The spatial impact of information and communication technologies

Master thesis in partial fulfillment of the requirements for obtaining an MSc degree in Transport & Supply Chain Management

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Abstract:

The improvement of information and communication technologies (ICT) is not only visible since the global COVID-19 outbreak. Indeed, ICT helped to shift work from the office into our homes and made offices a rarely seen place for many during the pandemic. Consequently, commuting patterns and settlement decisions have changed. The purpose of this descriptive, quantitative research is to analyze the Dutch commuting behavior, the development of population density and real estate prices in pre-COVID times. This is undertaken by calculating commuting quotients on commuting data on both a national level and on a selected city level, closely followed by an analysis of population density and real estate prices with respect to the distance to the city center. The findings show that commuting from a city into another city is increasing most among all commuting types. In addition, population density tends to increase more in areas that are close to the city center, but not in the city center itself. Similar results are found for real estate prices. Living in a city is becoming more expensive in almost every part of a city. Highest growth rates are again seen in areas close to the city center. It is advised for future research to repeat the analysis if the impact of the pandemic is covered in data.

Key words: Commuting, ICTs, Population density, Netherlands, Real estate prices

1. Introduction

"It must be awfully frustrating to get a small raise at work and then have it all eaten by a higher cost of commuting" (Bernanke, 2012)

Economist Ben Bernanke addresses a well-known dilemma of today's working population. Choosing where to live is inevitably linked to the question of how much one can shorten commuting time to the place of work while concurrently minimizing housing cost (Muhammad, 2007). However, the question arises as to which extend this development will continue steadily. The outbreak of the COVID-pandemic revealed the potential for breaking up entrenched structures and switching from working in the office to working from home. This sudden change was merely possible due to the advanced development of information and communication technologies (ICTs). Already at the beginning of the millennium, restrictions were minimized which, promoted by ICTs, make location-independent working possible, regardless of the office location (Harrison et. al., 2000). Undoubtedly, not every working activity can be done from home (e.g., blue collar jobs), but the likelihood is increasing that at least fractions of work can be undertaken from a location to be determined individually (Adams-Prassl et al., 2020). These findings might contribute to the ongoing debate whether distance is dying and whether it is theoretically possible to live anywhere. The debate of the importance of distance, started by Cairncross in 1997 with "The death of distance" and later by Friedman in 2005 by "The world is flat" is still going on but is under heavy discussion and is partly rejected (Rietveld & Vickerman, 2003, Nijkamp, 2017). Therefore, the question is rather what developments will occur in the future regarding urban development. Will real estate prices fall in densely populated urban centers due to declining demand, or will they continue to rise by cause of gentrification and further amenities an urban area can offer? Without a doubt, the role of commuting is linked to these scenarios. If the obligation for daily commuting to the workplace is minimized, settlement behavior as well as commuting behavior might adapt. However, to predict future developments the current situation needs to be known.

Since the research focus in the fields of commuting, population density and real estate prices are either focused on large geographical areas or on a single small geographic area, this thesis attempts to strike a middle ground. Furthermore, it will provide a descriptive perspective on the aspects of commuting, population density and real estate price development.

The main area of interest within this thesis is the Netherlands. The country yields an interesting environment to study since the level of urbanization and population density is extremely high as well as commuting, alternative forms of commuting and modern work practices are quite popular in the Dutch society. To underline that, cycling is exceptionally popular in the Netherlands (KiM, 2015). Moreover, the demand for alternatives to car ownership, such as e-bikes, is increasing. Incentives are being created to encourage people to switch from cars to (e) bikes (de Kruijf et al., 2018). In addition to that, working from home at least part time is, compared to other EU countries, largely popular and gains more and more attention (Gottlieb et al., 2020).

In sum, the goal of this thesis is to answer the following research questions:

RQ1: "How have commuting patterns changed concerning the largest Dutch cities and several agglomeration types between 2014-2019?"

In order to answer the first research question, Dutch commuting patterns will be analyzed on a country level and additionally on a city level. Having a solid data set (CBS) as a base, it is expected that commuting frequencies in general will stay on the same level or even decrease since the importance of living close to the place of work is not as important as it was years ago. With that being said, suburb-city commuting might become more popular, since in total it is required to drive less to work, but then longer. In general, improving ICT devices and techniques do not require workers to commute at all or at least less.

With an eye on the second research question,

RQ2: "How densely populated are Dutch cities on a macro level and how has this changed in 2014-2019?"

it will be examined to which extent the population density increases or decreases as the distance from the city center surges in 200m intervals. The focus is on the cities of Amsterdam, Rotterdam, Eindhoven, Groningen and Tilburg. Population density is expected to grow more in the outer areas of the cities than in the inner center, as the need to live as close to the city center (thus, having close proximity to the workplace) diminishes.

The third research question

RQ3: "How expensive are inner-city real estate transactions on a macro level and how did that change from 2011-2019?"

will be investigated with an extensive data set provided by the Dutch Association of Real Estate Agents, revealing more than 300.000 transactions in the above-mentioned cities. By using a related methodology to the second research question, it is anticipated that dwelling prices with a higher distance to the city center have a higher growth rate than in the center itself, since demand is expected to be higher in outer areas of the respective city.

This thesis is structured as follows: The next chapter will review the scientific state on commuting, population density and real estate developments. The third chapter will introduce the data sets and the methodology used in the analysis. The results of these analyses are presented in the fourth chapter. Followed by that, these results are critically contextualized into the existing literature. The thesis ends with a conclusion while limitations and further research approaches are mentioned.

2. Literature review

This literature review will cover the development in information and communication technology in relation to housing behavior and commuting patterns. For this purpose, theoretical basics, as well as different drivers for urbanization behavior in the (Dutch) housing market will be discussed.

Information and communication technologies

The spatial impact of information and communication technologies on urbanization patterns and land use change are evolving. During the last 20 years, information and communication technologies (ICTs) have improved to such an extent that they have led to a convergence of the physical world and the virtual word (Albach et al., 2015; Alghawli & Almekhlafi, 2019; Haseeb et al., 2019). Heeks (1999, p.3) defined ICTs as “electronic means of capturing, processing, storing, and communicating information”. Certain activities which were originally spatially separate, such as working, shopping and schooling can now be undertaken regardless of the geographic location with the help of ICTs (Couclelis, 1995, 1998; Gandolfi, 2021). These technical developments (mainly improving internet connection speed and more powerful devices to mention the most important drivers) supported the COVID-related rapid transition from working on-site to working from home (Wang et al., 2021) in 2020.

(Tele-)commuting

To further understand spatial impacts on housing prices an overview of housing price drivers as discovered in the literature will be presented as well as a description of the impact of (tele)commuting.

Although the words commuting and telecommuting appear extremely similar at first glance, there are differences which will be further discussed. Simply narrowed down, commuting can be defined as the regular management of the distance between the place of residence and the place of work (Haas & Osland, 2014). According to Rouwendal & Meijer (2001) decisions on the place of residence, the place of work and the mode to deal with commuting are heavily linked to each other and are interdependent. The authors analyzed workers preferences in housing, commuting and employment in the Netherlands by using logistic models and mixed logit models. As a result, they found that Dutch workers generally do not admire commuting and are thriving to keep their commuting as short as possible. However, the preference for a certain standard of living, reflected in the quality of housing (rental price, equipment of the housing, number of rooms, etc.) is stronger than shortening one's commuting time. That said, this collectively visible behavior can lead to commuting times being greatly increased by traffic congestion. If this is the case, relocalization of workers may be a consequence, according to the authors.

In addition, So et. al. (2001) analyzed the individual joint choices of residential and job locations by using an empirical model under the assumption of maximizing one's utility. Commuters who do not live and work in metropolitan areas are more in favor of lower housing costs than a higher wage they could possibly earn in the metropolitan area. Furthermore, those that commute from the periphery to urban centers trade off the higher salary against the increase of commuting time and costs. A final conclusion of that study is that if lower housing cost result in a financial saving compared to the commuting time itself, population will shift to nonmetropolitan areas. After analyzing commuting behavior in 15 EU countries including the Netherlands and Germany Giménez-Nadal et. al. (2020) discovered that commuting time in general is increasing over time. In the Netherlands for example, commuting time increased by 3.25% from 1990 to 2010. With survey data from the European Working Conditions Survey during 1995-2015 and regression analysis they also discovered that higher educated workers (university graduates) tend to commute longer distances.

In contrast to these findings, telecommuting might change this triangle of job location, commuting and housing location (Muhammad, 2007). Telecommuting can be defined as "the use of telecommunications technology to partially or completely replace the commute to and from work"(Mokhtarian, 1991, p. 1) and is often synonymously referred to as "telework, remote work, virtual work, distance work,…" (Allen et al., 2015).

According to Muhammad (2007) telecommuting is expected to be a main driver for changing urbanization patterns. By comparing a physical space and a hybrid space model in combination with spatial clumpiness indexes from 2000-2030 the author found out that in both models the urbanization behavior changes, whereas in the hybrid model (including increasing telecommuting-behavior) the changes are more visible by a population decentralization throughout the Netherlands. As a further result from that, house prices might be subject to change. Furthermore, the impact of telecommuting on the Los Angeles-Long Beach area urbanization pattern was analyzed by Delventhal et. al. (2020). By using a general equilibrium model of internal city structure the authors found three effects on telecommuting employees.

Firstly, jobs relocate from the outer city area into the urban area, while employees move to the outskirts of the city.[1] The second effect discovered is that the average time spent commuting shrinks, although distance to work increases.[2] Third, the average cost of purchasing real estate properties is sinking in urban areas while they increase in the periphery. The main driver for these discoveries is that employees no longer need to commute daily if they work remotely, followed by a movement to cheaper areas of living which causes less demand of office and living spaces in the urban area. Delventhal and Parkhomenko (2020) extended their L.A. methodology on the 48 contiguous US states including Washington D.C. and got to similar results concerning the development of real estate prices and commuter behavior.

This finding is in direct contrast to the idea of Alonso (1960) and Mills (1967). They modelled that areas which are in easier reach of the Central Business District (CBD) have higher house prices compared to areas further away from the CBD. An underlying assumption of their work is a fictitious monocentric city whereas later research also proofed that trend in polycentric cities (Wheaton, 2004). An aggregative model that explains a cities structure and further characteristics was used in their research.

House prices in the Netherlands

Since the Netherlands is the geographical focus of this thesis, the development of housing prices as discovered in the literature are of great importance.

House prices, especially in urban areas, were always subject to booms and busts (W. Miles, 2008).

