significant upwards trend can be seen which indicates that the higher floors tend to have

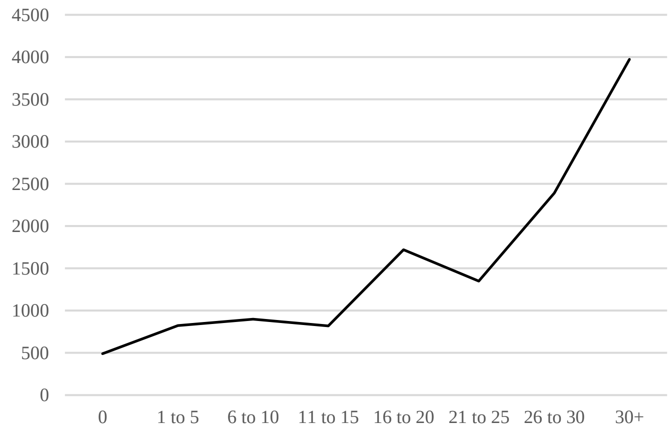

Figure 4.5 – Mean Transaction Size per Floor Bracket

larger transactions compared to the lower floors. This confirms that large tenants could possibly have a significant effect on rental price premiums per floor through a better negotiation position compared to lower floor tenants.

Two interaction models are run to gain insights in the differences of willingness to pay for both absolute and relative height per submarket. The outcomes of these models are depicted in table 4.2. Within the interaction term comparison the exp.(β)-1 formula is used as this formula is the most accepted throughout the field of study. Based on this formula the differences in sectors compared to the baseline can be expressed in percentages through the formula $((\exp(\beta)-1^{Submarket}) - (\exp(\beta)-1^{Baseline}))/(\exp(\beta)-1^{Baseline})$. Figure 4.6 illustrates the differences in terms of willingness to pay based on specific submarkets for both absolute and relative height. As can be seen in the model's table, the dummies Amsterdam West Axis, The Hague Laak and The Hague Haagse Hout are deemed insignificant and are therefore excluded from analysis for both absolute and relative height. Similar to previous models, the South Axis submarket is used as a baseline. The left graph in figure 4.6 shows that the willingness to pay for absolute height is lower for all submarkets compared to the South Axis. Two other submarkets in Amsterdam come relatively close, the Omval and City Centre submarket. Significant differences between the willingness to pay for absolute height can be seen, ranging from -26,5% in the Omval to -259% in Delfshaven. The right graph shows a similar stepwise order of submarkets, although the Westpoort submarket values relative height higher compared to the adjacent bars of Amsterdam South East and Rotterdam Delfshaven. The significant difference between Rotterdam Delfshaven and Amsterdam South East has also disappeared, indicating that the Delfshaven submarket puts a higher value on relative height than absolute height. Most interesting, however, is the positive value of the Omval, indicating a higher willingness to pay for relative height compared to the South Axis submarket. This result should however, be treated with care due to a limited sample in the submarket.

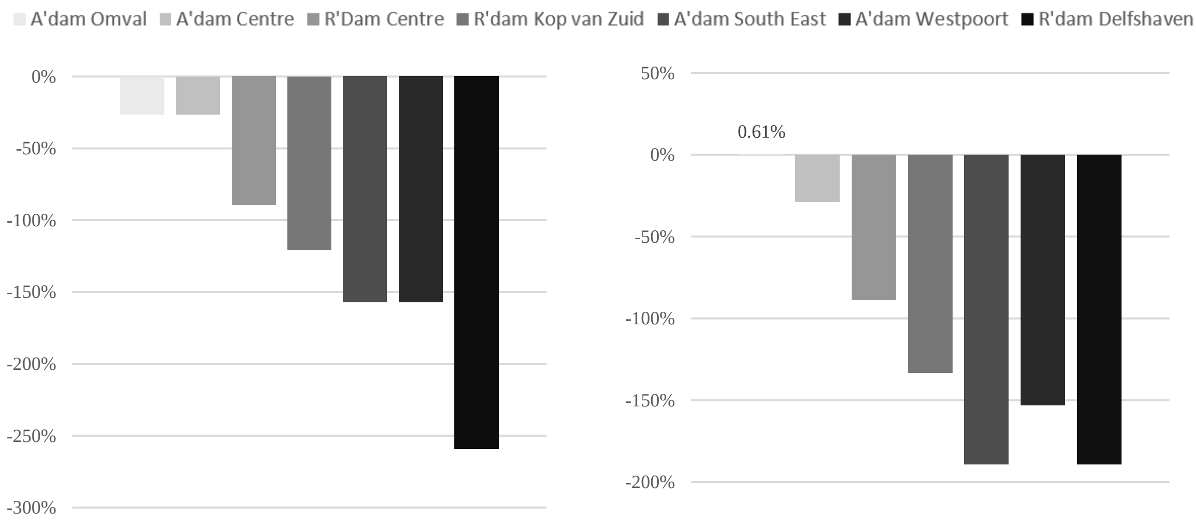

Figure 2.6 – Willingness to pay for Absolute (left) and Relative (right) height (legend illustrates bars from left to right)

** = 99% confidence interval	Model 11			Model 12		
* = 95% confidence interval	**Coefficient**	**t-value**	**VIF**	**Coefficient**	**t-value**	**VIF**
Constant	6.122**	41.603		6.159**	43.260	
Object # Floors	0.009**	10.213	2.470	0.012**	14.378	2.022
Object # Tenants	0.002**	13.596	5.864	0.002**	12.736	6.045
Ln Surface Area	0.005	1.069	1.886	0.003	0.726	1.904
Lease Term	0.005**	2.833	2.077	0.005**	2.732	2.087
Ln Distance to Station	-0.043**	-4.433	3.553	-0.056**	-6.031	3.359
Ln Distance to Highway	-0.066**	-4.566	2.906	-0.066**	-4.589	2.883
Ln Age since Renovation	-0.165**	-14.154	4.163	-0.158**	-13.944	3.960
Elevators #	-0.001	-1.155	2.720	-0.001	-0.701	2.866
Parking Spots	0.0000	0.024	3.161	-0.0000*	-2.369	3.174
Highest Floor * Dummy R'dam City Centre	0.002*	2.133	2.170			
Highest Floor * Dummy R'dam Delfshaven	-0.031**	-10.115	2.721			
Highest Floor * Dummy R'dam Kop van Zuid	-0.004**	-3.248	1.948			
Highest Floor * Dummy A'dam Omval	0.014**	9.733	1.630			
Highest Floor * Dummy A'dam South Axis	0.019**	15.352	2.646			
Highest Floor * Dummy A'dam South East	-0.011**	-3.736	1.387			
Highest Floor * Dummy A'dam Westpoort	-0.011**	-5.592	1.330			
Highest Floor * Dummy A'dam City Centre	0.014**	5.038	1.709			
Highest Floor * Dummy A'dam West Axis	-0.001	-0.185	1.199			
Highest Floor * Dummy The Hague Laak	-0.019	-1.825	1.062			
Highest Floor * Dummy The Hague Haagse Hout	0.000	0.052	1.751			
Relative Floor * Dummy R'dam City Centre				0.055*	2.238	2.249
Relative Floor * Dummy R'dam Delfshaven				-0.576**	-8.966	2.745
Relative Floor * Dummy R'dam Kop van Zuid				-0.178**	-3.796	1.723
Relative Floor * Dummy A'dam Omval				0.401**	8.566	1.437
Relative Floor * Dummy A'dam South Axis				0.399**	15.502	2.740
Relative Floor * Dummy A'dam South East				-0.198**	-3.563	1.416
Relative Floor * Dummy A'dam Westpoort				-0.302**	-6.213	1.313
Relative Floor * Dummy A'dam City Centre				0.299**	5.565	1.752
Relative Floor * Dummy A'dam West Axis				0.029	0.364	1.219
Relative Floor * Dummy The Hague Laak				-0.287	-1.845	1.067
Relative Floor * Dummy The Hague Haagse Hout				0.028	0.638	1.688
Dependent variable	Ln Transacted rent / m^2			Ln Transacted rent / m^2		
N	1.222			1.222		
k	39			39		
Nk-ratio	31,33			31,33		
Time Fixed Effects (Trans. Year)	Yes (19)			Yes (19)		
Space Fixed Effects (Submarket)	No (See interaction term)			No (See interaction term)		
R^2	0,697			0,697		
Adjusted R^2	0,687			0,687		
Standard Error Estimate	0,15497			0,15491		

*Table 4.2 – Interaction term models – Highest/Relative Floor * Submarkets*

4.3 Tenant characteristics in relation to price premiums and vertical sorting

Within the interrelationship between price premiums, vertical sorting and productivity, tenant characteristics play a vital role. The vertical sorting within this interrelationship through SBI-codes and productivity, or tenant characteristics are identified within this chapter on the basis of the table of ten linear multiple regression models in section 4.1. Additional interaction terms are used as input within models to shed more light on the relationship between productivity and floor levels.

Within the baseline model, ICT services, Real Estate and Business services are significant at a $p<0,05$ level while Financial Services and Consultancy Services are significant at a $p<0,01$ level. The coefficients of each respective industry sector variable describes to what extent the sector pays more rent per square meter in comparison to the 'Other Industries' sector baseline, *ceteris paribus*. Similar to the independent variables in section 4.2, the sector variables are controlled for both time and space fixed effects. The coefficients of these fixed effects within the baseline regression model are shown in appendix VII. Based on the baseline model, ICT Services, Financial Services, Real Estate, Business Services and Consultancy Services indicate 4,0%, 3,5%, 5,0%, 4,3% and 3,5% increased rent values per square meter in comparison to the Other Industries baseline.

When the baseline is compared to different iterations of the multiple regression model difference in significance levels as well as coefficients become apparent. By removing lease term as an independent variable, the transaction sample increases and the real estate sector loses its significant level of $p<0,05$ while law offices become significant. In comparison to model 1, model 3 adds relative floor level instead of highest floor. This adaptation leaves all the significant sectors in model 1, significant in model 4, except business services. The addition of model 5, brings a reduction to the number of transactions in the database, resulting in a loss of significance for the ICT sector as well as real estate. Model 6, with a transaction sample of 387, only financial services, remain significant. The analysis of the different models concludes that the differences between each regression model in the table yields altered results in terms of variance. The loss and gain of significance of multiple sector indicates a weakness within the predictive power of the variables in terms of rent paid per square meter. The only sector to remain significant throughout the different models is the financial services sector at a $p<0,05$ level with a coefficient range of 2,9% to 4,3%.

However, as this research analyses the interrelationship between productivity, in the form of revenue per employee, price premiums per floor level and vertical sorting, not only the coefficient with transacted rent / m^2 is interesting. In model 8 through 10 the dependent variable is changed to highest floor in log form to analyse the relationship between productivity, tenant characteristics and vertical sorting. The fixed effect coefficient overview is presented in appendix VIII.

Model 8, including tenant characteristic variables, results in an adjusted-R^2 of 0,149. In comparison to the previously analysed models, the sectors in this model are an indication whether specific sectors tend to locate higher within a building. Model 9 includes Ln Tenant Employees and Ln Asset/Employee as two new independent variables, increasing the predictive power of the model, but also increasing the spread between R^2 and adjusted R^2. Model 10 shows a higher spread as the transaction samples which are eligible as input reduces, also resulting in a lower Nk-ratio.

Within the final model, an elasticity of 4,8% between the Ln Tenant Revenue / Employee and Ln Highest Floor is reported. As both independent and dependent variable are in transformed form, the elasticity indicates that a one percent increase in productivity is correlated to a 4,8% change in floor height. This suggests that more productive firms locate higher up in a building. The elasticity between these two variables is proven on a 95% confidence interval ($p<0,05$). The reported elasticity of 4,8% is slightly higher compared to previous research of Liu et al. (2018). In their research a positive elasticity of 2,6% is reported. The compared research however, is significantly different in sheer size of the database and is also different in context. The context of the research is USA, resulting in a significantly different building context as well, as buildings there contain more floor levels.

An additional interesting observation within the last three models testing for vertical location is the consistent positive coefficient of 1,7% to 2.9% of multiple floor tenants, indicating that tenants who rent multiple floors within a single building, tend to locate 1,7% to 2,9% higher compared to single floor tenants. Throughout the three tested models the multiple floor tenant variable remains significant at a $p<0,05$ value.

In order to analyse the interrelationship between vertical sorting of tenant sectors in relation to rental prices per m^2, interaction terms are added within two separate models in table 4.3. By testing interaction terms within additional models the differences in terms of price for transacted rent / m^2 per tenant class are tested. Figure 4.7 illustrates the willingness to pay for height amenities for highest and relative floor respectively in comparison to the other industries baseline.

From the left graph a significant increase of willingness to pay in terms of price differentials can be seen for the business services sector followed by the financial services and consultancy sector. While comparing the first and second graph, consultancy firms are third highest in terms of the overall height differential while they are at the absolute bottom in terms of relative height. Real estate offices show marginal interest in overall height but are first in terms of relative height, indicating a strong preference for relative floor, which is connected to the status effect discussed in chapter 2. Despite the inaccuracies due to a unevenly distributed sample across the tenant sectors, it can be concluded that business services and financial services show the most willingness to pay while ICT services and insurance carriers show the least willingness to pay for height in comparison to the other industries category. All sectors also tend to locate higher on a relative level compared to other industries while this is not the case for absolute height.