Generally speaking, house prices are a function of supply and demand (Girouard et al., 2006). Because of the fixed geographical location of housing properties and the duration to satisfy demand, the supply of housing is slightly inelastic[3] (Saiz, 2010). Furthermore, major cities show a lower supply elasticity compared to minor cities (CPB, 2017). In addition, low to moderate supply elasticity is regularly related to either geographical constraints or a strict geographical planning system (Hilber & Vermeulen, 2012). Besides household income, financial wealth, tax(es), age and state of the housing and several other key influencers of housing prices, the geographical location of the house determines the price (Égert & Mihaljek, 2007). The Dutch housing market is characterized by subsidies, tax rules and governmental regulation to protect

[1] The same effect was mentioned by Van Ommeren et. al. (1999)
[2] See also Zhu et. al. (2018).
[3] Housing supply is not fully inelastic since housing stock can be adjusted, e.g. by expansion or transformation. However, this is a slow process.

the market (van der Klaauw & Kock, 1998, Boelhouwer et al., 2004). Despite these interventions in the free market, the price development of housing has been subject to fluctuations in recent years:

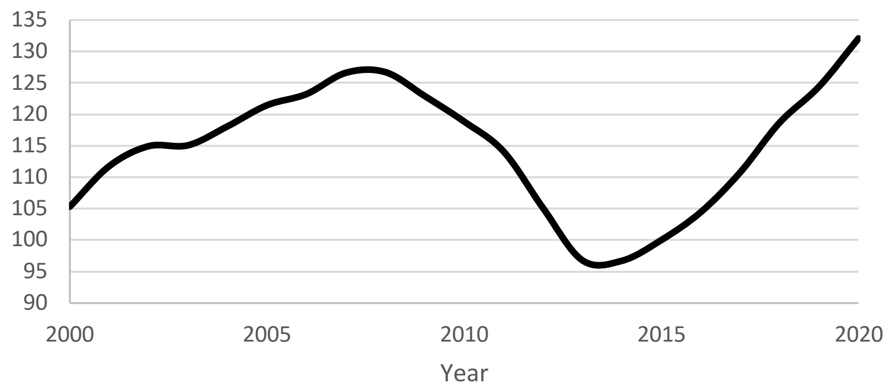


Figure 1: NL House price index, deflated (2015 ≙ 100, Author's illustration according to Eurostat, 2021)

Figure 1 shows the Dutch housing price index corrected for inflation in the years 2000 to 2020. It is visible that the index was growing at a relatively stable rate until the financial crisis led to a depression of prices in 2008. After 2016 the housing market was able to get back to the pre-crisis level and was followed by a stable growth in housing prices. One of the main reasons besides an increasing demand in houses is the comparatively low interest rate issued by the ECB to tackle the crisis' impact (Deelen et. al., 2020). Interestingly, if compared to the German housing market, the Dutch house price trend seems to be more volatile (Wijburg & Aalbers, 2017).

Urban development in the Netherlands

As the Netherlands is a densely populated country and on a high level of urbanization, urban growth guidance and spatial planning are both basic tenets of Dutch urban development planning (van der Valk, 2002). Density is undoubtedly one of the main attributes in the field of urbanity. Density is defined as a share of a given measurement of human activity to the area that is linked to that activity (Taylor & Van Nostrand, 2008). According to The World Bank (2021) the population density (people per km^2 of land area, ppl/km^2) has almost shown a linear growth from 345 ppl/km^2 to almost 512 ppl/km^2 from 1960 to 2018. These are somewhat higher ratios compared to neighboring countries like Belgium and Germany (Belgium grew from 280 to 377 ppl/km^2 whereas Germany almost stagnated from 210 up to 277 ppl/km^2). Since these numbers are considering a whole country, macro level analyses cannot be done with them. Eurostat publishes population data per commune, but this scale is again too great to determine developments on a city level. Koomen and Broitmann (2020) present an overview of population and dwelling density on a city level with data from 2000 and 2017. Concluding, a cities densification rate is higher in the city center compared to the densification of an outer area.

There are different views and findings on the price development of housing in the context of commuting and telecommuting which are partly triggered by the increased usage of ICTs. This thesis aims to investigate to what extent the effects are also occurring in the Netherlands. If that is the case, the housing prices close to major cities core center are expected to have a higher growth rate compared to the city center itself. Moreover, the thesis tries to examine the Dutch commuting behavior and the price development in the Dutch suburban and urban centers, respectively, while analyzing the current population density for five cities on a macro level.

3. Methodology, research design and data description

The next chapter of this thesis consists of a description of the data used for the analysis, an explanation of the research design and the general description of the methodology in order to answer the research questions. As mentioned before, the study area is The Netherlands (Figure 2).

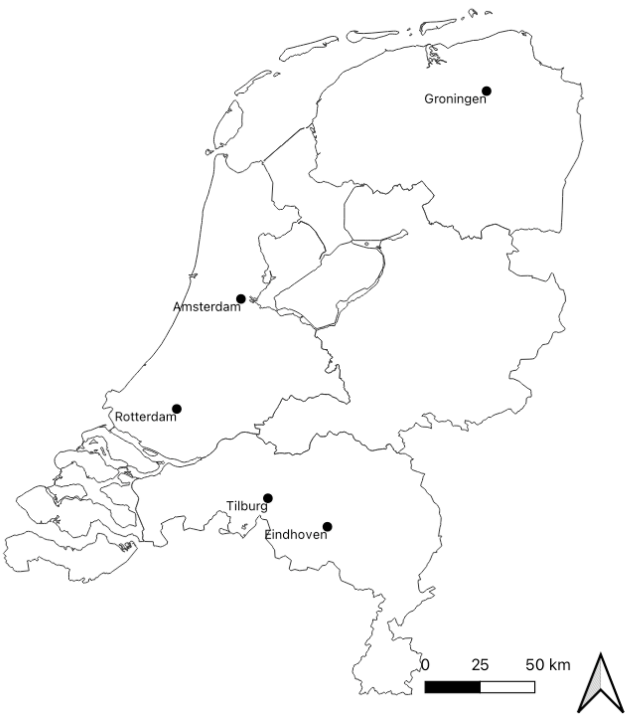


Figure 2: Study area (The Netherlands) and selected cities for analysis

3.1 Data description

3.1.1 Commuting data

The first dataset used in the analysis includes commuting data between every Dutch *Gemeente* in the period 2014-2019. The data was provided by the Dutch statistical office (CBS).
The data is based on information from the Dutch tax authorities and with data from the civil register. With these information CBS was able to draw a connection between the place of living and the place of work. The dataset assumes that if someone lives in city *i* and works in city *j*, daily commuting takes place. To give an example: The first row in Figure 3 is the commuting flow from people who both live and work in Gemeente 1, Aa en Hunze in 2014. Accordingly, the second row describes the commuting flow from Aa en Hunze to Aalbourg in 2014. Unfortunately, the mode of transport is not included in the data.

Gemeente *i*	Gemeente *j*	Flow from *i* to *j*	Year
1	1	x_{11}	2014
1	2	x_{12}	2014
.	.	.	.
.	.	.	.
3	1	x_{31}	2015
.	.	.	.
.	.	.	.
.	.	.	.
421	421	$x_{421\ 421}$	2019

Figure 3: Data structure of Dutch commuting flows in the period 2014-2019

3.1.2 Population data

Furthermore, a highly detailed dataset on population statistics was used. The dataset divides the Netherlands into squares of 100m x100m. Within these squares, a variety of information is contained. In addition to information on population compositions, ages, ethnicities and incomes, information on the number of dwellings, age of dwellings and much more is included. For data protection, the data are slightly modified for less populated areas so that no conclusions can be drawn about individuals. Again, this dataset is provided by the Dutch statistical office (CBS).

3.1.3 House prices

The third data set used in the analysis was kindly provided by the Dutch Association of Real Estate Brokers (De Nederlandse Vereniging voor Makelaars en Taxateurs). The content of the data set are all real estate transactions in the cities of Amsterdam, Rotterdam, Groningen, Eindhoven and Tilburg. Part of the transaction information were not only purchase price, size of the property in m^2 and detailed facts about the equipment but also geographical coordinates. With the help of the coordinates, it was possible to evaluate the data set in a GIS environment. The set covers the period 2011-2020. To make prices comparable, they were deflated to 2020 prices using the CBS CPI calculator. To minimize the influence of outliers on the analysis' results, transactions with a purchase price above 1.500.000€ and/or a property size above 300 m^2 were omitted. In addition to that, transactions with a transaction price below 40.000€ were omitted as well. After this data manipulation, 169.361 observations were left in the data set. See descriptive statistics of this data set in Appendix C.

3.2 Research Design & Methodology

This chapter explains the procedure and methodologies that are used to be able to answer the research questions from the evaluation.

3.2.1 Commuting Data

In order to perform an evaluation based on commuting types, a precise definition of the different urban areas (cities, suburbs, other) presented in the data is necessary. To define spatial areas as cities or suburbs, a variety of different criteria can be used to do so. These criteria might be population size, population density, administrative borders, morphological composition or further economic indicators (Tannier & Thomas, 2013). Due to the variety of metrics and measurement methods, a slightly adjusted focus can lead to different classifications of the above-mentioned geographic areas. In this thesis, the classification of municipalities is based on the classification of the Dutch statistical office (CBS). Roughly, this classification is based on administrative boundaries between municipalities. The authority divides cities into urban agglomerations and urban regions. Suburbs in urban agglomeration share some characteristics of the nearby city. There is both, a morphological and a functional proximity to the central city. In contrast, suburbs in urban regions do not have a distinct morphological proximity and are limited only to a functional proximity. Based on this and on a further selection process, a classification of cities was undertaken by Vliegen (2005). In subsequent years the classification was updated by the authority to take changes in the composition of some municipalities into account. According to that the 421 municipalities in the dataset were classified as follows: 22 municipalities were defined as *cities* (e.g., Amsterdam, Rotterdam, Eindhoven), 127 municipalities as *suburbs* (e.g., Uitgeest, Almere, Amstelveen) and the remaining 272 municipalities as *other*.

Since data is available between 2014 and 2019, annual and total changes in flows, as well as annualized changes can be calculated for these periods. This method is suitable for obtaining a general overview of commuting flows in the Netherlands.

As a possible commuting combination, all flows between municipality types are possible:

Figure 4: Overview of commuting combinations

Place of living		Place of work
City	➟	City
City	➟*	Suburb
City	➟	Other
Suburb	➟**	City
Suburb	➟	Suburb
Suburb	➟	Other
Other	➟	City
Other	➟	Suburb
Other	➟	Other

*: also known as reverse commuting (Glaeser et. al., 2001)

**: also known as the traditional way of commuting

However, it is not possible to analyze commuting flows on a municipality basis with the above-mentioned method. To do so for the 22 cities quotients are calculated.