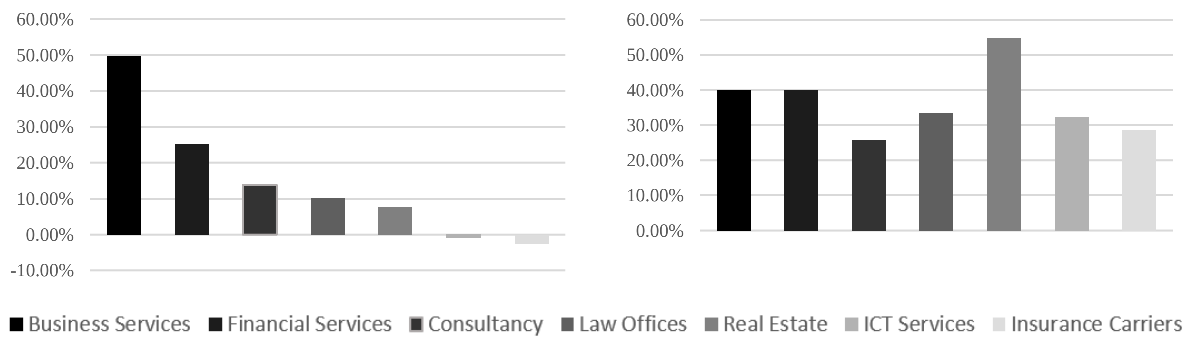

Figure 4.7 – Sector comparison in terms of rent for highest floor and relative height respectively

** = 99% confidence interval	Model 13			Model 14		
* = 95% confidence interval	Coefficient	t-value	VIF	Coefficient	t-value	VIF
Constant	5,757	39,082		5,664**	38,438	
Object # Floors	0,007**	7,100	2,879	0,010**	12,305	2,261
Object # Tenants	0,001**	12,196	6,208	0,001**	12,253	6,226
Ln Surface Area	-0,003	-0,739	2,021	-0,002	-0,525	2,008
Lease Term	0,004	1,948	2,217	0,003	1,938	2,211
Ln Distance to Station	0,0005	0,045	4,731	-0,001	-0,135	4,588
Ln Distance to Highway	-0,018	-1,191	3,742	-0,016	-1,013	3,779
Ln Age since Renovation	-0,111**	-9,522	4,627	-0,112**	-9,658	4,624
Elevators #	0,004**	2,902	3,395	0,004**	2,887	3,419
Parking Spots	-0,0002**	-6,379	3,893	-0,0002**	-6,293	3,897
Int. HFL * ICT Services	0,0058**	4,127	1,339			
Int. HFL * Financial Services	0,0073**	7,559	1,855			
Int. HFL * Insurance Carriers	0,0057**	2,807	1,172			
Int. HFL * Real Estate	0,0063**	3,524	1,232			
Int. HFL * Business Services	0,0087**	5,164	1,240			
Int. HFL * Law Offices	0,0064**	4,890	1,350			
Int. HFL * Consultancy	0,0066**	6,330	1,615			
Int. HFL * Other Industries	0,0058**	5,483	1,764			
Int. RFL * ICT Services				0,168**	5,437	1,337
Int. RFL * Financial Services				0,168**	8,096	1,752
Int. RFL * Insurance Carriers				0,152*	2,470	1,134
Int. RFL * Real Estate				0,160**	3,731	1,203
Int. RFL * Business Services				0,184**	5,383	1,241
Int. RFL * Law Offices				0,159**	4,902	1,276
Int. RFL * Consultancy				0,155**	6,717	1,614
Int. RFL * Other Industries				0,123**	5,363	1,725
Dependent variable	Ln Transacted rent / m^2			Ln Transacted rent / m^2		
N	1.222			1.222		
k	47			47		
Nk-ratio	26,00			26,00		
Time Fixed Effects (Trans. Year)	Yes (19)			Yes (19)		
Space Fixed Effects (Submarket)	Yes (10)			Yes (10)		
R^2	0,727			0,730		
Adjusted R^2	0,716			0,719		
Standard Error Estimate	0,14758			0,14681		

*Table 4.3 – Interaction term models – Highest/Relative floor * sectors*

Alongside the interaction tests presented above, additional interaction tests between the highest floor and tenant employees, as well as relative floor and tenant employees are conducted. These test do not yield significant results. Additionally, a model is constructed to analyse the interaction between tenant revenue per employee and floor bracket levels dummy, which is added in appendix IX. However, these also do not report significant coefficients.

When the findings from figure 4.7 are compared to previously conducted research by Van Assendelft (2017) and Nase et al. (2018), different patterns in terms of vertical sorting per industry sector can be seen. Both studies, which are based on the same dataset, indicate that law firms tend to locate the highest in terms of absolute height while they are only the fourth sector in figure 4.7. A test model is run, identical to model 13, only using the Amsterdam data as input, as this city is the context of both the previous studies. The results of this model indicates that the different data sources in terms of coding is one of the main causes of the differences in terms of vertical sorting conclusions. As the data source which is used in previous research is no longer accessible due to licensing limitations, an accurate substitute source is used. This source, however, classifies businesses differently in terms of SBI-coding. The database of Van Assendelft (2017) is recoded in terms of sectors in order to create a complete data set which uses the same data source. While the original source provided more in-depth SBI-codes, several large tenants, in terms of employees, within the deployed dataset are classified under a holding code. Additionally, the utilized source for tenant characteristics suffers from a liability where corporate structures become increasingly tangled and difficult. These discrepancies cause a different order of sectors in terms of vertical sorting.

In order to obtain a better understanding of the transaction database sample in terms of tenant sectors and the size of each respective category, an overview is made in table 4.4. This table provides an overview of the complete dataset categorized by sector and floor bracket. Each floor bracket holds a specific percentage of observations. Within the table the large differences in terms of population is observable within the 'All' column. While Other Industries and Financial Services hold 27,5% and 26,3% of the dataset respectively, Real Estate and Insurance carriers only hold 4,8% and 2,2% of the total rental transactions.

Similarly to the sector division of all transaction data, the build-up of office space within certain sectors also indicate particular patterns. While the ICT Services, Financial Services, Real Estate, Consultancy & Research and Other Industries sectors show relatively evenly divided build-ups of office space divided over the brackets, with a few ups and downs, the Insurance and Law sector show a particular upwards trend near the 16-20th floor level. The table also shows the significant reduction of office space transactions per floor bracket. 63% of all office transactions are located within the first ten floors while only 1,5% is above 30 floors and 4,3% is situated on the ground floor.

Sector	All	GF	Fl. 1-5	Fl. 6-10	Fl. 11-15	Fl. 16-20	Fl. 21-25	Fl. 26-30	Fl. 30+
ICT Services	7,7%	4,7%	7,1%	8,6%	8,2%	3,6%	11,7%	6,9%	13,0%
Financial Services	26,3%	18,8%	20,7%	23,5%	34,3%	43,6%	23,4%	24,1%	13,0%
Insurance Carriers	2,2%	4,7%	1,9%	1,1%	0,4%	4,3%	6,5%	10,3%	4,3%
Real Estate	4,8%	9,4%	6,4%	3,3%	3,2%	5,0%	5,2%	3,4%	8,7%
Business Services	5,5%	3,1%	4,8%	6,2%	5,7%	8,6%	3,9%	0,0%	0,0%
Law Offices	6,5%	6,3%	5,7%	6,4%	5,4%	5,0%	10,4%	17,2%	17,4%
Consultancy & Research	19,5%	12,5%	21,7%	21,1%	17,5%	11,4%	28,6%	13,8%	17,4%
Other Industries	27,5%	40,5%	31,7%	29,7%	25,4%	18,6%	10,4%	24,1%	26,1%
Percentage of brackets	**100%**	**4,3%**	**28,3%**	**30,4%**	**18,9%**	**9,4%**	**5,2%**	**2,0%**	**1,5%**

Table 4.4 – Dataset division per sector and floor brackets

Table 4.5 presents an overview of the floor height levels per sector, divided into percentile ranges. By comparing floor levels between sectors within certain percentiles, a pattern for vertical sorting can be identified. This pattern, however, is not as significant as the previously conducted statistical analysis as percentiles are highly susceptible to deviations in sample size per sector.

By looking at the 50th percentile, relatively large differences in terms of floor height are immediately identifiable. While Real Estate holds the lowest highest floor within the percentile of 6, insurance carriers tend to be higher up on the 12,5th floor within the deployed dataset. The 75th percentile shows a similar pattern where insurance carriers are significantly higher up in a building on the 24th floor compared to law offices which are on the 18th floor.

Percentiles	All Sectors	Other Industries	ICT Services	Financial Services	Insurance Carriers	Real Estate	Business Services	Law Offices	Consultancy & Research
1st Percentile	0,00	0,00	1,00	0,00	1,00	0,00	0,00	2,00	0,00
5th Percentile	2,00	1,00	2,00	2,00	1,00	1,00	1,00	3,00	2,00
10th Percentile	2,00	2,00	2,00	3,00	2,00	2,00	3,00	4,00	3,00
25th Percentile	5,00	4,00	5,00	6,00	4,00	4,00	5,00	6,00	5,00
50th Percentile	8,00	7,00	8,00	11,00	12,50	6,00	9,00	10,00	7,00
75th Percentile	13,00	12,00	13,00	16,00	24,00	15,00	15,00	18,00	13,00
90th Percentile	20,00	16,00	23,00	20,00	30,00	22,00	19,00	28,00	21,00
95th Percentile	24,00	22,00	25,00	22,00	34,00	27,00	20,00	31,00	24,00
99th Percentile	33,89	34,00	35,00	30,00	34,00	34,00	24,00	34,00	33,00

Table 4.5 – Floor heights divided by percentiles and tenant sector

Other sectors, however, tend to even out more towards the 13th to 16th floor level. This dividing pattern into three groups of sectors can be better observed in figure 4.8. Other industries remain lower within a building while insurance carriers and law offices locate higher, leaving the other sectors clustered in between. The 95th percentile shows the relative reduction of floor level within the business services sector, while other industries join the cluster of sectors. Finally, the 99th percentile shows a group of sectors near the 34th floor while financial services and business services remain below at 30 and 24 floor respectively. The graph also shows a relatively close pattern which starts to spread around the 50th percentile.

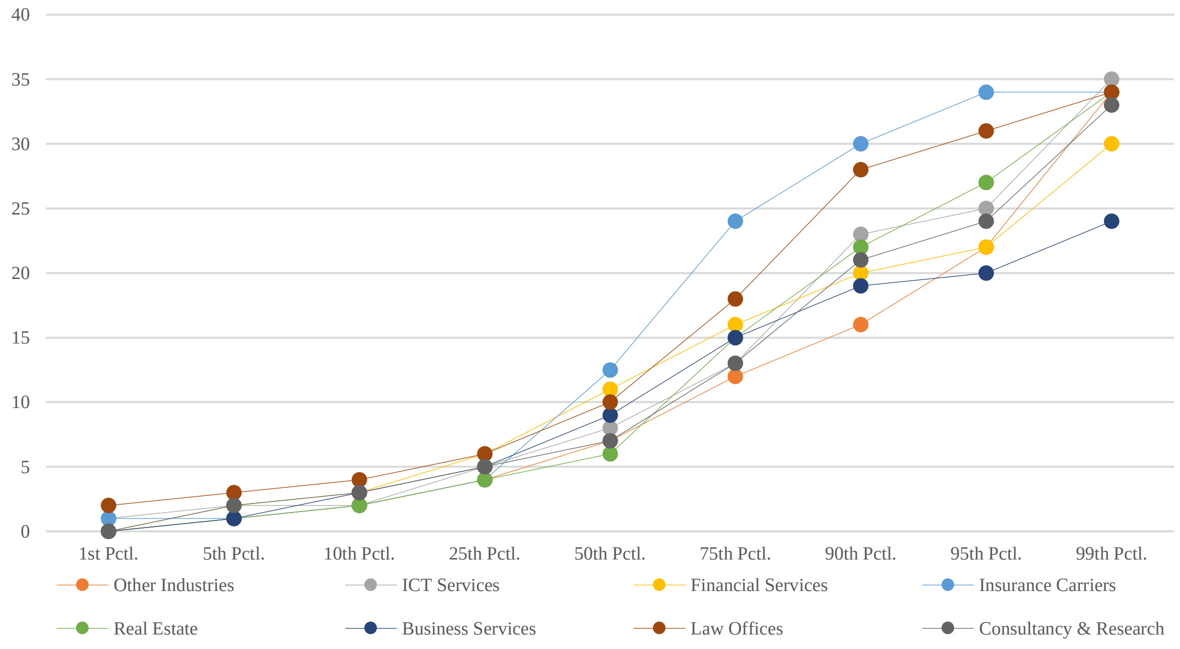

Figure 4.8 – Vertical location in terms of floor per sectors divided in percentiles

While the figure above illustrates some levels of vertical sorting between tenants, it does not provide any information on the relative position of each tenant within an office building. Despite the fact that the differences between sectors appear to be relatively small within figure 4.9, the differences are quite impactful as the relative floor term only holds values ranging from zero to one. This results in significant differences between sectors in the drive to locate above another sector in search for the status effect. Similar to the results in the second graph of figure 4.7, most sectors show a positive deviance from the other industry sector, indicating that the selected sectors want to locate higher up in a tall office building. While differences between sectors within the 50th percentile only occur significantly between the real estate sector and other sectors, more deviances can be seen within the lower percentiles, possibly indicating the sectors which prefer not to locate within the lower parts of a building. One outlier can also be seen in the 90th percentile of the graph, indicating that insurance carriers tend to locate relatively higher in a building compared to other sectors. The 1st percentile of the graph also indicates three sectors which do not locate on the ground floor within a building at all, possibly due to the low value these firms put into accessibility for possible clients. Privacy preferences could also lead to tenants within this sector to steer away from the ground floor. Additionally, status effects could play a role in the avoidance of the ground floor.

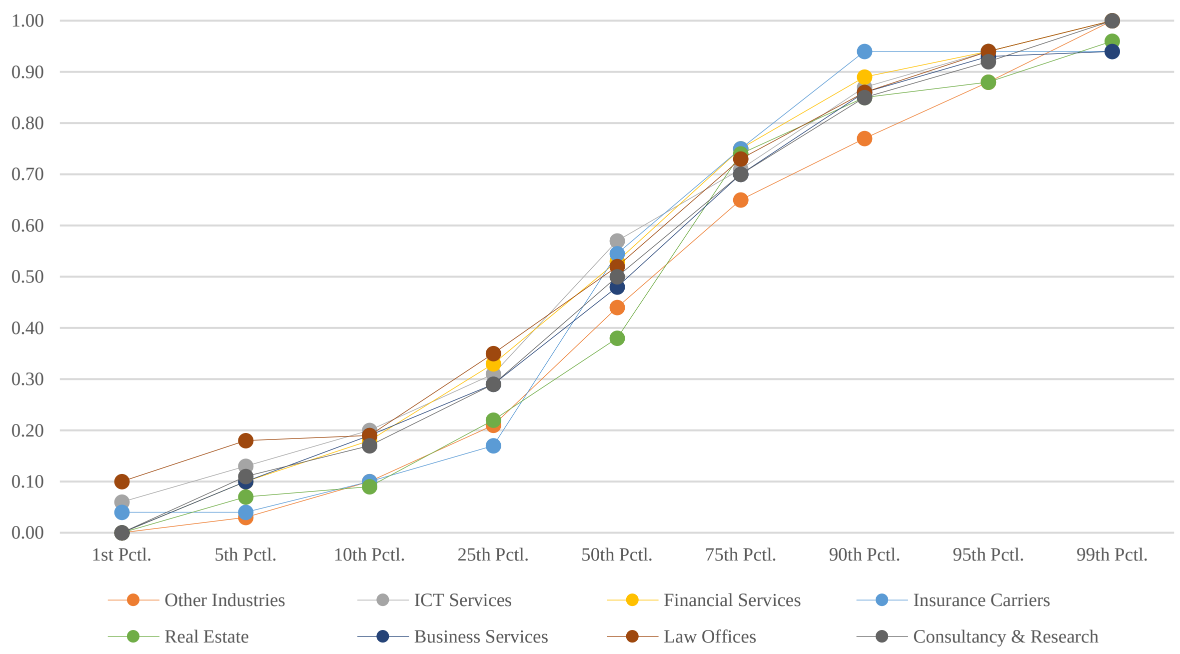

Figure 4.9 – Relative location in terms of floors per sector divided by percentiles

4.4 Summary

The empirical analysis chapter focuses on the execution and analysis of the multiple-regression models. The first section of this chapter provides an introduction to the steps taken towards the model which is designed according to the methodology in chapter three. First, the general goal of the analysis of the interrelationship between price premiums, vertical sorting and productivity is explained. This is followed by a first set of ten models. Seven of which are utilize to analyse coefficients for the Ln Transacted Rent / m^2 dependent variable, while three are constructed to study the dependent variable of Ln Highest Floor. As previous studies concerning price premiums and vertical sorting already covered different iterations of the baseline model in terms of fixed effects, the first model including the fixed effects is immediately constructed.

Section 4.2 offers a more in-depth analysis concerning rental price premiums within the multi-tenant office buildings in Amsterdam, Rotterdam and The Hague. The deployed statistical models conclude in a vertical rent premium for transacted rent per square meter per consecutive floor amounting to 0,6%, which remains stable in terms of coefficient and significance throughout the models, indicating a robust conclusion. Alongside a price premium of 0,6% per consecutive floor, the models also indicate an increasing rental price of 1,5% per tenth of a relative floor.

A separate model is constructed within this section to determine an individual coefficient value per floor level. These coefficients are plotted next to each other to analyse the development of coefficients as floor levels rise. Within the development an apparent reduction of rental price after the first floor can be seen, where accessibility is reduced and vertical amenities such as view and status hardly increase. In order to gain a better understanding of the patterns within the floor levels, brackets are created to analyse patterns throughout floor levels. ΔCoefficient data is provided within the graphs to indicate the rent level changes between two respective floor brackets. Resulting in a ΔC0 to 1-5 = 0,078, ΔC1-5 to 6-10 = 0,058, ΔC6-10 to 11-15 = 0,005, ΔC11-15 to 16-20 = 0,020, ΔC16-20 to 21-25 = 0,015, ΔC21-25 to 26-30 = -0,013 and ΔC26-30 to 30+ = -0,060. This results in a non-monotonic rent premium graph between floor brackets.

Section 4.3 covers the interaction between tenant characteristics and their relation to vertical sorting. Tenant sector dummies, based on SBI-codes are compared against the ‘Other Industries’ baseline. ICT Services, Financial Services, Real Estate, Business Services and Consultancy Services indicate 4,0%, 3,5%, 5,0%, 4,3% and 3,5% increased rent values per square meter in comparison to the Other Industries baseline. In order to analyse the vertical sorting the dependent variable of Ln Highest Floor is used in models 8-10.

The new dependent variable models conclude an elasticity of 4,8% between the dependent variable and independent variable Ln Tenant Revenue / Employee. Resulting in a relationship where a 1% increase in productivity correlates to a 4,8% higher floor within a building, concluding that more productive firms locate higher in a building. Additionally, the models conclude that tenants who rent multiple floors tend to locate 1,7% to 2,9% higher in a building in comparison to tenants who rent in a singular floor.

Section 4.3 also provides insight into willingness to pay for total and relative height by creating interaction variables between total or relative floor height and sector dummies. Resulting in a conclusion that business services and financial show the most willingness to pay for linear height while the real estate and financial services sectors have the highest willingness to pay for relative height in comparison to the baseline sector.

By dividing relative floor levels over percentiles, categorized by tenant sectors, patterns for location within a building are identified. Concluding in an observation that ICT services, law offices and insurance carriers tend to avoid locating on the ground floor as they possibly put no value in accessibility. Insurance carrier firms also appear to locate significantly higher on a relative level within the 90th percentile.

5

Conclusion & Discussion

The overall goal of this research is to expand the existing knowledge, and shed more light on the interrelationship between vertical sorting, price premiums and productivity. The research focuses on tall office buildings above ten floors and 40 meters within the three largest cities in The Netherlands, Amsterdam, Rotterdam and The Hague. The study employs a total of 1.311 transactions of office space divided over 61 multi-tenant office buildings with more than 10 floors. An average rent premium of 0,6% per consecutive floor level is identified throughout the different cities while an increase of 1,5% in terms of transacted rent per square meter is concluded per relative floor level. Both values indicating a positive correlation between height and floors which indicates an increased willingness to pay for height effects in search for amenities such as status and view.

Positive rent premium values are identified starting from floor level six while negative rent premiums are observed between floor two and five, which is in line with previously conducted research. The negative values indicate a reduction in willingness to pay for lower floor levels as accessibility diminishes while vertical amenities do not increase. As the study only covers office spaces, which are amenity driven, and ignores retail space, which are access driven, a negative coefficient can also be seen for the ground floor. Office tenants are willing to pay less rent for office space on the ground floor.

A non-monotonic trend is observed when the individual floor levels are grouped in brackets of five levels. The trend in floor bracket coefficients increase progressively after the 1st to 5th floor up to the 25th floor. A regressive trend in rent premiums becomes apparent as floor levels go up after the 25th floor. This regressive trend indicates a reduction in willingness to pay for floor height in the higher floor levels.

Three possible explanations for the drop-off in price premiums per floor after the 25th floor level are identified. First, confidence intervals bars increase the higher floor brackets go, due to limited transaction data, indicating inaccuracies due to lack of predictive power. The extremely limited transactions within the 26-30th floor bracket (27 out of 1.311) and the 30+ floor bracket (23 out of 1.311) offers a possible explanation for a decrease in price premiums. The second explanation which is provided within this study is the diminishing returns on the amenity versus accessibility trade-off. As floor height increases, amenities, which are identified through previously conducted research, such as the view- and status effect no longer outweigh the disadvantages of higher floors in terms of accessibility. This explanation could indicate a shifting point within the Dutch office sector near the 25th floor level. This would require additional research. A third explanation gathered from the analysis results is the presence of large tenants within tall office buildings. Large tenants could be more willing to locate within a certain office building if they are allowed to locate higher due to status effects. These large tenants could be able to enter negotiations regarding rental prices due to their importance in within-building agglomeration economies. A significantly larger mean surface area of transactions are found within the upper levels of floor brackets, possibly indicating the presence of large tenants. Further research is required to determine the effect of large tenants on the price premiums and vertical sorting within a multi-tenant tall office building. Additionally, multi-regression modelling concludes that the number of tenants is highly correlated and shows a 0,1% increase in transacted rent per square meter for each tenant within a multi-tenant office building.

This research provides additional insight into the increased rental prices tenants of different sectors are paying. The research concludes that ICT services, financial services, business services and consultancy services are willing to pay 4,0%, 3,5%, 5,0%, 4,3% and 3,5% more transacted rent per m^2 respectively, in comparison to other industries. A difference in willingness to pay for height is found within the industries as well. Industry sectors are willing to pay 49,6% to -2,6% more, or less, rent for height within a building. In this range the business services sector is willing to pay the most rent in relation to floor height while insurance carriers are willing to pay the least for height. All studied industry are also willing to pay at least 25% more for relative height compared to other industries. The positive value for relative height indicates that all industries are willing to pay more for the 20th floor in a 21 floor building compared to the 20th floor in a 30 floor building. The real estate sector is most willing to pay for relative height with an increase of 54,7% while the consultancy & research sector is only willing to pay 25,8% more for relative height in comparison to other industries.

A weak correlation is found which results in an elasticity of 4,8% between highest floor and revenue per employee. This result indicates that when the tenant revenue per employee, productivity, increases by 1%, the highest floor value increases by 4,8%. Thus, implying that more productive firms tend to locate higher within a tall building. More research is required to identify the relationship between these two factors. In comparison to the first study focussed on this variable, which concluded an elasticity of 2,6%, higher values are found which could be influenced by different contexts and database sizes. Another standalone result within this research concludes that tenants which occupy more than a single floor, and are therefore larger tenants, tend to locate higher in a building with a range of 1,5 to 2,7 floors.

Through the division of highest floor and relative floor in percentiles, categorized by tenant sectors, patterns for vertical sorting are identified at a weak level. Up to the 50th percentile mark in terms of rental transactions, floor levels tend to be relatively even between the different sectors. However, as the percentile increases the absolute height levels for sectors start to divide, resulting in three groups of sectors. The Other Industries baseline remains the lowest sector, while the Insurance Carrier and Law Office firms differentiate from the remaining sectors at a higher level. These trends continue as Insurance Carriers and Law Offices occupy the highest floors within buildings by a relatively large margin within the 95th percentile. While the absolute height figures provide some insight into the vertical sorting pattern of different sectors, relative floor height patterns generate more insightful results. A similar pattern as in the absolute height plot is observed, insurance carriers distance themselves in terms of relative height from the rest of the sectors within the 90th percentile. Additionally, within the 1st percentile the ICT Services, Insurance Carriers and Law sectors become apparent which appear to avoid locating on the ground floor, possibly due to their lack of interest in accessibility for clients.

A minor limitation of the study is that the gathered data on tenant characteristics including the revenue and employee values entail restrictions. Most tenants occupy multiple offices throughout The Netherlands, however, the available data does not offer information regarding location specific revenues and employee numbers. All gathered data is collected on a national scale and therefore does not allow for a specific building and tenant productivity analysis. The data which is gathered entails the national revenue and employee numbers which are generalized to create a the productivity variable. This limits the research in identifying the within-building agglomeration effects as reported in section 2.1.2. Ideally, as was possible in the works of Liu et al. (2018), the location specific tenant characteristics would be deployed to gain a better understanding of the object specific effects.

The second limitation concerning the availability of data is the comparison of different years. As not all tenants are publicly traded, financial records for each year are unavailable. Within the study all possible tenant characteristic data points are gathered. This does, however, result in a difference between the reported revenue source year and the start year of a specific contract. Through this unavailability of data a comparison is made between two different time fixed effects, possibly resulting in less significant results within the final models. Despite the correction of inflation on both variables to 2019 euros the accuracy of the data is less than ideal as major events within a company such as mergers, acquisitions, sales and significant differences in revenue and employees which have significant impact on the productivity variable, could not be taken into account.

Offices within a mixed-use building, would have significant peak loads on elevator systems. Within these buildings, to deal with these peak loads, offices are brought down to a lower floor level. In contrast with this research, if such a mixed-use building would be analysed in a similar fashion, vertical sorting patterns could be significantly different as the increased usage and number of elevators would be reflected in the rent levels for higher floor spaces. These increased rent levels, in turn, influence the vertical sorting of tenants and might reduce the willingness to pay for height in different sorts of building types.

As is discussed in previously conducted research by Van Assendelft (2017), Liu et al. (2018) and Nase et al. (2018), effective rent levels generate more accurate insights. Effective rent levels are adjusted for concessions and incentives and are a tool used by developers and real estate owners to encourage tenants to occupy in their buildings. These effective rent levels, however, are very difficult to gather on a larger and accurate scale. The implication of these rent levels could provide different results.

Within the result section three possible explanations for a drop-off in price premiums are given which require additional research. By occupying the database with more transactions, especially in the higher floor brackets, could improve the predictive power of the coefficient analysis. The second possible explanation that requires further research is on the point where the trade-off between amenity and access shifts within the Dutch office sector specifically, as this could be different for different supplies in height. Finally, further research is needed to analyse the effect that a large tenant has on price premiums and vertical sorting as mean rents within higher floors could be skewed due to the strong negotiation position of a tenant.