The incommuting quotient of municipality *j* is calculated as follows:

$$InComQ_j = \sum_{i \wedge s(j)=3}^{421} \frac{cflow_{ij}}{jobs_j}$$

where

$cflow_{ij}$ is the commuting flow from municipality *i* to municipality *j*

$jobs_j$ is the number of jobs in municipality *j*

s(i) is the classification of municipality $i \in \{1,2,3\}$

s(j) is the classification of municipality $j \in \in \{1,2,3\}$

here 3 refers to *city*, 2 to *suburb*, and 1 to *other*

The incommuting quotient measures the origin of people working in municipality *j*. It can determine the fraction of people that commute to work in municipality *j* either from a suburb, a city, a municipality whether defined as a city nor suburb and the fraction of people living and working in municipality *j*, labelled as “same” in the following tables. The quotients sum is equal to 1.

The outcommuting quotient of municipality *j* is calculated as follows:

$$OutComQ_i = \sum_{i \wedge s(j)=3}^{421} \frac{cflow_{ij}}{pop_j}$$

where

$cflow_{ij}$ is the commuting flow from municipality *i* to municipality *j*

pop_j is the amount of the working population in municipality *j*

s(i) is the classification of municipality $i \in \{1,2,3\}$

s(j) is the classification of municipality $j \in \{1,2,3\}$

here 3 refers to *city*, 2 to *suburb*, and 1 to *other*

The outcommuting quotient determines the commuting destinations of municipality *i*'s workers. It measures the fraction if municipality *i*'s working population works in another city, suburb, other or in municipality *i* itself, again labelled as "same" in the following tables.

In order to calculate changes from 2014 to 2019 the quotients changes are calculated as percentages by using the formulas:

$$\Delta InComQ_j = \frac{InComQ_j(2019) - InComQ_j(2014)}{InComQ_j(2014)} * 100$$

$$\Delta OutComQ_i = \frac{OutComQ_i(2019) - OutComQ_i(2014)}{OutComQ_i(2014)} * 100$$

3.2.1 Population data

In order to quantify the population density in respect to the distance from the city center, a spatial analysis methodology influenced by Broitman & Koomen (2020) is used. Due to the historical development of the cities in scope, the marketplace or the city hall (in case no central marketplace available) was defined as city center (Lemoy & Caruso, 2020). Furthermore, rings were defined around the city center. A radius of 200m was chosen for the first ring. Subsequently, 49 further rings were defined within 200m intervals. As a result, 50 rings are defined around every city in scope with a radius range from 200m to 10.000m. With the QGIS[4] operation *joining attributes by location* the number of inhabitants was counted for every ring.

[4] All calculations were performed on a 1,4 GHz Quad-Core Intel Core i5 on macOS Big Sur 11.4 with QGIS 3.14

Since the population for every ring is cumulated[5], the following formula was used to calculate the total number of inhabitants per ring:

$$I_{sd} = CI_{sd} - CI_{sd-1}$$

where

I_{sd} is the total number of inhabitants in the ring with the radius *d* in city *s*

CI_{sd} is the cumulated number of inhabitants in the ring with the radius *d* in city *s*

Following this, the area of every ring in hectare was calculated:

$$A_{sd} = \frac{\pi * r_{sd}^2 - \pi * r_{sd-1}^2}{1000}$$

where

A_{sd} is the area of the ring with radius *d* in city *s*

r_{sd} is the radius of the ring with radius *d* in city *s*

Finally, the inhabitants per hectare were calculated:

$$IH_{sd} = \frac{I_{sd}}{A_{sd}}$$

where

IH_{sd} is the number of inhabitants per hectare in the ring radius *d* in city *s*

3.2.2 House prices

In order to determine the average m^2 price depending on the distance to the city center, a similar methodology as in 3.2.1 is used. First, the data set on house prices was imported to a GIS environment. As in the previous section, rings were introduced around the city centers. These rings also have diameters around the centers that increase in 200m intervals. Consequently, 50 rings from diameter sizes 200m up to 10.000m were established to gain observations about the price development in respect to the distance from the city center. Since the house price observations are point data, it is necessary to determine the ring each observation is located in. For this purpose, the GIS operation distance to nearest hub (points) was chosen. As part of the

[5] As an example: The 10.000m ring includes all inhabitants that are also already included in the 9.800m ring.

operation, the already defined city centers (Amsterdam, Rotterdam, Eindhoven, Tilburg and Groningen) acted as hubs. The operation calculates the linear distance in meters to the nearest city center. Using this distance, each observation is assigned to a specific ring. As an example: A house transaction in Amsterdam's Gerrit van der Veenstrat is situated approximately 3.078m from the city center of Amsterdam. That means that it is located in the ring with the diameter 3.200m. Since it is of interest to what extend the average price per square meter changes with ascending distance to the city center, the average price per square meter is calculated by the following formula:

$$asm_{rst} = \frac{\sum p_{rst}}{\sum m_{rst}}$$

where

asm_{rst} is the average price per square meter in the ring with radius *r* in city *s* in period *p*

p_{rst} is the sum of all prices in the ring with radius *r* in city *s* in period *p*

m_{rst} is the sum of all apartment sizes in the ring with radius *r* in city *s* in period *p*

Since there are not enough observations in the dataset in every cities ring per year, the explanatory power lacks. In order to overcome that the final analysis does not compare two individual years with each other, but rather compares the average of two time periods (2011-2014 and 2017-2020) . Figure 5 presents a graphical illustration of 50 consecutive rings in the city of Amsterdam and every housing transaction.

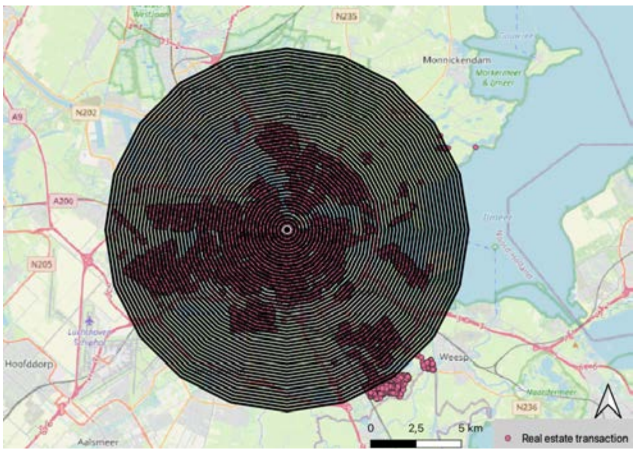


Figure 5: Graphical illustration of ring calculations and real estate transactions for the city of Amsterdam

4. Results

The following chapter describes the results of the analyses introduced in 3. In addition, graphical representations are presented.

4.1 Commuting flows

Figure 6: Commuting flows between cities, suburbs and other areas in 2014-2019

	Year						
Commuting type	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**Sparkline**
City - City	1.510.800	1.551.200	1.584.000	1.622.600	1.667.800	1.718.600	
City - Other	291.800	286.800	293.000	298.500	306.400	311.500	
City - Suburb	360.800	368.700	370.000	394.600	401.700	401.600	
Other - City	657.200	653.800	673.100	693.600	717.400	745.100	
Other - Other	2.159.900	2.160.800	2.197.300	2.259.000	2.320.000	2.401.900	
Other - Suburb	300.000	298.900	302.700	312.400	324.300	334.400	
Suburb - City	730.200	757.400	772.000	785.700	803.900	788.100	
Suburb - Other	237.700	242.600	245.300	257.600	253.400	252.400	
Suburb - Suburb	826.500	857.600	865.200	884.800	901.500	898.000	
∑	7.074.900	7.177.800	7.302.600	7.508.800	7.696.400	7.851.600	

Red dot in sparkline represents lowest flow, blue dot represents highest flow

Figure 6 shows the total amount of commuters based on their commuting type in the time period 2014-2019. Generally speaking, it is visible that the total amount of every commuting type is rising from 2014 to 2019 by ~ 11%. The most common type of commuting is *other* → *other*, clearly because this category inherits more workers and municipalities compared to the amounts of *cities* and *suburbs.* Interestingly, the common and traditional understanding of commuting from *suburb* into the *city* reached its local maximum in 2018 and is facing a downward trend in 2019. Furthermore, reversed commuting (*city* → *suburb*) is experiencing an upwards trend until 2016 and remains stable after that. Commuting from a suburb to an area whether defined as a city, nor a suburb gained its peak interest in 2017, but is facing a downward trend since. In total, the number of employed persons has increased with a continuous and relatively linear growth during the observation period.

In addition to that, figure 7 shows the annual percentage changes by commuting type. One can see that *city* → *city* commuting faced the highest growth rate by 13.8%, closely followed by *other* → *city* commuting with 13.4%. In contrast, the traditional understanding of commuting *suburb* → *city* has a much lower growth rate of 7.9%. Here, in 2019, the largest negative growth of all commuting types in the entire observation period occurred by -2%. The lowest total growth rate is visible for *suburb* → *other* with 6.2%.

Figure 7: Change in commuting flows in 2014-2019 in percentages

	Year						
Commuting type	**2015**	**2016**	**2017**	**2018**	**2019**	**total change**	**annualized**
City - City	2,7	2,1	2,4	2,8	3,0	13,8	2,6
City - Other	-1,7	2,2	1,9	2,6	1,7	6,8	1,3
City - Suburb	2,2	0,4	6,6	1,8	0,0	11,3	2,2
Other - City	-0,5	3,0	3,0	3,4	3,9	13,4	2,6
Other - Other	0,0	1,7	2,8	2,7	3,5	11,2	2,2
Other - Suburb	-0,4	1,3	3,2	3,8	3,1	11,5	2,2
Suburb - City	3,7	1,9	1,8	2,3	-2,0	7,9	1,6
Suburb - Other	2,1	1,1	5,0	-1,6	-0,4	6,2	1,2
Suburb - Suburb	3,8	0,9	2,3	1,9	-0,4	8,7	1,7

Figure 8: Outcommuting quotients and Incommuting quotients for all cities in 2019

	Outcommuting Quotient				Incommuting Quotient			
	City - Sub	**City - Other**	**City-City**	**Same**	**Sub - City**	**Other - City**	**City-City**	**Same**
Amsterdam	0,18	0,05	0,09	0,68	0,27	0,16	0,13	0,44
s-Gravenhage	0,20	0,08	0,18	0,54	0,29	0,14	0,14	0,44
Amersfoort	0,21	0,17	0,25	0,37	0,25	0,25	0,16	0,34
Apeldoorn	0,10	0,20	0,14	0,56	0,15	0,29	0,10	0,46
Arnhem	0,18	0,18	0,22	0,42	0,29	0,26	0,14	0,32
Breda	0,15	0,17	0,21	0,47	0,23	0,22	0,16	0,39
Dordrecht	0,23	0,10	0,26	0,41	0,30	0,15	0,15	0,41
Eindhoven	0,20	0,13	0,15	0,51	0,23	0,30	0,14	0,33
Enschede	0,08	0,23	0,07	0,62	0,10	0,35	0,03	0,53
Groningen	0,03	0,19	0,06	0,72	0,06	0,38	0,03	0,53
Haarlem	0,30	0,05	0,31	0,33	0,39	0,12	0,10	0,39
Heerlen	0,22	0,14	0,24	0,40	0,33	0,22	0,16	0,29
's-Hertogenbosch	0,09	0,21	0,23	0,46	0,15	0,36	0,16	0,33
Leeuwarden	0,02	0,24	0,07	0,67	0,06	0,38	0,04	0,52
Leiden	0,26	0,07	0,32	0,34	0,39	0,13	0,17	0,32
Maastricht	0,08	0,09	0,22	0,62	0,20	0,20	0,16	0,44
Nijmegen	0,13	0,19	0,18	0,50	0,24	0,23	0,10	0,43
Rotterdam	0,22	0,10	0,15	0,53	0,32	0,18	0,11	0,39
Sittard-Geleen	0,08	0,22	0,26	0,44	0,13	0,36	0,14	0,36
Tilburg	0,11	0,17	0,20	0,52	0,20	0,22	0,15	0,43
Utrecht	0,19	0,12	0,22	0,47	0,28	0,23	0,20	0,30
Zwolle	0,06	0,23	0,12	0,60	0,09	0,46	0,07	0,37
ø	0,15	0,15	0,19	0,51	0,23	0,25	0,12	0,40