Throughout the study, the interrelationship between price premiums, vertical sorting and productivity is analysed within the Amsterdam, Rotterdam and The Hague market. These markets are selected as they are the three largest cities within The Netherlands, and they contain the largest amount of tall office buildings. The availability of data is another reason why these markets are chosen. However, to gain a better understanding of the differences between these markets and what local or regional effects contribute to the functioning of tall office buildings, more research is required. The extension of similar studies throughout the studies result in more data points which could strengthen the accuracy of the results of this study.

6

Reflection

This research indicates the end of the Management in the Built Environment master track within the MSc Architecture, Urbanism and Building Sciences programme. The research illustrates the final work of the information which is gathered throughout the master track. The graduation topic of price premiums and vertical sorting originates from the Real Estate Management graduation lab with Dr. I. Nase as my main supervisor. Ing. P. de Jong served as a second mentor offering additional insights from the Design and Construction Management graduation lab. The topic of this graduation study originated from a combination of courses within the general master track and a personal interesting in financial functions of real estate properties. Even though the financial aspects with a quantitative focus was a relatively small part of the academic structure, the topic still holds a strong relationship with the master track as it sheds light on the objects and their economic models that will probably a significant part of the lives of MBE graduates. The choice of this topic with a commercial focus also started with a focus on my personal professional career after graduation as this would be the field that I could see myself working.

Despite the relatively narrow focus on tall multi-tenant office buildings within Amsterdam, Rotterdam and The Hague a strong and primarily scientific relevance can be attributed to the research. One of my personal focusses was to ensure as much direct applicability or contribution to the body of knowledge in the real life real estate market as possible. By analysing actual transactions through a quantitative approach, realistic patterns and information is gathered which provides insights into the theoretical economic model of tall office buildings within The Netherlands.

The quantitative focus is also one of the strongest points within the methodology as it enables factual and realistic results by analysing real world transactions. The design of data gathering methods also enabled a smooth process by using both private and public data sources. This combination limited the dependability of a specific source. The vital individual rental transaction data, however, was only possible through the internship with Cushman & Wakefield which offered significant additional insights and data sources which would otherwise be inaccessible. Although most data was readily accessible, limitations in terms of accuracy where also present through the research. Differences of data sources due to licensing, compared to previous research results in different conclusions as tenant sector coding deviates per data source. Separate licenses through the internship generated different SBI-codes per transaction, altering the sector in which a number of tenants operate in. As this research could be compared to the works of Van Assendelft (2017), manual analysis in terms of regression models could be made to identify whether the differences in terms of coding had a significant impact on the results of the study. The differences in terms of data gathering for these tenant characteristic variables was less than ideal as identical data sources would be preferred. However, as this was not possible within the set timeframe the new data source was used. This does not mean that the results are inaccurate, however, the comparability between two studies revolving around the same subject became slightly weaker.

The data gathering process was a manual task in which rental transactions needed to be transcribed to a single database. Locating these rental transactions, however, was the most challenging part of the data gathering process. Through the Research Department within Cushman & Wakefield, a tool was made in which the location of certain transactions could be identified which significantly sped up the gathering process.

As this results has a relatively limited social relevance by shedding more light into the interrelationship between price premiums, vertical sorting and productivity no real social relationship can be identified with the real world. From a scientific perspective, however, relatively high transferability of the research to the real world can be made for a specific building type. As this research focuses on a single building type while ignoring residential and other functions there is limited transferability to other types. However, with a focus on the office sector, directly applicable knowledge is found which helps businesses operating within this area to understand the behaviour of tenants.

Due to the quantitative and scientific focus of the research no ethical issues and dilemmas were experiences throughout the process of the research. From the start of the study the secrecy of tenant information was a main focus as this information is not and should not be publicly accessible. Great care has been put in making it difficult to trace tenants back to their characteristics and rental value. As the internship company does not want their data to become public, the database covering all transactions is seen only by other people when strictly necessary. This approach was also reflected in the professional code of ethics which is signed mandatorily within the internship company.

All in all, the graduation process was an interesting and valuable experience which taught me both scientific but also practical skills through the experience with the internship company. The approach chosen throughout the study has been successful in generating the desired results and conclusions. By writing the methodology in such an explicit manner, the structure and steps towards the end goal became clear to me and helped me by scheduling each section in terms of time and output.

The feedback in the past months from both my first and second mentor were incredibly valuable and helpful towards the final product. By submitting the work so far at specific scheduled moments and then by going over the newly written parts improvements and directions were given which helped me continue and enhance the quality of the study. Especially in the final weeks towards the submission data, both mentors were continuously available to answer specific questions which needed to be answered before I could continue. The collaboration with both mentors was incredibly valuable and improved the final product significantly. I appreciated the form of feedback they gave me by not answering the questions that I had directly, but by providing insights so I could figure out as much as possible by myself.

The graduation thesis helped me improve my scientific, statistical, report writing and analytical skills drastically. I indicated to my mentors at the start that I wanted to learn something new, in the form of a quantitative, statistics oriented research because I knew that by learning something new I would be challenged the most. This challenge, however, has also improved me significantly.

7

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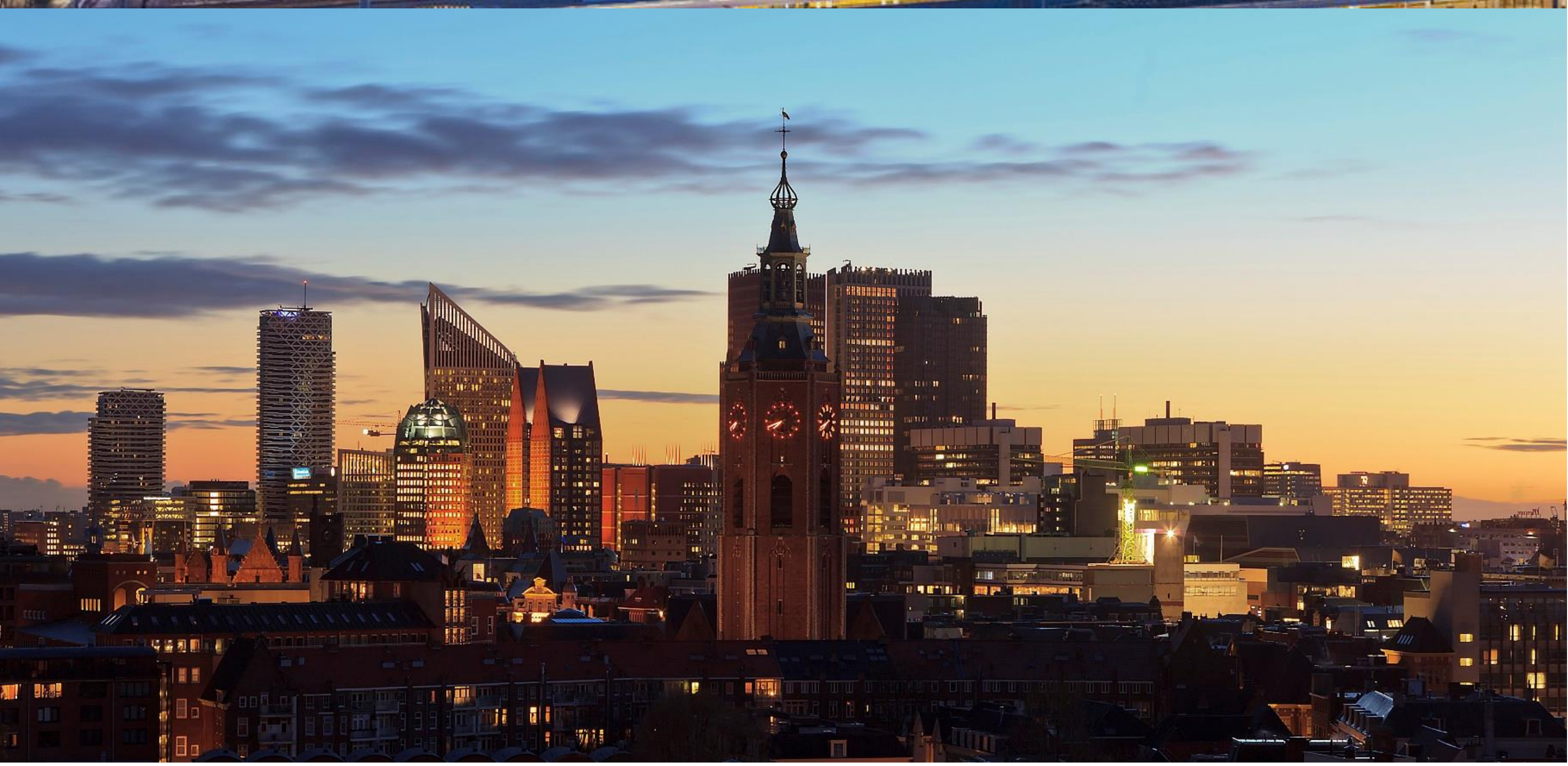
8 Appendices



Page 82 – Top Picture - Rotterdam Skyline – Source: https://www.werkaandemuur.nl/nl/werk/Rotterdam-Skyline-/332521

Page 82 – Middle Picture – Amsterdam Skyline - Source: https://parkpnp.com/blog/de-6-beste-tips-om-te-parkeren-bij-de-zuidas/

Page 82 – Bottom Picture – The Hague Skyline – Source: https://www.digitaldoes.com/skyline-of-the-hague-at-dusk-seen-from-westeinde-2/

Appendix I

Rotterdam

		
1. Willemswerf City Centre	2. Blaak 16 City Centre	3. Blakeburg City Centre
		
4. Blaak 31 City Centre	5. Thornico Building City Centre	6. Beurs-WTC Rotterdam City Centre
		
7. Hofpoort City Centre	8. Weenatoren City Centre	9. Central Post City Centre
		
10. Delftse Poort City Centre	11. Plaza Building City Centre	12. Millenium Tower City Centre

		
13. Groothandelsgebouw City Centre	14. First Rotterdam City Centre	15. Adriaan Volkerhuis City Centre
		
16. The Mark City Centre	17. Rotterdam Science Tower Delfshaven	18. World Port Center Kop van Zuid
		
19. De Rotterdam Kop van Zuid	20. Maastoren Kop van Zuid	21. Wilhelminatoren Kop van Zuid

Amsterdam

<table>
<tr><td></td><td></td><td></td></tr>
<tr><td>1. Infinity
South Axis</td><td>2. The Edge
South Axis</td><td>3. NoMa House
South Axis</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>4. Mahler 4 UN Studio
South Axis</td><td>5. The Rock
South Axis</td><td>6. ITO-Toren
South Axis</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>7. Viñoly
South Axis</td><td>8. Symphony Office Towers
South Axis</td><td>9. Atrium
South Axis</td></tr>
<tr><td></td><td>
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<tr><td>10. World Trade Center – H Toren
South Axis</td><td>11. World Trade Center – A, B, C & D Toren
South Axis</td><td>12. World Trade Center – E Toren
South Axis</td></tr>
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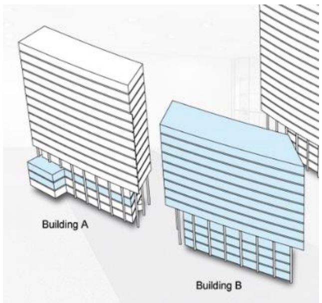
13. Cross Towers South Axis	14. Eurocenter South Axis	15. Adam Smith Building West Axis
		
16. B.3 West Axis	17. Queens Towers West Axis	18. Teleport Towers Westpoort
		
19. Q-Port Westpoort	20. Bright Offices B Westpoort	21. Bright Offices A Westpoort
		
22. Crystal Tower Westpoort	23. Millenium Tower Westpoort	24. Mondriaantoren Omval

25. Rembrandt Toren
Omval

26. 100 Watt
Omval

27. Sarphati Plaza
City Centre

28. Europlaza
South East

29. Entree II
South East

30. Margriet Toren
South East

31. Alpha Tower
South East

32. Oval Tower
South East

33. UP Office Building
City Centre

34. Havengebouw
City Centre

The Hague

		
1. HS Building Laak	2. De Haagsche Zwaan Haagse Hout	3. WTC The Hague / Prinsenhof Haagse Hout
		
4. New Babylon Haagse Hout	5. Stichthage Haagse Hout	6. Zurichtoren City Centre

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Rotterdam

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The Hague

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Appendix II

Floor range	N	%	Mean	Std.Dev.	Minimum	Maximum
Ground Floor	22	3,3%	210.67	59.79	121,78	372,18
Floor 1 to 5	141	21,3%	239.05	75,39	70,39	468,76
Floor 6 to 10	191	28,9%	278,67	75,73	40,02	478,34
Floor 11 to 15	159	24,1%	275,02	65,90	124,25	407,16
Floor 16 to 20	82	12,4%	297,73	67,58	148,24	434,32
Floor 21 to 25	48	7,2%	280,19	84,53	163,16	451,35
Floor 26 to 30	15	2,3%	334,22	69,14	171,75	412,31
Floor 31 to 35	3	0,5%	282,28	101,71	196,57	394,66
Total	661	100%				

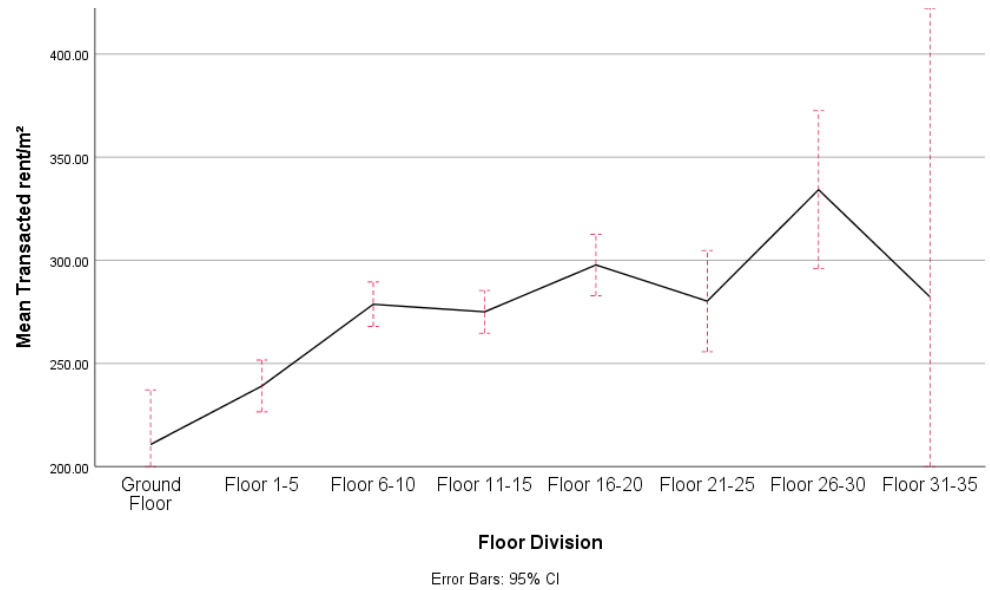
Rent levels per floor division Amsterdam

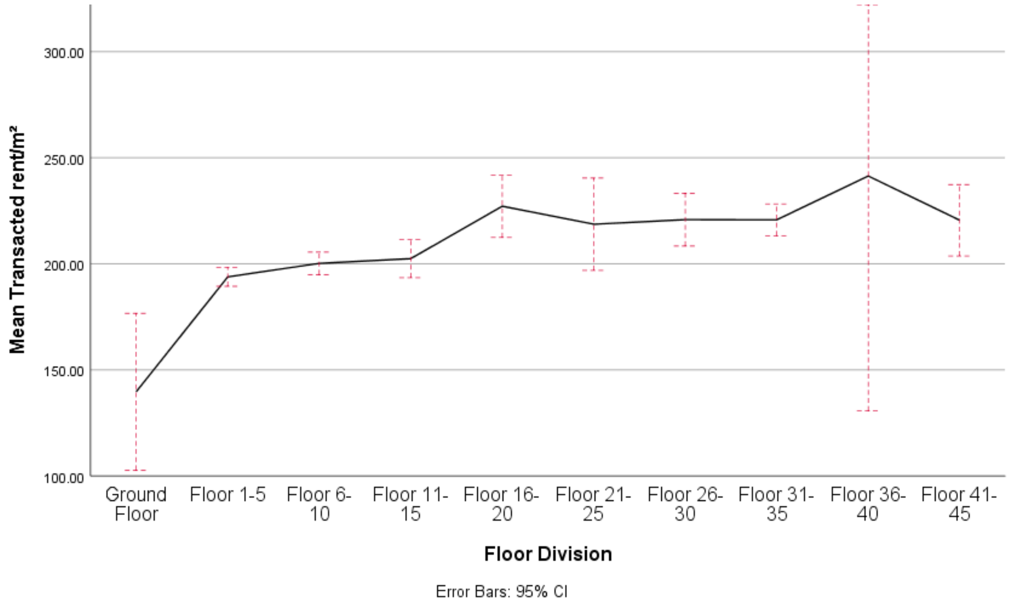
Floor range	N	%	Mean	Std.Dev.	Minimum	Maximum
Ground Floor	9	1,5%	139,70	48,09	72,77	212,67
Floor 1 to 5	204	33,5%	193,85	32,22	61,94	269,87
Floor 6 to 10	222	36,5%	200,21	39,97	91,56	297,85
Floor 11 to 15	87	14,3%	202,43	42,16	114,04	276,55
Floor 16 to 20	37	6,1%	227,15	44,25	107,77	294,26
Floor 21 to 25	17	2,8%	218,65	42,35	160,55	300,02
Floor 26 to 30	12	2,0%	220,81	19,61	180,08	253,05
Floor 31 to 35	13	2,1%	220,74	12,37	198,91	244,90
Floor 36 to 40	2	0,3%	241,39	12,33	232,67	250,11
Floor 41 to 45	6	1,0%	220,52	16,04	201,87	244,36
Total	609	100%				

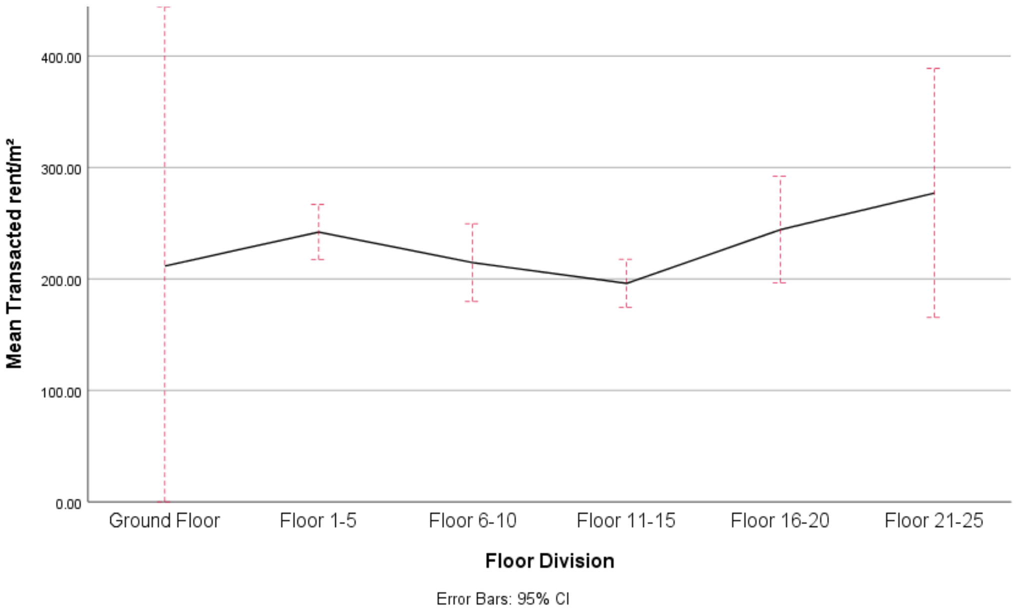
Rent levels per floor division Rotterdam

Floor range	N	%	Mean	Std.Dev.	Minimum	Maximum
Ground Floor	2	2,4%	211,61	41,97	181,94	241,29
Floor 1 to 5	34	40,5%	242,00	71,16	127,70	436,13
Floor 6 to 10	17	20,2%	214,62	68,01	145,60	452,69
Floor 11 to 15	15	17,9%	194,98	39,17	113,26	260,06
Floor 16 to 20	9	10,7%	244,22	62,39	128,03	366,81
Floor 21 to 25	7	8,3%	277,05	120,80	177,21	457,97
Total	84	100%				

Rent levels per floor division The Hague


Mean Transacted rent/m²
400.00
350.00
300.00
250.00
200.00
Ground Floor
Floor 1-5
Floor 6-10
Floor 11-15
Floor 16-20
Floor 21-25
Floor 26-30
Floor 31-35
Floor Division
Error Bars: 95% CI


Mean Transacted rent/m²
300.00
250.00
200.00
150.00
100.00
Ground Floor
Floor 1-5
Floor 6-10
Floor 11-15
Floor 16-20
Floor 21-25
Floor 26-30
Floor 31-35
Floor 36-40
Floor 41-45
Floor Division
Error Bars: 95% CI


Mean Transacted rent/m²
400.00
300.00
200.00
100.00
0.00
Ground Floor
Floor 1-5
Floor 6-10
Floor 11-15
Floor 16-20
Floor 21-25
Floor Division
Error Bars: 95% CI

Appendix III

Amsterdam							
Variable	**#**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Skewness**	**Kurtosis**
Headline rent / m^2	661	270,83	75,89	40,02	478,34	-0,207	-0,49
Real rent / m^2	211	242,90	76,25	91,10	424,85	-0,12	-0,90
Ln. Headline rent / m^2	661	5,56	0,32	3,69	6,17	-1,09	1,97
Ln. Real rent / m^2	221	5,44	0,35	4,51	6,05	-0,65	-0,53
Number of floors	661	21	6,40	10	36	0,80	-0,13
Number of tenants	661	89,63	92,42	2	219	0,64	-1,50
Transaction area (LFA)	661	1127,83	2013,78	68	24.359	5,29	38,92
Distance to nearest station	661	408,01	507,25	56	3.314	2,21	6,05
Distance to nearest highway	661	1.855,13	827,90	289	4.428	1,42	2,73
Total term of lease	573	5,67	2,81	0,50	19,84	1,32	2,40
Age of building	661	25,46	11,03	3	60	0,55	-0,11
Date since last renovation	70	4,64	2,23	2	7	-0,13	-1,80
Number of elevators	661	8,42	3,46	2	13	-0,25	-1,44
Number of parking spots	661	478,34	328,08	40	914	0,36	-1,52
Yearly revenue of a tenant	240	2,88E9	1,12E10	263.284	1,54E11	10,82	142,25
Total assets of a tenant	359	1,44E10	7,81E10	144.885	8,92E11	8,00	70,16
Number of employees of a tenant	361	6.441	28.382	2	300.000	7,63	68,35
Assets/employee	359	1,72E7	1,11E8	8.393	1,68E9	11,70	157,02
Productivity variable (rev/empl.)	240	2,17E6	8,51E6	10.622	1,11E8	9,62	113,17
Floors Above	661	9,89	6,53	0	36	0,95	1,00
Floors Below	661	10,82	6,79	0	35	0,70	0,15
Ground Floor Dummy	661	0,033	0,18	0	1	5,22	25,28
Floor 1 to 5 Dummy	661	0,213	0,41	0	1	1,40	-0,32
Floor 6 to 10 Dummy	661	0,289	0,45	0	1	0,93	-1,13
Floor 11 to 15 Dummy	661	0,241	0,43	0	1	1,22	-0,52
Floor 16 to 20 Dummy	661	0,124	0,33	0	1	2,29	3,24
Floor 21 to 25 Dummy	661	0,073	0,26	0	1	3,30	8,93
Floor 26 to 30 Dummy	661	0,023	0,15	0	1	6,43	39,40
Floor 31 to 35 Dummy	661	0,005	0,07	0	1	14,78	216,99
Financial services	661	0,166	0,37	0	1	1,80	1,23
Insurance carriers	661	0,011	0,10	0	1	9,58	90,13
Real Estate	661	0,014	0,12	0	1	8,41	68,99
Business services	661	0,038	0,19	0	1	4,86	21,65
ICT services	661	0,039	0,20	0	1	4,75	20,63
Law offices	661	0,029	0,17	0	1	5,65	30,06
Engineering & Management	661	0,030	0,17	0	1	5,50	28,30
Other categories	661	0,673	0,47	0	1	-0,74	-1,46
Year Dummy 2000	661	0,014	0,12	0	1	8,41	68,99
Year Dummy 2001	661	0,021	0,14	0	1	6,67	42,57
Year Dummy 2002	661	0,029	0,17	0	1	5,65	30,06
Year Dummy 2003	661	0,009	0,10	0	1	10,38	105,99
Year Dummy 2004	661	0,038	0,19	0	1	4,86	21,65
Year Dummy 2005	661	0,045	0,21	0	1	4,38	17,22
Year Dummy 2006	661	0,077	0,27	0	1	3,18	8,12
Year Dummy 2007	661	0,068	0,25	0	1	3,44	9,85
Year Dummy 2008	661	0,056	0,23	0	1	3,87	13,03
Year Dummy 2009	661	0,042	0,20	0	1	4,56	18,80
Year Dummy 2010	661	0,082	0,27	0	1	3,06	7,40
Year Dummy 2011	661	0,068	0,25	0	1	3,44	9,85
Year Dummy 2012	661	0,123	0,33	0	1	2,31	3,33
Year Dummy 2013	661	0,051	0,22	0	1	4,07	14,62
Year Dummy 2014	661	0,070	0,26	0	1	3,39	9,53
Year Dummy 2015	661	0,118	0,32	0	1	2,37	3,65
Year Dummy 2016	661	0,067	0,25	0	1	3,49	10,18
Year Dummy 2017	661	0,008	0,09	0	1	11,39	128,18
Year Dummy 2018	661	0,015	0,12	0	1	7,96	61,59
Dummy Submarket Omval	661	0,088	0,28	0	1	2,92	6,55
Dummy Submarket South-Axis	661	0,661	0,47	0	1	-0,68	-1,54
Dummy Submarket South-East	661	0,085	0,28	0	1	2,99	6,96
Dummy Submarket Westpoort	661	0,064	0,24	0	1	3,59	10,90
Dummy Submarket City Centre	661	0,074	0,26	0	1	3,26	8,64
Dummy Submarket West-Axis	661	0,029	0,17	0	1	5,65	30,06