Figure 9: Change in Incommuting and Outcommuting quotients 2014-2019 percentages

	Outcommuting changes				Incommuting changes			
	City - Sub	**City - Other**	**City-City**	**Same**	**Sub - City**	**Other - City**	**City-City**	**Same**
Amsterdam	5,64	-18,23	-4,09	0,96	-2,25	2,67	3,14	-0,45
s-Gravenhage	-0,40	-7,91	4,38	0,07	-0,32	-6,29	-1,24	2,73
Amersfoort	-0,60	5,34	2,48	-3,46	5,13	9,70	-9,38	-5,13
Apeldoorn	15,98	3,57	-0,11	-3,57	2,00	0,62	-9,27	1,11
Arnhem	8,93	-7,50	18,22	-7,51	-2,52	0,09	3,97	0,65
Breda	4,59	0,19	-0,03	-1,41	0,18	-7,42	16,66	-1,40
Dordrecht	-11,55	-6,98	10,06	3,38	-1,06	-13,67	13,18	2,50
Eindhoven	8,29	-13,47	9,58	-1,55	-2,64	-0,03	8,64	-1,40
Enschede	3,13	-4,79	0,30	1,48	-2,52	1,78	-16,37	0,33
Groningen	-59,54	-5,77	-17,77	9,86	-68,20	26,76	9,81	10,93
Haarlem	-7,78	-14,16	6,49	3,23	-3,67	11,50	-11,90	4,17
Heerlen	-11,10	32,76	2,12	-3,10	-16,75	18,98	17,13	3,23
s-Hertogenbosch	0,26	-3,67	5,82	-1,10	-3,24	2,11	-5,82	2,36
Leeuwarden	-46,64	11,39	7,63	-1,62	-65,21	16,53	-8,35	12,67
Leiden	-1,46	-11,38	14,24	-7,23	4,76	-3,11	-1,92	-3,10
Maastricht	-15,65	-14,66	10,93	1,15	-13,54	31,27	-5,99	-1,09
Nijmegen	16,83	-11,97	5,11	-0,42	-0,06	-6,26	22,04	-0,64
Rotterdam	5,27	-6,67	7,69	-2,77	13,37	-20,53	8,36	-0,01
Sittard-Geleen	-12,29	24,97	-2,86	-5,53	-24,81	21,09	-8,61	-1,84
Tilburg	-12,06	-4,30	0,81	4,31	1,72	7,18	-0,48	-3,85
Utrecht	-6,72	-1,44	1,96	2,43	-3,07	-0,77	9,49	-2,08
Zwolle	-0,64	-12,56	4,47	4,84	-10,94	0,83	26,25	-1,76
Ø	-5,34	-3,06	3,97	-0,34	-8,80	4,23	2,70	0,81

Figure 8 gives an overview of the in- and outcommuting quotients for 2019. Quotients for 2014 can be seen in Appendix D. With regard to the outcommuting quotient one can see that in all cases most of the city's population lives and works in the same municipality since the fraction in column *same* is always the highest in its row. Regarding the incommuting quotient one can see that most of the fractions have their highest value in *same*. However, taking Leiden as an example: 32% of all incommuting workers started their journey in Leiden itself, whereas 39% of incommuters are based in a suburb. This is merely due to the high number of commuters from Katwijk and Leiderdorp, both suburbs.

Figure 9 reveals the changes in quotients from 2014-2019 in percentages. It is easily visible that reverse commuting is decreasing rapidly, from an outcommuting point of view. Groningen has seen the largest decline. In absolute numbers, 28.000 people who were living in Groningen commuted to a suburb in 2014, while in 2019 it was only 9.500. Further cities with a large decrease in reverse commuting from an outcommuting point of view are Leeuwarden, Maastricht, Sittard-Geleen and Tilburg. In most cases, increases are visible in city → city connections. Largest increases are visible in Arnhem, Leiden and Maastricht. Considering the incommuting perspective a decline in suburb → city connections is evident.

Again, using Groningen as an example one can see that the share of people who commuted from a suburb into Groningen fell by 68%. In contrast to that, 26% more people from regions either classified as cities or suburbs now commute to Groningen and roughly 10% more people decided to live and work in Groningen.

4.2 Population density

This section focuses on the population density of the cities of Amsterdam, Rotterdam, Tilburg, Eindhoven and Groningen.

Figure 10 shows the population density per hectare with respect to the distance to the city center for the city of Amsterdam. The most densely populated ring is not located directly in the city center, but 2.200m away from it. Comparing the years 2011 and 2020, it is noticeable that 47 out of 50 rings show a growth in population density, while only three rings show a minimal decrease with approximately 1-2%.[6] The highest growth rates are observed in the rings 4.000m and 4.400m distant from the city center. In summary, Amsterdam is becoming more densely populated in almost every area.

Figure 10: Population density (inhabitants/ha) Amsterdam

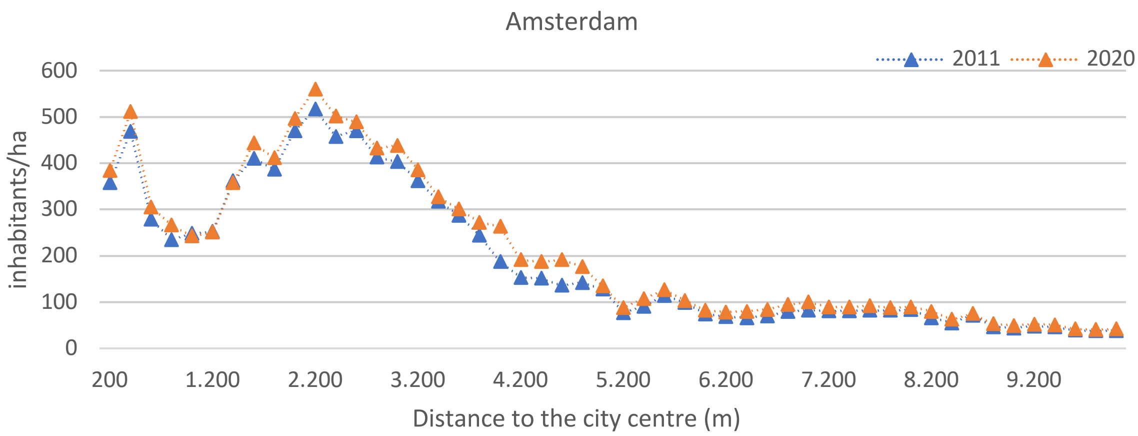


Figure 11 shows the development of population density for the city of Eindhoven. It is noticeable that the density in the city center (200m ring) is by far not as high as the following rings. The most densely populated ring is located 1.200m away from the city center. Aside from that it is noteworthy that the inner urban area of Eindhoven experiences a strong growth in terms of density. By comparing 2011 and 2020 growth rates per ring of up to 100% (400m ring) are visible. However, the increase in growth rate reduces to single-digit growth rates by enlarging distance to the city center.

[6] See a full table on growth rates in Appendix A.

As one can see in Figure 12, Groningen's city center is again not the most densely populated area in the city but reaches its most densely populated ring at 600m distance. The highest growth rates are in the subsequent rings up to a distance of 2.600m. Not much has changed with an increasing distance between 2011 and 2020. In some rings, the population density grew slightly, whereas in other it decreased somewhat. In summary, Groningen's inner-city area has encountered growth rates of up to 39% per ring, but with greater distance to the center this growth rates decreased significantly.

Figure 11: Population density (inhabitants/ha) Eindhoven

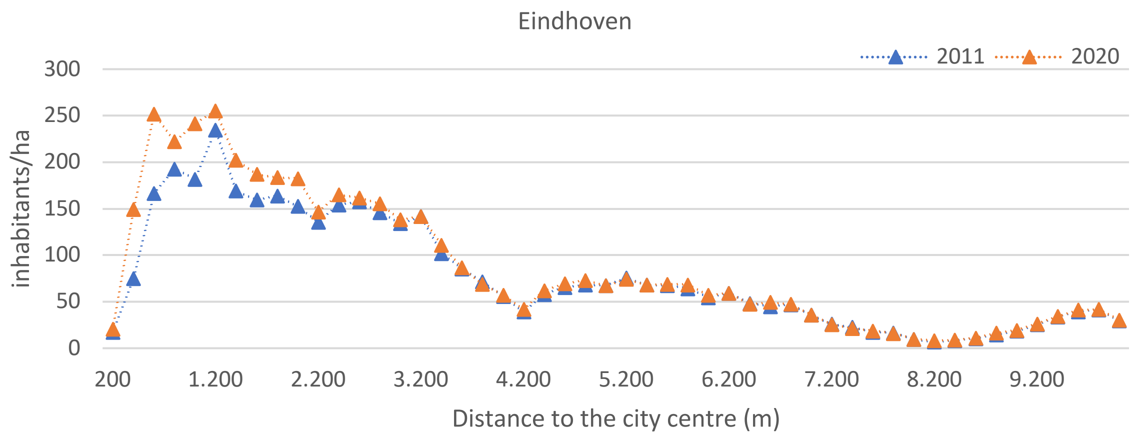
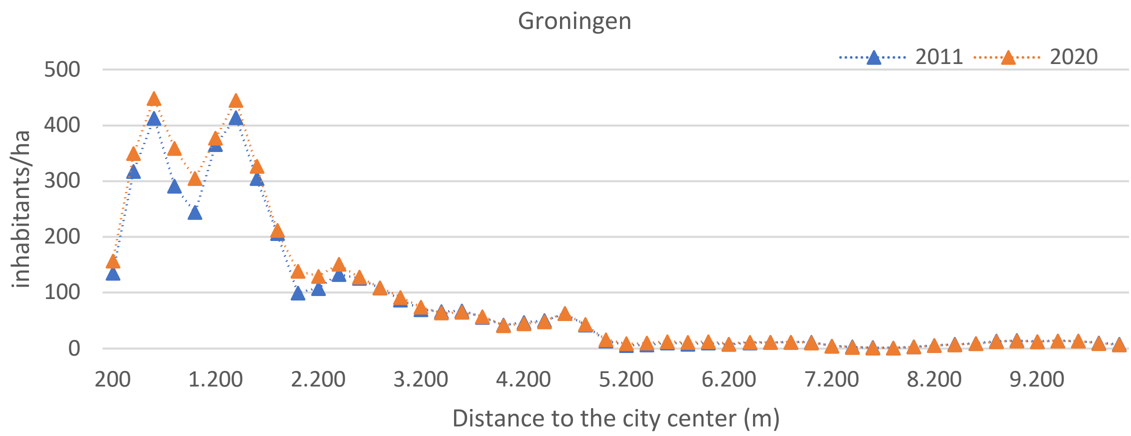


Figure 12: Population density (inhabitants/ha) Groningen



Rotterdam's population density in 2011 and 2020 can be seen in Figure 13. As in the cities of Groningen and Eindhoven it is easily detectable that the most densely populated area of the city is not the city center. The most populated area is 2.200m away from the center and has a population density of approximately 458 inhabitants/ha. However, after this observation point, population density declines. The rings which are 200-2.600m distant to the city center face significantly higher growth rates in the period 2011 to 2020 compared to the rings 2.800-10.000m away from the center.