Descriptive statistics variables Amsterdam

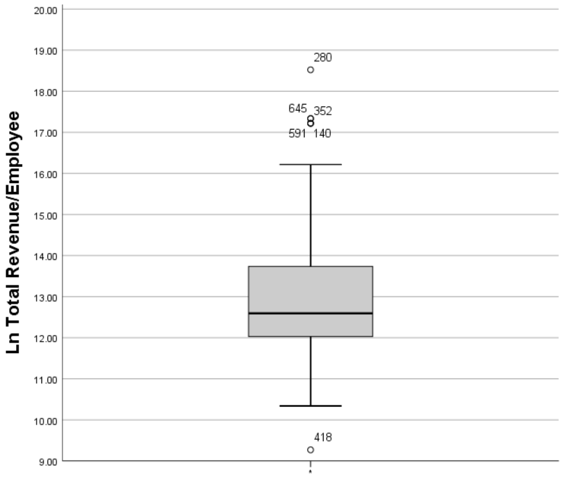
Rotterdam							
Variable	**#**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Skewness**	**Kurtosis**
Headline rent / m^2	609	200,83	39,16	61,94	300,02	-0,37	0,29
Real rent / m^2	98	166,46	41,36	67	260	-0,33	0,07
Ln. Headline rent / m^2	609	5,28	0,22	4,13	5,70	-1,25	2,99
Ln. Real rent / m^2	98	5,08	0,28	4,21	5,56	-1,15	1,37
Number of floors	609	19,29	9,12	10	44	0,84	0,28
Number of tenants	609	114,63	76,84	3	192	-0,36	-1,67
Transaction area (LFA)	609	869,80	2.715,04	15	41.480	8,71	101,74
Distance to nearest station	609	303,59	227,25	50	1.385	1,65	4,42
Distance to nearest highway	609	2.992,22	791,05	476	4.803	0,94	0,65
Total term of lease	609	6,32	4,06	0,35	30,02	0,96	1,80
Age of building	609	44,50	18,32	4	68	0,02	-1,00
Date since last renovation	609	1,19	2,96	0	11	2,20	3,17
Number of elevators	609	14,31	6,78	4	28	-0,04	-1,15
Number of parking spots	609	501,18	161,33	80	1.094	-0,57	2,84
Yearly revenue of a tenant	173	1,59E9	4,59E9	451.103	4,37E10	5,67	42,87
Total assets of a tenant	365	1,04E10	8,87E10	17.550	1,25E12	11,19	136,41
Number of employees of a tenant	366	1.505,59	7.059	1	95.088	8,91	97,98
Assets/employee	356	1,07E6	3,09E6	7.815	1,20E8	4,43	19,83
Productivity variable (rev/empl.)	165	6,50E5	1,22E6	41.411	5,37E6	2,88	6,94
Floors Above	609	10,15	7	0	42	0,98	1,12
Floors Below	609	9,14	8	0	44	1,96	4,43
EI (Energy Index)	537	0,99	0,18	0,71	1,40	1,26	0,81
Ground Floor Dummy	609	0,015	0,12	0	1	8,06	63,21
Floor 1 to 5 Dummy	609	0,335	0,47	0	1	0,70	-1,51
Floor 6 to 10 Dummy	609	0,365	0,48	0	1	0,56	-1,69
Floor 11 to 15 Dummy	609	0,143	0,35	0	1	2,05	2,19
Floor 16 to 20 Dummy	609	0,061	0,24	0	1	3,69	11,63
Floor 21 to 25 Dummy	609	0,028	0,16	0	1	5,75	31,12
Floor 26 to 30 Dummy	609	0,020	0,14	0	1	6,93	46,16
Floor 31 to 35 Dummy	609	0,021	0,14	0	1	6,64	42,22
Floor 36 to 40 Dummy	609	0,003	0,06	0	1	17,41	301,99
Floor 41 to 45 Dummy	609	0,010	0,10	0	1	9,95	97,32
Financial services	609	0,085	0,28	0	1	2,97	6,87
Insurance carriers	609	0,011	0,11	0	1	9,19	82,70
Real Estate	609	0,010	0,10	0	1	9,95	97,32
Business services	609	0,041	0,20	0	1	4,64	19,57
ICT services	609	0,061	0,24	0	1	3,69	11,63
Law offices	609	0,048	0,21	0	1	4,26	16,19
Engineering & Management	609	0,076	0,26	0	1	3,22	8,40
Other categories	609	0,668	0,47	0	1	-0,72	-1,49
Year Dummy 2000	609	0,007	0,08	0	1	12,25	148,48
Year Dummy 2001	609	0,015	0,12	0	1	8,06	63,21
Year Dummy 2002	609	0,010	0,10	0	1	9,95	97,32
Year Dummy 2003	609	0,015	0,12	0	1	8,06	63,21
Year Dummy 2004	609	0,031	0,17	0	1	5,41	27,32
Year Dummy 2005	609	0,016	0,13	0	1	7,63	56,39
Year Dummy 2006	609	0,056	0,23	0	1	3,88	13,09
Year Dummy 2007	609	0,071	0,26	0	1	3,36	9,32
Year Dummy 2008	609	0,062	0,24	0	1	3,63	11,19
Year Dummy 2009	609	0,072	0,26	0	1	3,31	9,00
Year Dummy 2010	609	0,076	0,26	0	1	3,22	8,40
Year Dummy 2011	609	0,077	0,27	0	1	3,18	8,12
Year Dummy 2012	609	0,092	0,29	0	1	2,83	6,04
Year Dummy 2013	609	0,071	0,26	0	1	3,36	9,32
Year Dummy 2014	609	0,105	0,31	0	1	2,58	4,68
Year Dummy 2015	609	0,038	0,19	0	1	4,86	21,71
Year Dummy 2016	609	0,039	0,19	0	1	4,75	20,59
Year Dummy 2017	609	0,100	0,30	0	1	2,67	5,15
Year Dummy 2018	609	0,043	0,20	0	1	4,54	18,63
Year Dummy 2019	609	0,005	0,07	0	1	14,18	199,65
Dummy Submarket City Centre	609	0,821	0,38	0	1	-1,68	0,82
Dummy Submarket Delfshaven	609	0,110	0,31	0	1	2,50	4,26
Dummy Submarket Kop van Zuid	609	0,069	0,25	0	1	3,41	9,66

Descriptive statistics variables Rotterdam

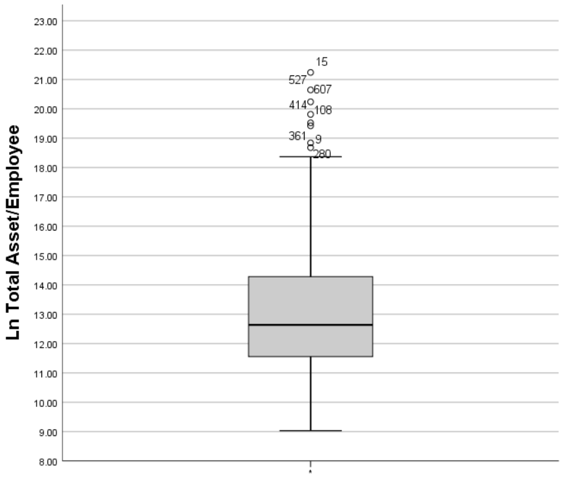
The Hague							
Variable	**#**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Skewness**	**Kurtosis**
Headline rent / m^2	84	230,68	71,75	113,26	457,97	1,66	3,08
Real rent / m^2	5	130,86	18,42	117,00	157,40	0,93	-1,44
Ln, Headline rent / m^2	84	5,40	0,28	4,73	6,13	0,63	1,22
Ln, Real rent / m^2	5	4,87	0,14	4,76	5,06	0,89	-1,63
Number of floors	84	21,07	5,16	14	26	-0,34	-1,64
Number of tenants	84	24,48	14,10	4	39	-0,07	-1,76
Transaction area (LFA)	84	1.485,95	2.442,95	25	15.198	3,35	13,59
Distance to nearest station	84	603,45	176,95	155	847	-0,83	0,64
Distance to nearest highway	84	998,29	675,33	352	2.298	0,58	-1,47
Total term of lease	84	7,58	3,91	1	21	1,07	0,87
Age of building	84	22,24	12,93	10	45	0,93	-0,98
Date since last renovation	17	8,00	0,00	8	8	-	-
Number of elevators	84	13,11	5,85	3	19	-0,18	-1,63
Number of parking spots	84	579,68	335,33	0	925	-0,09	-1,67
Yearly revenue of a tenant	29	2,14E9	5,00E9	1,39E6	2,37E10	3,50	13,14
Total assets of a tenant	44	8,34E9	4,29E10	257.743	2,85E11	6,53	43,02
Number of employees of a tenant	44	2.889,80	6.746,86	2	38.280	3,98	18,33
Assets/employee	44	3,16E6	1.51E7	9.003	1E8	6,45	42,26
Productivity variable (rev/empl.)	29	4,43E5	4,75E5	32.328	1,82E6	1,75	2,24
Floors Above	84	11,96	7,45	1	26	0,30	-1,27
Floors Below	84	9,11	6,46	0	24	0,67	-0,70
EI (Energy Index)	19	1,27	0,19	1,14	1,54	0,86	-1,42
Ground Floor Dummy	84	0,024	0,15	0	1	6,36	39,40
Floor 1 to 5 Dummy	84	0,405	0,49	0	1	0,40	-1,89
Floor 6 to 10 Dummy	84	0,202	0,40	0	1	1,51	0,28
Floor 11 to 15 Dummy	84	0,179	0,39	0	1	1,71	0,94
Floor 16 to 20 Dummy	84	0,107	0,31	0	1	2,59	4,81
Floor 21 to 25 Dummy	84	0,083	0,28	0	1	3,07	7,61
Financial services	84	0,107	0,31	0	1	2,59	4,81
Insurance carriers	84	0,012	0,11	0	1	9,17	84,00
Real Estate	84	0,060	0,24	0	1	3,79	12,68
Business services	84	0,024	0,15	0	1	6,36	39,40
ICT services	84	0,048	0,21	0	1	4,33	17,12
Law offices	84	0,024	0,15	0	1	6,36	39,40
Engineering & Management	84	0,048	0,21	0	1	4,33	17,12
Other categories	84	0,679	0,47	0	1	-0,78	-1,43
Year Dummy 2000	84	0,012	0,11	0	1	9,17	84,00
Year Dummy 2001	84	0,000	0,00	0	0	-	-
Year Dummy 2002	84	0,000	0,00	0	0	-	-
Year Dummy 2003	84	0,000	0,00	0	0	-	-
Year Dummy 2004	84	0,012	0,11	0	1	9,17	84,00
Year Dummy 2005	84	0,048	0,21	0	1	4,33	17,12
Year Dummy 2006	84	0,048	0,21	0	1	4,33	17,12
Year Dummy 2007	84	0,107	0,31	0	1	2,59	4,81
Year Dummy 2008	84	0,095	0,30	0	1	2,81	6,03
Year Dummy 2009	84	0,071	0,26	0	1	3,39	9,72
Year Dummy 2010	84	0,119	0,33	0	1	2,40	3,83
Year Dummy 2011	84	0,071	0,26	0	1	3,39	9,72
Year Dummy 2012	84	0,012	0,11	0	1	9,17	84,00
Year Dummy 2013	84	0,071	0,26	0	1	3,39	9,72
Year Dummy 2014	84	0,048	0,21	0	1	4,33	17,12
Year Dummy 2015	84	0,107	0,31	0	1	2,59	4,81
Year Dummy 2016	84	0,036	0,19	0	1	5,10	24,54
Year Dummy 2017	84	0,048	0,21	0	1	4,33	17,12
Year Dummy 2018	84	0,024	0,15	0	1	6,36	39,40
Year Dummy 2019	84	0,060	0,24	0	1	3,79	12,68
Dummy Submarket Laak	84	0,060	0,24	0	1	3,79	12,68
Dummy Submarket Haagse Hout	84	0,940	0,24	0	1	-3,79	12,68