Finally, the population density numbers for the city of Tilburg can be found in Figure 14, which once again demonstrates that the direct city center is not the most densely populated area of the city. Indeed, the most densely populated area is to be found 1.200m distant to the city with a population density of 341 inhabitants/ha. After reaching the maximum, the population density decreases the further one moves away from this point. Comparing the numbers of 2011 with 2020, it can be seen that the numbers in the inner area of the city (200-2.600m rings) have increased more than in the wider area of the city (2.600-10.000m).

Figure 13: Population density (inhabitants/ha) Rotterdam

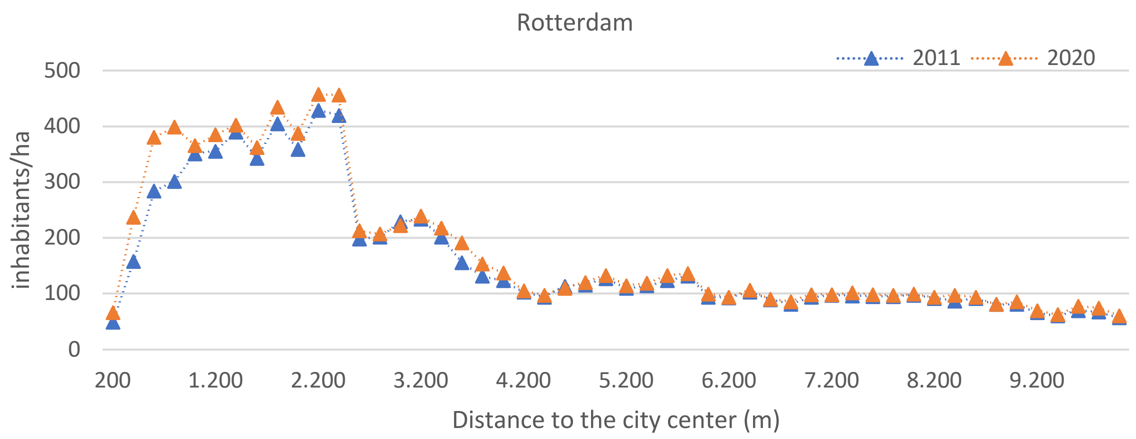
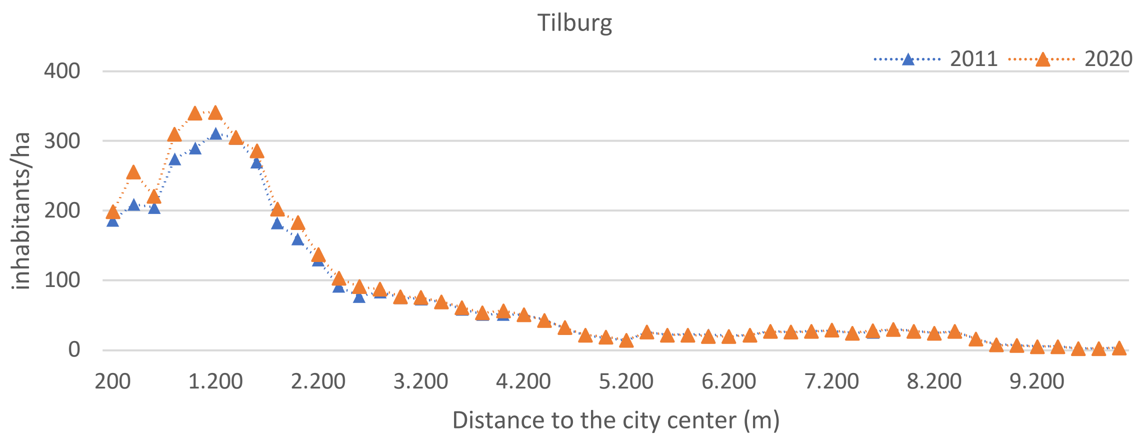


Figure 14: Population density (inhabitants/ha) Tilburg

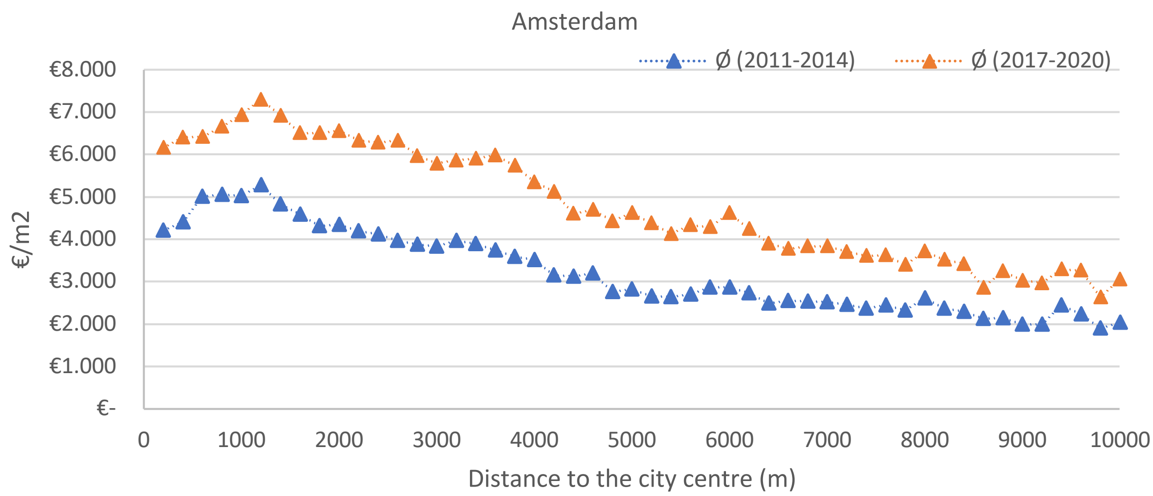


4.3 Real estate prices

The following section summarizes the results regarding the house price development in the cities of Amsterdam, Rotterdam, Tilburg, Eindhoven and Groningen. In the presentation of the results, the current situation will be briefly addressed, as well as the changes in growth rates by comparing the observation periods.

Figure 15 shows the development of real estate prices per square meter for the city of Amsterdam. As already mentioned in 3.3, it is not possible to consider the result data on a yearly basis due to data availability and their explanatory power. Nevertheless, and in order to present results with sufficient explanatory power, the periods 2011-2014, as well as the periods 2017-2020 were summarized and averaged. One can see that the highest price per square meter does not occur in the direct center of the city, but rather in the further course of the city center at a distance of about 1.200m. After reaching this maximum level with a price of about 7.300€€/m^2 the price drops steadily with increasing distance. After comparing the figures for the time periods one can see that a price increase in every distance ring occurred. Areas close to the city center (200m to 1.600) face an average price increase of approximately 39%. Shortly thereafter, the average growth rate rises to about 55% in the rings 1.800m-6.400m, while it drops again to 47% in the remaining rings (6.600m-10.000m). The highest growth rate can be observed within a distance of 5.000m. This rate reaches 64%. In contrast the lowest growth rate of 28% is in close proximity to the city center with 600m distance.

Figure 15: €/m2 prices development (Amsterdam)



The real estate prices on a square meter basis for the city of Eindhoven are visualized in Figure 16. Since the data set of the Dutch Association of Real Estate Agents is limited to observations withing the respective cities, no transactions in Eindhoven are available with a greater distance to the city center than 6.500m. Again, it is noticeable that the peak of the current price development is not to be found in the direct city center area, but immediately after at a distance of 400m with a price of 3.889€/m². As the distance increases, the price drops to a level of 2.516 €/m² and then remains relatively constant between 2.390 €/m² and 2.750 €/m² (2.400m to 6.500m). It is again noteworthy that by comparing the time periods in each distance range a price increase is taking place.

The city of Groningen shows a somewhat different development, as can be seen in Figure 17. The highest price range is in the immediate city center (200m) with a price of 5.049 €/m². Closely followed by that the prices drop to 2.700€/m² and remain fairly constant with minimal breakouts at about 5.000m and at 7.400m distance. In a direct comparison of the time periods, some differences from the previously studied cities stand out. First, the growth rate in the immediate center is 124%. After consulting the raw data, this is due to the rapid increase in real estate sales in the area (200m), which includes almost exclusively high-priced properties. Second, prices are decreasing in some areas in Groningen. For example, prices in a distance of 7.600m and 9.200m have fallen by 3% and 2%, respectively.