Descriptive statistics variables The Hague

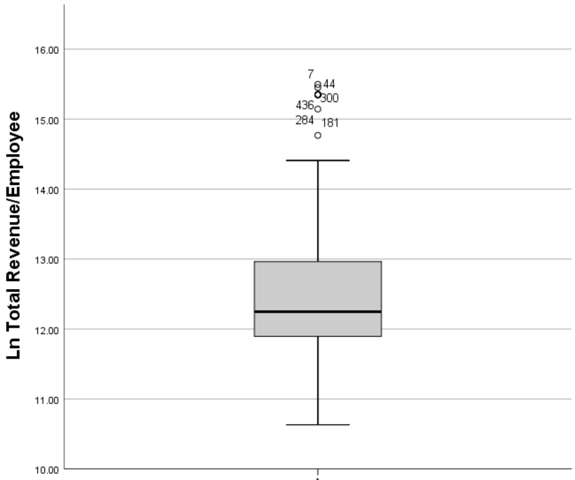
Appendix IV



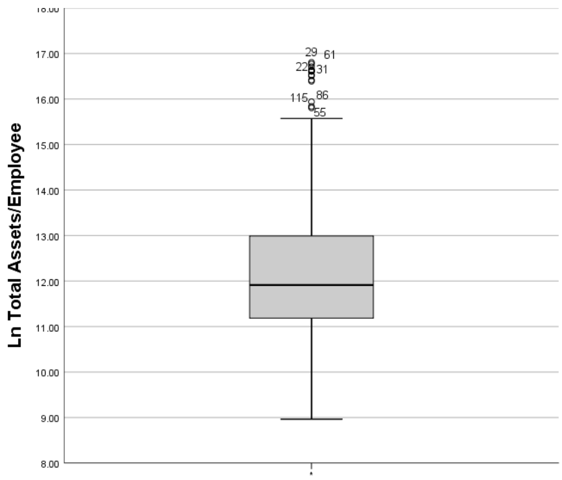
Ln Total Revenue/Employee Amsterdam



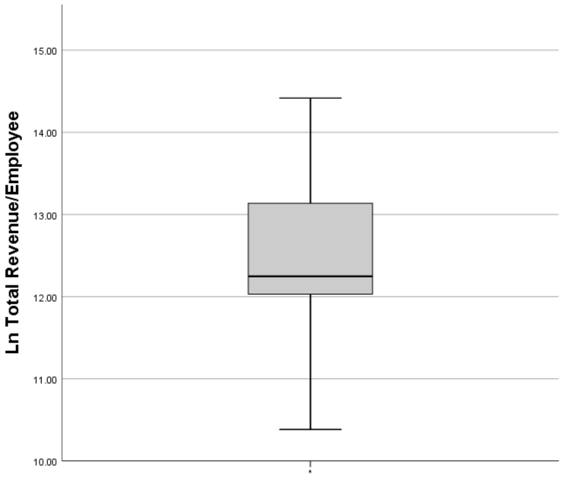
Ln Total Assets/Employee Amsterdam



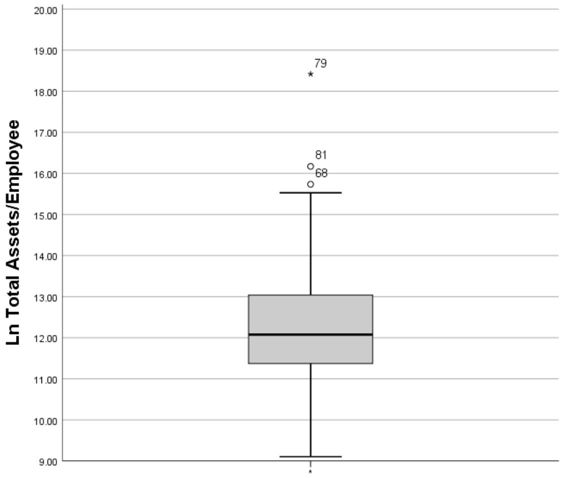
Ln Total Revenue/Employee Rotterdam



Ln Total Assets/Employee Rotterdam

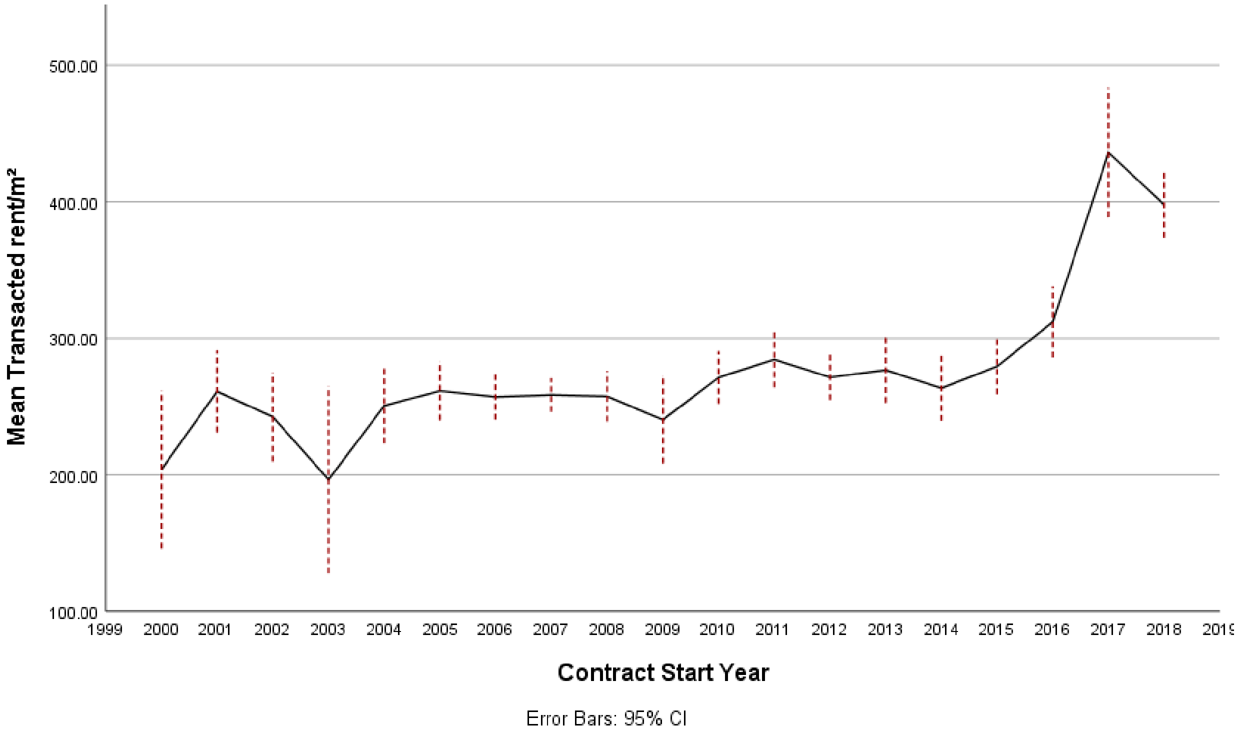


Ln Total Revenue/Empoloyee The Hague

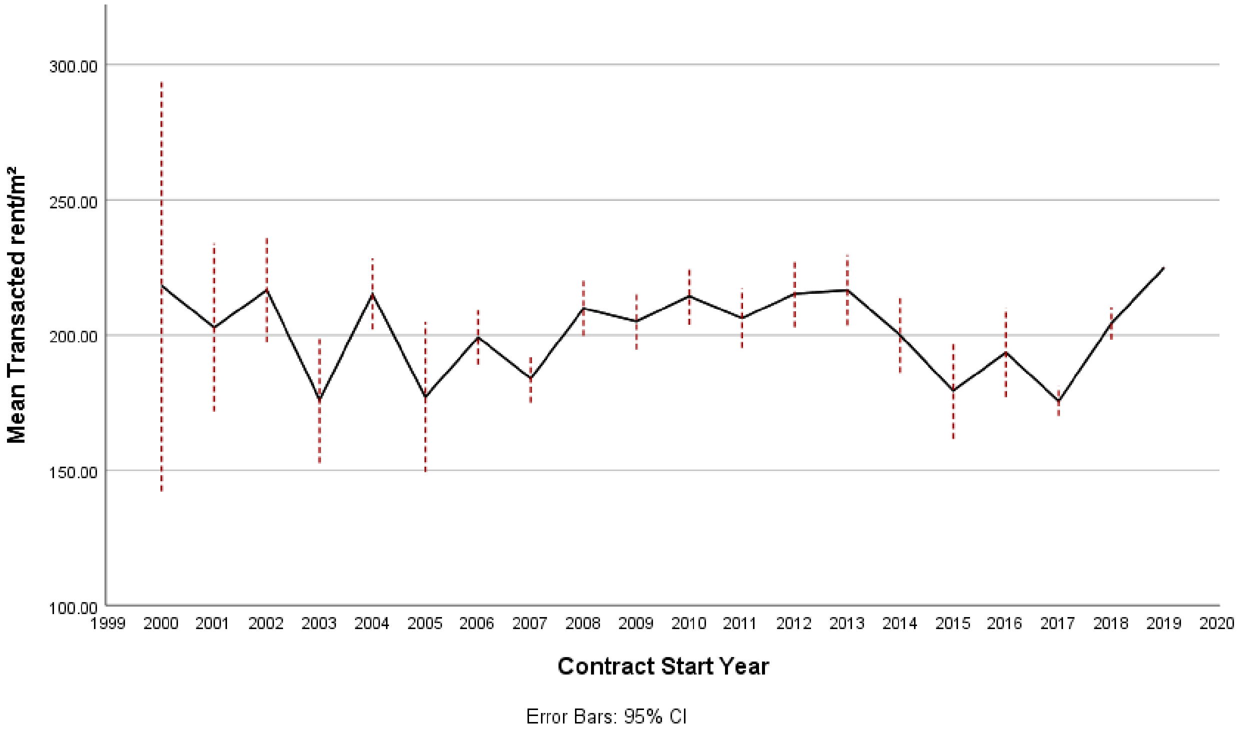


Ln Total Assets/Employee The Hague

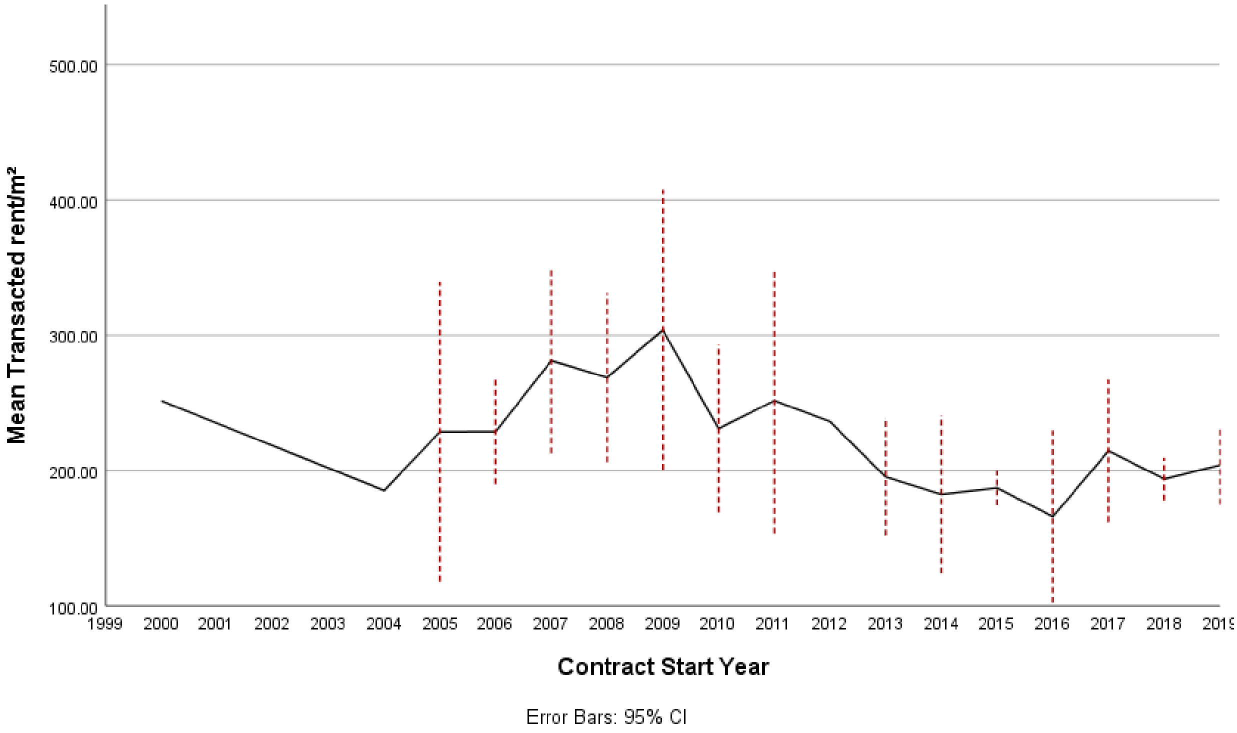
Appendix V



Mean transacted rent / m² per year in Amsterdam



Mean transacted rent / m² per year in Rotterdam



Mean transacted rent / m² per year in The Hague

Appendix VI

Floor Model Coefficient Model

** = 99% confidence interval	Floor Coefficient Model		
* = 95% confidence interval	**Coefficient**	**t-value**	**VIF**
Constant	5,759**	38,226	
Object # Floors	0,009**	10,408	2,722
Object # Tenants	0,001**	11,271	6,574
Ln Surface Area	-0,0001**	-0,027	2,686
Lease Term	0,004*	2,016	2,286
Ln Distance to Station	-0,005	-0,500	4,930
Ln Distance to Highway	-0,020	-1,285	3,825
Ln Age since Renovation	-0,115**	-9,604	4,819
Elevators #	0,004**	3,049	3,672
Parking Spots	-0,0002**	5,587	4,191
ICT Services	0,045*	2,490	1,308
Financial Services	0,036**	2,842	1,674
Insurance Carriers	0,053	1,341	1,234
Real Estate	0,059*	2,504	1,221
Business Services	0,045*	2,325	1,225
Law Offices	0,053**	2,664	1,313
Consultancy Services	0,038**	2,952	1,521
Floor Fixed Effects			
Floor 0 Dummy	-0,093**	-4,106	1,206
Floor 2 Dummy	-0,009	-0,520	1,228
Floor 3 Dummy	-0,022	-1,279	1,233
Floor 4 Dummy	-0,025	-1,540	1,167
Floor 5 Dummy	-0,015	-1,048	1,188
Floor 6 Dummy	-0,010	-0,662	1,109
Floor 7 Dummy	0,025	1,695	1,198
Floor 8 Dummy	0,037*	2,048	1,226
Floor 9 Dummy	0,014	0,795	1,153
Floor 10 Dummy	0,005	0,282	1,183
Floor 11 Dummy	0,029	1,508	1,160
Floor 12 Dummy	0,018	1,031	1,165
Floor 13 Dummy	-0,004	-0,164	1,254
Floor 14 Dummy	0,016	0,694	1,255
Floor 15 Dummy	-0,027	-1,165	1,223
Floor 16 Dummy	0,054*	2,285	1,221

	Model (continuation)		
	Coefficient	**t-value**	**VIF**
Floor 17 Dummy	-0,013	-0,381	1,496
Floor 18 Dummy	-0,058	-1,762	1,501
Floor 19 Dummy	0,043	1,588	1,310
Floor 20 Dummy	-0,002	-0,053	1,379
Floor 21 Dummy	0,012	0,315	1,623
Floor 22 Dummy	0,012	0,335	1,508
Floor 23 Dummy	0,005	0,126	1,.445
Floor 24 Dummy	0,070	1,708	1,347
Floor 25 Dummy	0,028	0,606	1,432
Floor 26 Dummy	0,027	0,465	1,940
Floor 27 Dummy	0,005	0,079	2,354
Floor 28 Dummy	0,024	0,356	2,037
Floor 29 Dummy	-0,117	-1,923	1,814
Floor 30 Dummy	0,095	0,925	2,850
Floor 30+ Dummy	-0,040	-0,998	1,632
Dependent variable	Ln Transacted Rent / m^2		
N	1.223		
k	68		
Nk-ratio	17,99		
Time Fixed Effects (Trans. Year)	Yes (19)		
Space Fixed Effects (Submarket)	Yes (10)		
R^2	0,730		
Adjusted R^2	0,712		
Standard Error Estimate	0,14856		