Figure 16: €/m2 prices development (Eindhoven)

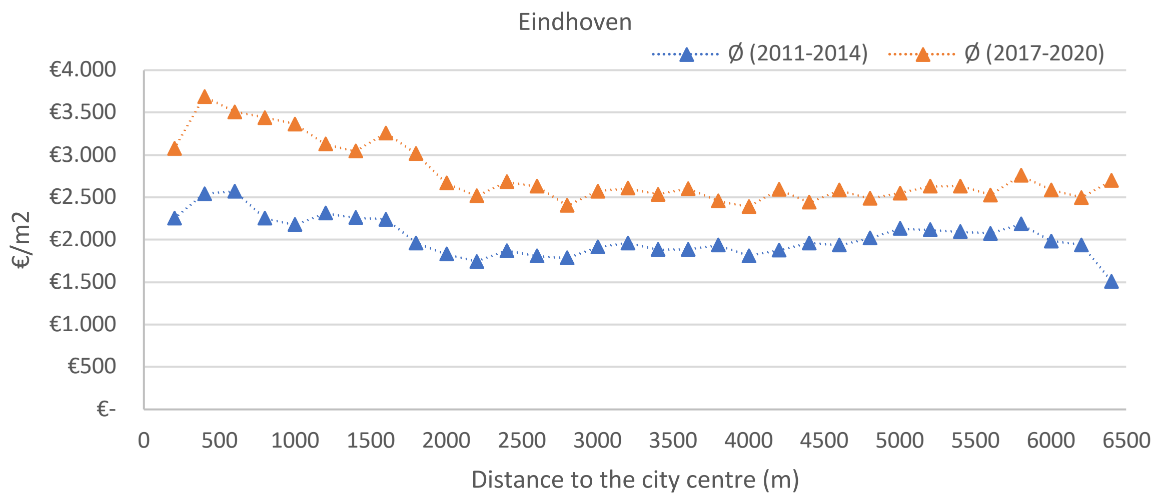
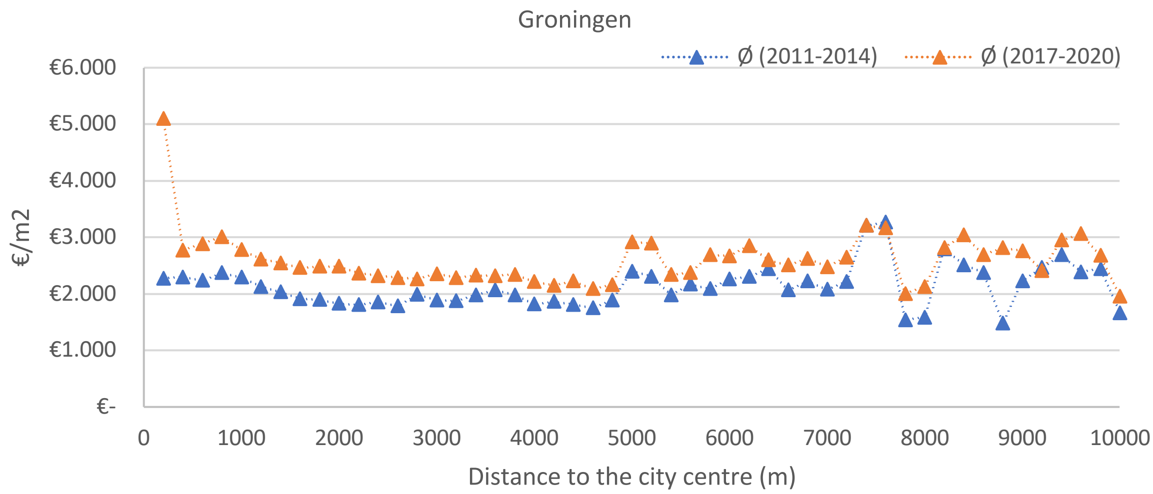
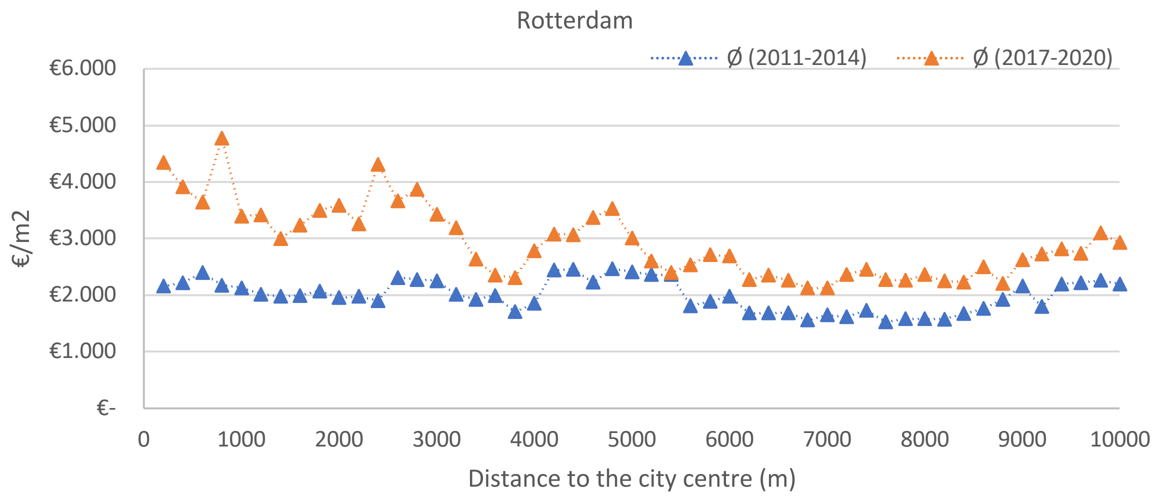


Figure 17: €/m2 prices development (Groningen)



The most expensive residential area in the city of Rotterdam is located in the ring with 800m distance to the city center, see Figure 18. The price per square meter also decreases as the distance to the city center increases. However, this trend only continues up to a distance of around 6.800m. Interestingly, from this point on the price increases slowly but continuously close to 3.000 €/m^2. One can see by comparing the observation periods that every ring faces a positive growth in terms of prices. The highest growth rate is visible after 800m from the center with approximately 120%. In contrast the smallest growth rate is visible after 5.400m with just 2%.

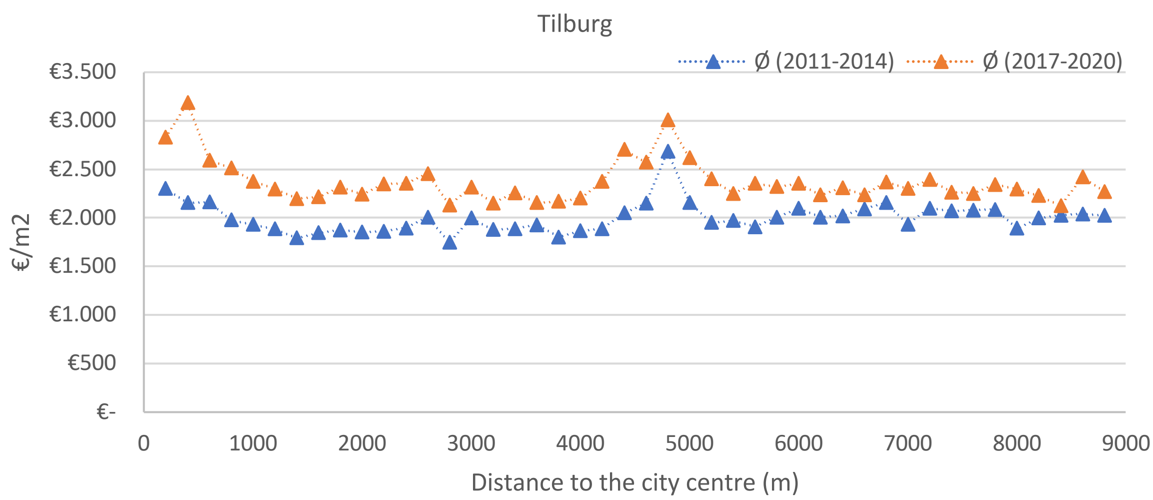
Figure 18: €/m2 prices development (Rotterdam)



The price level in the city of Tilburg is somewhat balanced, see Figure 19. Thus, the difference between the highest price level (3.184 €/m^2 at 400m distance) and the lowest price level (2.125

€/m² at 8.400m distance) is no more than 1.059€, representing the least max min spread of all cities in scope. Moreover, prices start to decline after reaching the peak but rise after a distance of 5.000m and almost reach the maximum level. While comparing the observation periods one can see that a negative development is not taking place in Tilburg. Indeed, the growth rate reaches a maximum of 48% in the area 400m apart from the city center. The lowest growth rate with 5% exists in the outer part of Tilburg with 8.400m distance. As it was the case for Eindhoven, no observations were included in the data set that have a higher distance to the city center than 8.800m. Because of that the observation area does not consider any further distances.

Figure 19: €/m2 prices development (Tilburg)



5. Discussion

The results of the analysis show that both commuting patterns and trends in population density and dwelling prices are highly volatile. In some cases, the results have turned out to be different than expected.

In terms of commuting behavior, it was expected that longer distances would be accepted since proximity to the place of work loses its importance due to ICTs. That is just partly the case. With a focus on the analyzed cities incommuting patterns it is visible that suburb-city commuting decreases by almost 9% whereas commuting flow from areas whether defined as a city nor suburb increases by 4% on average. Some cities, such as Rotterdam and Tilburg, stand out with contrary developments, but they remain the exception in this regard. With a focus on the cities outcommuting behavior, the rise of reverse commuting mentioned by Glaeser et al. (2001) can be neglected in general. In conclusion, suburbanization of jobs is not really existing in the Netherlands[7]. Amsterdam, Appeldoorn and Arnhem are again exceptions, as the share of reverse commuting is in fact rising in these cities. The reasons for this slightly unpredictable behavior are highly speculative. Since unemployment in the Netherlands rose and fell in the period 2011-2019, reaching a peak in 2007 at around 7% unemployment rate, and then fell again slightly (Statista, 2021), the working population may be unwilling to change jobs due to financial insecurities.

Regarding the population density development in dependency on the distance to the city center it was expected that the population density shows a higher growth rate in areas that have a greater distance to the city center. As a matter of fact, these expectations are not met regarding the analysis. In the case of Amsterdam, the area with the highest growth rate (2011 to 2020) is located 4.000m-5.000m to the city center. In Eindhoven's, Rotterdam's, and Tilburg's case the area with the highest growth rate is in close proximity to the city center (0m-1.000m). Looking at Groningen, the population density decreases by 9% on average in the area 7.000m to 10.000m distant to the center. The fact that urban centers seem to gain in attractiveness are in line with recent findings by Wolff et al. (2018) and Haase et al. (2013). Again, the reasons for this development are deeply speculative. Urban centers are more attractive for certain population groups. International expats for instance have a relevant impact on the Dutch residential market

[7] Interestingly, suburbanization of jobs is expected to be one of the leading cause for an increasing reverse commuting pattern in France (Aguiléra et al., 2009) and California (Cervero & Tsai, 2003).

since the Netherlands and especially the Randstad region and the university cities are popular for them (CBS, 2015)[8].

Focusing on the m^2 price development it was predicted that dwelling prices will have a greater growth rate with greater distance to the city center. This prediction, again, did not come true. Looking at Eindhoven, Groningen, Rotterdam and Tilburg, the areas with the highest growth rates (concerning the period 2011-2019) are located in immediate proximity to the city center, i.e. 0m-800m. The city of Amsterdam is an exception in this case. Here, although a high growth rate is visible in the immediate center zone, the area with the highest growth rates can be seen in the 4.200m to 6.400m range. Interestingly in this analysis, population density growth rates and price per square meter growth rates behave relatively similarly. Consequently, a higher density implies higher demand in a specific region. This connection was empirically proven by Miles (2012).

[8] Many international companies have their (European) headquarters in the Randstad region

6. Conclusions, limitations and further research

6.1 Conclusions

This thesis used a descriptive approach to investigate commuting behavior in the Netherlands on a country and city level, respectively. Furthermore, it was analyzed how population density and real estate prices develop with increasing distance to the city center in the cities of Amsterdam, Rotterdam, Tilburg, Eindhoven and Groningen.

Looking at research question 1,

"How has commuting patterns changed concerning the largest Dutch cities and several agglomeration types between 2014-2019?",

it can be answered as follows: The number of full-time workers in the Netherlands increased by 11% in the period 2011-2019. However, the increase in the number of employed persons has not been evenly distributed across all types of agglomerations. While all commuting types rise in numbers during the observation period, suburb to city commuting and suburb to other areas whether defined as cities nor suburbs have gained in interest but seem to have reached their peak since their frequencies are diminishing in 2019. In contrast, commuting from other areas into cities, into suburbs and into another type of agglomeration with an equal size seem to have filled this gap with the highest recent growth rates in 2019 among all types examined. In addition to that, city to city commuting is growing steadily and has the highest overall growth rate. After calculating in- and outcommuting quotients, it was possible to determine the work destination of the cities working population as well as the cities working populations origin. Looking at the development at city level, it is noticeable that in all cases the biggest share of people live in the city where they also work, concluding that the way to commute is comparably short. For example, 68% of Amsterdam's working population also works in the city (outcommuting perspective). Cities with the lowest values are Haarlem (33%) and Leiden (34%). Notable major changes in commuting patterns have occurred in some cities. Residents of Groningen and Leeuwarden have mostly made the decision to minimize their commuting activities from Groningen to suburbs with a decrease of 59% and 47%, respectively. While in the case of Groningen, the working population increasingly repositioned their job location to Groningen itself, the population of Leeuwarden tended to reorient to other cities or areas that are neither defined as cities nor as suburbs. From an incommuting point of view the highest growth change occurs in Maastricht. While 14% fewer people from suburbs commute to the city, the share of commuters from areas not defined as cities or suburbs grow by 31%. To sum up, the general developments from an outcommuting perspective are declining demand for city-suburb and city-other commuting, while the demand for city-city commuting is increasing. From an incommuting point of view, suburb-city commuting is losing its importance, while all other commuting types are facing increases.

Regarding the second research question,

"How densely populated are selected Dutch cities on a macro level and how has this changed in 2014-2019?",

it can be concluded that population density in general diminishes the further one moves away from the city center. However, after analyzing the population densities for Amsterdam, Rotterdam, Eindhoven, Groningen and Tilburg, the area with the highest population density is not found in the immediate city core. In the case of Rotterdam, the most densely populated area is located at about 2.000m-2.400m to the city center and aggregates to about 450 inhabitants/ha. The cities of Tilburg, Eindhoven and Groningen show a somewhat similar peak area of their highest population densities. In these cities the most densely populated territory is located approximately 800m-1.400m to the city center. Amsterdam's population density peak is partially similar to Rotterdam, as Amsterdam's population density is also highest after about 2.400m distance to the city center at over 550 inhabitants/ha. In all cities, density decreases after the peak and eventually settles at a relatively stable level from roughly 5.000m to 10.000m. All in all, population density is more volatile as one gets closer to the city center.

To answer the third research question,

"How expensive are inner-city real estate transactions on a macro level and how did that change from 2011-2019?",

it can be generally said that real estate prices calculated per square meter have increased in almost all areas in the cities of Amsterdam, Eindhoven, Rotterdam, Groningen and Tilburg. Looking at Amsterdam, the most expensive area in the city is 1.200m apart from the city center and adds up to more than 7.300 €/m^2. However, the area with the highest growth rate in prices is 4.800m-6.400m distant to the core city. Additionally, the area with the greatest growth rate in terms of population density also shows high growth rates in terms of prices per square meter. Tilburg in contrast, has its most expensive area in the immediate city center (400m distance). This is also the same area, which faced the highest growth rate if the observation periods are compared. Nonetheless, this peak is almost caught up again by the ring, which includes observations that are 4.800m apart from the center. Groningen faces the highest square meter price in direct neighborhood of its center with more than 5.000 €/m^2. However, if the distance is increased only marginally the price per square meter drops rapidly and stabilizes in the range of 400m – 4.800m distance. If the distance is increased further after this point, the prices show a more volatile behavior and rises to 3.200 €/m^2 (7.400m distance). This is also the only area where a decrease in prices has occurred during the observation periods out of all cities that have been analyzed. The sharpest increase in value has occurred in the center (200m). Here the price increased by 124%. Eindhoven shows a slightly similar development than Amsterdam. Prices in the immediate center are high but increase steadily after reaching its peak 400m apart from the center (3.700 €/m^2). After the decline the prices seem to stabilize in the range 2.500 €/m^2 and 2.600 €/m^2 after 2.200m distance. Values increases in the city range from 20% to 79%. In Rotterdam, the most expensive area, with a price per square meter of 4.700€, is located 800m from the city center. The further price development shows some ups and downs, settling at a price level of 2.400 €/m^2 in the range 6.200m – 8.800m. After that stabilization, prices interestingly rise on a small scale with increasing distance.

6.2 Limitations

The results of the analysis are based on the assumptions addressed and the data used. Nonetheless, different assumptions can lead to varying results. As part of the analysis of population density and real estate price trends, the marketplace of each city was defined as the city center. If this definition is changed to the Central Business District for instance, the analysis might lead to different results. In addition to that the size of each ring was chosen to be 200m. Again, if this range is increased or decreased, results will most likely differ.

Although the data set of real estate prices has more than 161.000 observations in total, the number of observations covered in each ring varies per city. Therefore, the explanatory power per ring is not always the same and the weight per observation differs. Concerning the CBS data set in 100m x 100m cells, some information regarding inhabitants per cell were omitted by CBS due to data security reasons. It should be noted that in the commuting analysis, alternative definitions of cities and suburbs might change the flows. In addition to that the data gave no insights on any further information such as demographic composition or the mean of transport.

6.3 Future research

To gain further conclusions regarding commuting, population density and real estate prices in the Netherlands, several things should be considered for future research. At the time of writing, data depicting the impact of the global COVID-19 pandemic were not yet available. Here, it would be particularly interesting to see how the metrics have changed as a result of an increased share of people working from home, which was mainly only possible because of the improvement of ICT devices. In terms of commuting large scale analysis on the mean of transportation would add valuable insights to the topic. Lastly, it would be valuable to be able to compare the Dutch figures with other countries or regions to evaluate country-specific peculiarities.

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Appendix A – Population density (inhabitants/ha) with distance to the city center

Amsterdam			
Distance to city center (m)	2.011	2.020	Change in %
200	358,10	383,56	7%
400	467,92	511,42	9%
600	278,84	305,26	9%
800	235,09	265,79	13%
1.000	247,93	242,80	-2%
1.200	252,19	250,74	-1%
1.400	361,53	357,24	-1%
1.600	410,62	442,98	8%
1.800	386,28	411,65	7%
2.000	469,93	496,40	6%
2.200	516,95	560,60	8%
2.400	458,02	501,82	10%
2.600	470,40	489,24	4%
2.800	412,92	432,19	5%
3.000	403,49	438,55	9%
3.200	362,62	385,77	6%
3.400	317,10	326,70	3%
3.600	287,75	300,44	4%
3.800	243,77	272,63	12%
4.000	187,03	263,10	41%
4.200	153,29	191,37	25%
4.400	151,09	187,54	24%
4.600	135,78	191,27	41%
4.800	142,09	177,14	25%
5.000	127,36	134,86	6%
5.200	77,21	88,19	14%
5.400	90,84	107,41	18%
5.600	114,42	126,43	10%
5.800	98,40	103,39	5%
6.000	74,16	81,65	10%
6.200	67,94	78,48	16%
6.400	66,39	79,96	20%
6.600	70,30	84,13	20%
6.800	79,36	94,23	19%
7.000	82,53	100,34	22%
7.200	80,86	89,80	11%
7.400	81,32	88,87	9%
7.600	81,87	92,39	13%
7.800	81,83	87,70	7%
8.000	83,45	89,51	7%
8.200	66,28	79,75	20%
8.400	54,96	62,82	14%
8.600	71,66	75,40	5%
8.800	46,72	52,87	13%
9.000	44,26	49,53	12%
9.200	48,39	52,52	9%
9.400	46,29	50,88	10%
9.600	38,83	41,53	7%
9.800	37,44	40,72	9%
10.000	38,44	41,88	9%

Eindhoven			
Distance to city center (m)	2011	2020	Change in %
200	17,51	20,69	18%
400	75,33	149,61	99%
600	166,79	252,10	51%
800	192,80	222,13	15%
1.000	181,97	241,74	33%
1.200	234,54	255,23	9%
1.400	168,95	202,62	20%
1.600	159,47	186,85	17%
1.800	164,12	183,68	12%
2.000	152,62	182,44	20%
2.200	135,58	146,88	8%
2.400	154,38	164,90	7%
2.600	157,56	162,02	3%
2.800	145,95	155,32	6%
3.000	134,02	138,08	3%
3.200	141,55	141,80	0%
3.400	101,86	110,93	9%
3.600	85,63	86,40	1%
3.800	71,45	68,74	-4%
4.000	55,91	57,30	2%
4.200	39,05	41,92	7%
4.400	57,89	62,11	7%
4.600	65,71	69,18	5%
4.800	68,00	73,25	8%
5.000	67,56	67,27	0%
5.200	75,61	74,30	-2%
5.400	67,96	67,84	0%
5.600	67,51	69,10	2%
5.800	64,00	68,35	7%
6.000	54,63	57,05	4%
6.200	59,20	59,51	1%
6.400	48,25	47,37	-2%
6.600	44,88	49,39	10%
6.800	46,89	47,25	1%
7.000	35,59	35,82	1%
7.200	25,89	25,58	-1%
7.400	22,43	21,06	-6%
7.600	17,36	18,89	9%
7.800	16,54	16,00	-3%
8.000	9,41	9,77	4%
8.200	6,70	8,23	23%
8.400	8,57	8,76	2%
8.600	10,60	11,25	6%
8.800	14,73	16,39	11%
9.000	18,44	19,33	5%
9.200	25,36	26,23	3%
9.400	34,02	34,38	1%
9.600	39,50	40,96	4%
9.800	41,61	41,82	1%
10.000	29,42	30,56	4%