Appendix VII

Complete coefficient list baseline model (Ln Transacted Rent / m²)

** = 99% confidence interval	Floor Coefficient Model		
* = 95% confidence interval	Coefficient	t-value	VIF
Constant	5,745**	38,920	
Object # Floors	0,007**	7,133	2,939
Object # Tenants	0,001**	12,224	6,198
Highest Floor	0,006**	7,774	1,924
Ln Surface Area	-0,007	-1,487	2,542
Lease Term	0.003	1.600	2.209
Ln Distance to Station	-0.001	-0.116	4.748
Ln Distance to Highway	-0.015	-0.970	3.780
Ln Age since Renovation	-0.110**	-9.478	4.657
Elevators #	0.003**	2.670	3.459
Parking Spots	0.000**	-6.133	3.911
Penthouse	-0.008	-0.201	1.107
Multiple Floor Dummy	0.030	1.872	1.835
ICT Services	0.040*	2.246	1.279
Financial Services	0.035**	2.875	1.626
Insurance Carriers	0.041	1.118	1.107
Real Estate	0.050*	2.191	1.194
Business Services	0.043*	2.271	1.207
Law Offices	0.038	1.999	1.257
Consultancy Services	0.035**	2.780	1.478
Year Dummy 2001	0.011	0.201	2.836
Year Dummy 2002	0.045	0.841	2.944
Year Dummy 2003	-0.011	-0.198	2.295
Year Dummy 2004	0.092	1.871	4.615
Year Dummy 2005	0.030	0.605	4.698
Year Dummy 2006	0.050	1.084	8.226
Year Dummy 2007	0.050	1.073	8.617
Year Dummy 2008	0.114*	2.422	7.715
Year Dummy 2009	0.112*	2.360	7.141
Year Dummy 2010	0.151**	3.219	9.343
Year Dummy 2011	0.121*	2.564	8.526
Year Dummy 2012	0.152**	3.252	11.477
Year Dummy 2013	0.135**	2.783	7.492
Year Dummy 2014	0.106*	2.208	9.152
Year Dummy 2015	0.140**	2.909	8.378
Year Dummy 2016	0.184**	3.731	5.948
Year Dummy 2017	0.177**	3.327	8.223
Year Dummy 2018	0.111*	2.066	4.926
Year Dummy 2019	0.020	0.288	1.959

	Model (continuation)		
	Coefficient	t-value	VIF
Submarket Rotterdam City Centre	-0.334**	-15.489	6.331
Submarket Rotterdam Delfshaven	-0.655**	-17.763	3.664
Submarket Rotterdam Kop van Zuid	-0.438**	-12.938	2.155
Submarket Amsterdam Omval	-0.079**	-2.823	1.684
Submarket Amsterdam South East	-0.515**	-14.469	2.219
Submarket Amsterdam Westpoort	-0.550**	-14.878	1.433
Submarket Amsterdam City Centre	-0.253**	-6.178	2.948
Submarket Amsterdam West Axis	-0.359**	-7.560	1.553
Submarket The Hague Laak	-0.602**	-8.224	1.241
Submarket The Hague Haagse Hout	-0.254**	-9.436	2.255
Dependent variable	Ln Transacted Rent / m²		
N	1.223		
k	49		
Nk-ratio	24,96		
Time Fixed Effects (Trans. Year)	Yes (See table)		
Space Fixed Effects (Submarket)	Yes (See table)		
R^2	0,730		
Adjusted R^2	0,719		
Standard Error Estimate	0,14672		

Appendix VIII

Complete coefficient list baseline model (Ln Highest Floor)

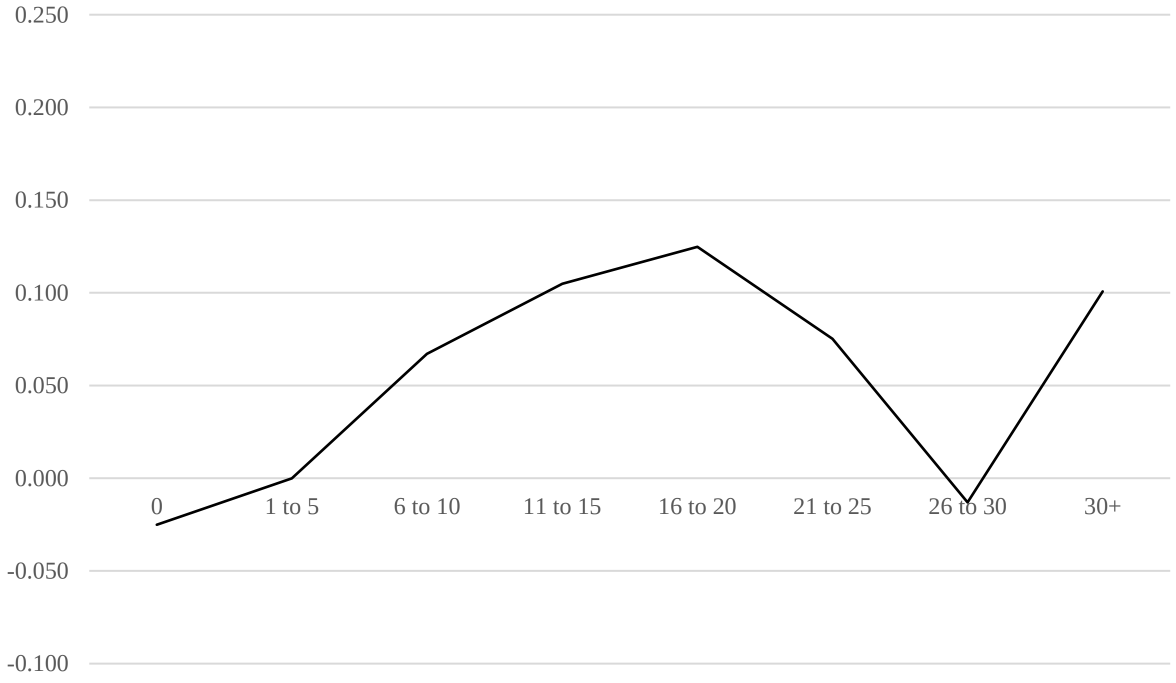
** = 99% confidence interval	Floor Coefficient Model		
* = 95% confidence interval	**Coefficient**	**t-value**	**VIF**
Constant	1,933**	9,906	
Multiple Floor Dummy	0,181**	3,266	1,177
ICT Services	0.181*	2.425	1.249
Financial Services	0.273**	5.261	1.560
Insurance Carriers	0.282	1.728	1.082
Real Estate	-0.004	-0.045	1.182
Business Services	0.225**	2.704	1.171
Law Offices	0.403**	4.801	1.198
Consultancy Services	0.158**	2.899	1.439
Year Dummy 2001	0.106	0.449	2.886
Year Dummy 2002	-0.027	-0.113	2.886
Year Dummy 2003	-0.098	-0.380	2.253
Year Dummy 2004	0.092	0.426	4.472
Year Dummy 2005	-0.138	-0.636	4.488
Year Dummy 2006	0.143	0.703	7.878
Year Dummy 2007	-0.049	-0.242	8.188
Year Dummy 2008	0.029	0.142	7.236
Year Dummy 2009	-0.098	-0.472	6.918
Year Dummy 2010	0.183	0.905	9.172
Year Dummy 2011	0.109	0.538	8.393
Year Dummy 2012	0.230	1.149	11.149
Year Dummy 2013	0.156	0.757	7.278
Year Dummy 2014	0.074	0.364	9.052
Year Dummy 2015	0.176	0.868	9.322
Year Dummy 2016	0.253	1.218	6.547
Year Dummy 2017	0.409	1.823	7.226
Year Dummy 2018	0.381	1.733	4.089
Year Dummy 2019	0.056	0.186	1.834
Submarket Rotterdam City Centre	-0.237**	-5.080	1.520
Submarket Rotterdam Delfshaven	0.015	0.119	2.120
Submarket Rotterdam Kop van Zuid	0.594**	5.313	1.163
Submarket Amsterdam Omval	0.319**	3.338	1.138
Submarket Amsterdam South East	-0.135	-1.392	1.149
Submarket Amsterdam Westpoort	0.429**	3.885	1.136
Submarket Amsterdam City Centre	-0.139	-1.338	1.162
Submarket Amsterdam West Axis	-0.436**	-2.624	1.062
Submarket The Hague Laak	-0.719*	-2.369	1.049
Submarket The Hague Haagse Hout	-0.016	-0.176	1.202
Dependent variable		Ln Highest Floor	
N		1.311	
k		37	
Nk-ratio		35,43	
Time Fixed Effects (Trans. Year)		Yes (See table)	
Space Fixed Effects (Submarket)		Yes (See table)	
R^2		0,173	
Adjusted R^2		0,149	
Standard Error Estimate		0,66108	

Appendix IX

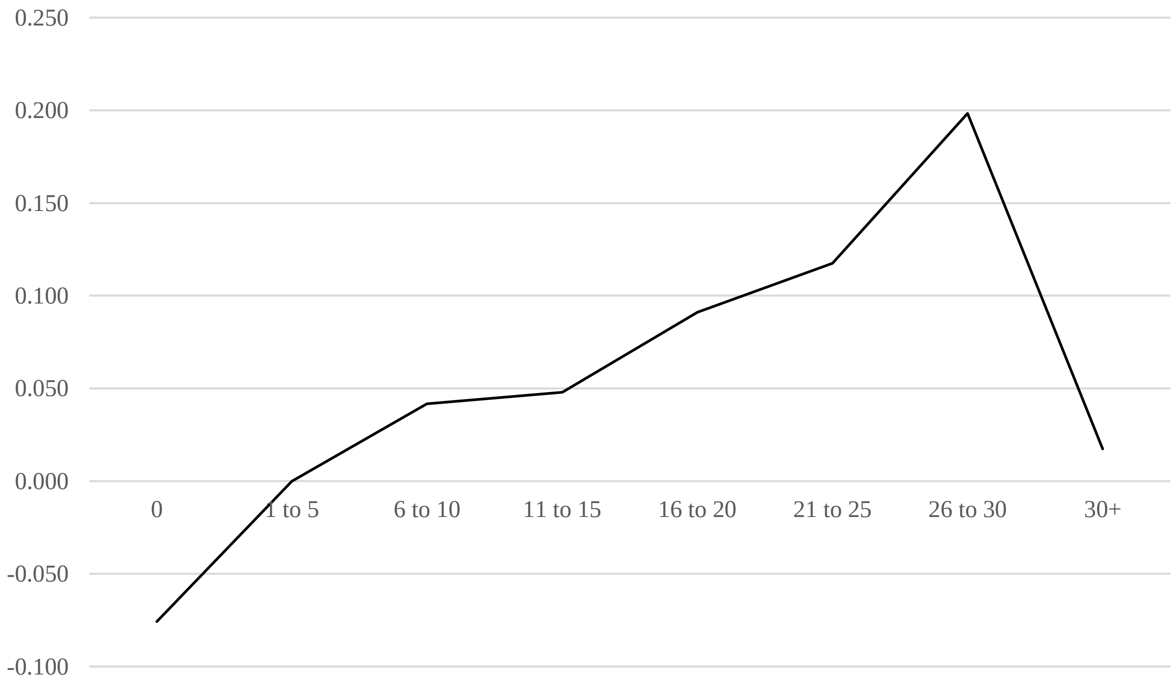
*Ln Revenue / Employee * Floor Bracket Interaction Model*

** = 99% confidence interval	Floor Coefficient Model		
* = 95% confidence interval	**Coefficient**	**t-value**	**VIF**
Constant	5,722**	23,038	
Object # Floors	0,006**	3,746	3,868
Object # Tenants	0,001**	3,061	9,255
Ln Surface Area	-0,004	-0,500	2,495
Lease Term	0,006*	2,017	2,376
Ln Distance to Station	0,001	0,073	4,945
Ln Distance to Highway	-0,028	-1,084	3,408
Ln Age Since Last Renovation	-0,070**	-3,715	4,293
# Elevators	0,003	1,207	3,876
Parking Spots	-0,0000	-0,809	5,282
ICT Services	0,053	1,550	1,387
Financial Services	0,029	1,456	1,602
Insurance Carriers	0,065	1,416	1,410
Real Estate	0,056	0,974	1,307
Business Services	0,026	0,603	1,390
Law Offices	0,005	0,100	1,424
Consultancy Services	0,046	1,931	1,554
Int. Ln Revenue/Employee * Ground Floor	0,0005	0,192	1,448
Int. Ln Revenue/Employee * Floor 1 to 5	-0,006**	-3,464	2,141
Int. Ln Revenue/Employee * Floor 6 to 10	0,0003	0,189	1,734
Int. Ln Revenue/Employee * Floor 11 to 15	0,001	0,846	1,475
Int. Ln Revenue/Employee * Floor 16 to 20	0,002	1,262	1,541
Int. Ln Revenue/Employee * Floor 21 to 25	0,002	0,860	1,504
Int. Ln Revenue/Employee * Floor 26 to 30	0,007	1,937	1,480
Int. Ln Revenue/Employee * Floor 30+	-0,0005	-0,101	2,098
Dependent variable	Ln Highest Floor		
N	387		
k	53		
Nk-ratio	7,30		
Time Fixed Effects (Trans. Year)	Yes (19)		
Space Fixed Effects (Submarket)	Yes (10)		
R^2	0,777		
Adjusted R^2	0,741		
Standard Error Estimate	0,14109		

Appendix X



Price premium development per floor bracket Rotterdam



Price premium development per floor bracket Amsterdam