Groningen			
Distance to city center (m)	2011	2020	Change in %
200	135,28	157,56	16%
400	317,78	349,61	10%
600	412,85	448,18	9%
800	291,03	358,55	23%
1.000	244,04	304,87	25%
1.200	365,48	377,20	3%
1.400	414,29	444,90	7%
1.600	304,41	326,69	7%
1.800	206,81	211,77	2%
2.000	100,10	139,13	39%
2.200	107,85	129,90	20%
2.400	133,34	150,99	13%
2.600	125,61	127,90	2%
2.800	108,76	109,17	0%
3.000	87,43	92,15	5%
3.200	70,23	73,88	5%
3.400	65,88	63,61	-3%
3.600	67,85	65,16	-4%
3.800	56,35	57,42	2%
4.000	41,99	41,30	-2%
4.200	47,16	44,25	-6%
4.400	49,78	48,56	-2%
4.600	62,46	62,99	1%
4.800	42,33	43,14	2%
5.000	14,16	16,18	14%
5.200	5,80	9,02	55%
5.400	6,19	9,64	56%
5.600	10,42	12,85	23%
5.800	8,35	10,86	30%
6.000	9,82	12,71	29%
6.200	7,85	7,91	1%
6.400	10,59	11,49	9%
6.600	10,80	10,92	1%
6.800	11,43	11,43	0%
7.000	11,37	10,40	-9%
7.200	5,02	4,62	-8%
7.400	2,97	2,51	-15%
7.600	1,61	1,29	-20%
7.800	1,57	1,32	-16%
8.000	3,28	2,84	-13%
8.200	5,99	5,36	-10%
8.400	7,50	6,81	-9%
8.600	9,51	8,80	-7%
8.800	13,08	12,18	-7%
9.000	14,45	13,82	-4%
9.200	12,92	12,37	-4%
9.400	14,12	14,19	0%
9.600	13,44	13,13	-2%
9.800	10,62	9,35	-12%
10.000	7,64	6,62	-13%

Rotterdam			
Distance to city center (m)	2011	2020	Change in %
200	49,34	66,85	35%
400	158,62	237,67	50%
600	284,25	380,38	34%
800	302,17	398,57	32%
1.000	351,03	365,70	4%
1.200	355,64	385,15	8%
1.400	390,17	402,91	3%
1.600	343,14	362,66	6%
1.800	404,91	434,40	7%
2.000	359,02	387,58	8%
2.200	429,04	457,68	7%
2.400	419,89	456,01	9%
2.600	198,82	213,20	7%
2.800	201,48	207,55	3%
3.000	229,90	222,93	-3%
3.200	233,70	239,19	2%
3.400	201,79	217,70	8%
3.600	155,52	191,85	23%
3.800	131,84	153,69	17%
4.000	123,32	137,20	11%
4.200	102,67	105,20	2%
4.400	94,46	97,90	4%
4.600	113,81	110,56	-3%
4.800	115,84	120,79	4%
5.000	127,88	133,33	4%
5.200	109,85	115,00	5%
5.400	114,17	119,19	4%
5.600	123,65	133,20	8%
5.800	132,46	136,31	3%
6.000	94,47	100,27	6%
6.200	93,07	94,03	1%
6.400	103,27	107,06	4%
6.600	89,86	90,20	0%
6.800	81,95	86,51	6%
7.000	93,53	99,09	6%
7.200	97,51	98,99	2%
7.400	96,63	101,95	6%
7.600	95,26	98,99	4%
7.800	95,22	97,39	2%
8.000	97,67	99,74	2%
8.200	92,17	94,02	2%
8.400	87,23	97,64	12%
8.600	91,52	93,53	2%
8.800	81,35	81,17	0%
9.000	81,17	85,76	6%
9.200	66,23	70,26	6%
9.400	60,51	62,84	4%
9.600	70,15	77,92	11%
9.800	67,11	74,56	11%
10.000	56,85	60,67	7%

Tilburg			
Distance to city center (m)	2011	2020	Change in %
200	186,21	198,94	7%
400	209,55	256,24	22%
600	204,67	220,59	8%
800	274,88	309,90	13%
1.000	290,72	340,59	17%
1.200	311,22	341,46	10%
1.400	303,62	305,09	0%
1.600	270,46	285,84	6%
1.800	182,84	202,41	11%
2.000	159,57	183,36	15%
2.200	129,90	137,86	6%
2.400	92,10	103,87	13%
2.600	77,60	91,29	18%
2.800	83,59	87,65	5%
3.000	75,24	77,27	3%
3.200	73,62	75,98	3%
3.400	69,55	69,88	0%
3.600	59,21	61,66	4%
3.800	51,57	53,94	5%
4.000	51,87	56,89	10%
4.200	50,77	51,12	1%
4.400	43,97	43,38	-1%
4.600	31,83	32,64	3%
4.800	21,50	22,01	2%
5.000	18,19	19,49	7%
5.200	14,45	14,70	2%
5.400	25,61	26,28	3%
5.600	22,66	22,28	-2%
5.800	23,06	22,23	-4%
6.000	22,44	20,34	-9%
6.200	21,50	20,01	-7%
6.400	21,40	22,33	4%
6.600	28,28	27,01	-5%
6.800	26,06	26,18	0%
7.000	28,30	27,08	-4%
7.200	27,82	28,87	4%
7.400	25,25	24,99	-1%
7.600	25,97	28,56	10%
7.800	30,51	30,03	-2%
8.000	27,72	27,78	0%
8.200	24,82	25,03	1%
8.400	26,56	27,25	3%
8.600	16,83	16,80	0%
8.800	8,93	7,70	-14%
9.000	7,30	7,05	-3%
9.200	5,47	5,65	3%
9.400	5,42	5,42	0%
9.600	3,10	2,40	-23%
9.800	2,61	2,71	4%
10.000	3,73	3,89	4%

Appendix B – Real estate prices per m² (€/m²)

Amsterdam			
Distance to city center (m)	∅ (2011-2014)	∅ (2017-2020)	Change
200	4.214,72 €	6.162,20 €	46%
400	4.411,72 €	6.408,06 €	45%
600	5.004,41 €	6.412,29 €	28%
800	5.062,01 €	6.660,03 €	32%
1000	5.022,48 €	6.937,77 €	38%
1200	5.280,66 €	7.300,37 €	38%
1400	4.832,71 €	6.918,32 €	43%
1600	4.594,60 €	6.506,06 €	42%
1800	4.313,30 €	6.507,12 €	51%
2000	4.340,34 €	6.558,40 €	51%
2200	4.192,64 €	6.329,21 €	51%
2400	4.113,96 €	6.280,47 €	53%
2600	3.966,79 €	6.336,28 €	60%
2800	3.875,57 €	5.968,17 €	54%
3000	3.828,13 €	5.790,62 €	51%
3200	3.971,43 €	5.866,65 €	48%
3400	3.900,87 €	5.902,93 €	51%
3600	3.742,92 €	5.987,39 €	60%
3800	3.589,44 €	5.736,17 €	60%
4000	3.515,23 €	5.356,44 €	52%
4200	3.156,11 €	5.123,20 €	62%
4400	3.124,02 €	4.605,88 €	47%
4600	3.197,29 €	4.698,72 €	47%
4800	2.769,20 €	4.431,59 €	60%
5000	2.815,78 €	4.621,15 €	64%
5200	2.661,90 €	4.377,33 €	64%
5400	2.648,00 €	4.129,17 €	56%
5600	2.697,09 €	4.333,37 €	61%
5800	2.863,04 €	4.293,21 €	50%
6000	2.871,25 €	4.623,27 €	61%
6200	2.735,79 €	4.242,46 €	55%
6400	2.487,33 €	3.903,81 €	57%
6600	2.546,39 €	3.779,78 €	48%
6800	2.538,80 €	3.836,93 €	51%
7000	2.523,08 €	3.838,33 €	52%
7200	2.466,03 €	3.709,17 €	50%
7400	2.367,49 €	3.611,12 €	53%
7600	2.441,06 €	3.627,37 €	49%
7800	2.320,95 €	3.396,80 €	46%
8000	2.612,86 €	3.715,60 €	42%
8200	2.374,41 €	3.520,98 €	48%
8400	2.299,97 €	3.421,73 €	49%
8600	2.127,57 €	2.861,15 €	34%
8800	2.150,68 €	3.246,88 €	51%
9000	1.992,50 €	3.028,31 €	52%
9200	1.991,45 €	2.967,44 €	49%
9400	2.444,04 €	3.291,10 €	35%
9600	2.241,32 €	3.267,46 €	46%
9800	1.899,44 €	2.635,76 €	39%
10000	2.040,28 €	3.061,43 €	50%

Eindhoven			
Distance to city center (m)	∅ (2011-2014)	∅ (2017-2020)	Change
200	2.251,23 €	3.074,74 €	37%
400	2.542,04 €	3.688,82 €	45%
600	2.570,69 €	3.506,32 €	36%
800	2.253,39 €	3.438,93 €	53%
1000	2.178,32 €	3.365,27 €	54%
1200	2.311,36 €	3.125,90 €	35%
1400	2.259,92 €	3.044,72 €	35%
1600	2.242,17 €	3.259,77 €	45%
1800	1.961,31 €	3.014,79 €	54%
2000	1.829,18 €	2.666,17 €	46%
2200	1.742,04 €	2.516,74 €	44%
2400	1.872,64 €	2.682,20 €	43%
2600	1.807,37 €	2.628,97 €	45%
2800	1.787,04 €	2.404,61 €	35%
3000	1.914,30 €	2.571,79 €	34%
3200	1.962,52 €	2.607,01 €	33%
3400	1.881,61 €	2.536,21 €	35%
3600	1.886,55 €	2.603,88 €	38%
3800	1.937,36 €	2.454,67 €	27%
4000	1.809,89 €	2.390,13 €	32%
4200	1.877,31 €	2.593,70 €	38%
4400	1.960,87 €	2.439,93 €	24%
4600	1.935,84 €	2.584,83 €	34%
4800	2.018,11 €	2.486,08 €	23%
5000	2.132,75 €	2.550,46 €	20%
5200	2.118,49 €	2.630,45 €	24%
5400	2.095,27 €	2.632,49 €	26%
5600	2.077,13 €	2.526,15 €	22%
5800	2.183,05 €	2.758,61 €	26%
6000	1.984,74 €	2.586,96 €	30%
6200	1.939,13 €	2.499,62 €	29%
6400	1.511,23 €	2.698,49 €	79%

Groningen			
Distance to city center (m)	Ø (2011-2014)	Ø (2017-2020)	Change
200	2.274,75 €	5.094,19 €	124%
400	2.298,82 €	2.774,17 €	21%
600	2.236,91 €	2.886,17 €	29%
800	2.371,75 €	3.008,42 €	27%
1000	2.291,52 €	2.776,17 €	21%
1200	2.128,19 €	2.614,83 €	23%
1400	2.029,96 €	2.547,74 €	26%
1600	1.915,50 €	2.462,67 €	29%
1800	1.894,23 €	2.485,80 €	31%
2000	1.826,02 €	2.481,91 €	36%
2200	1.806,87 €	2.366,27 €	31%
2400	1.857,11 €	2.317,74 €	25%
2600	1.782,03 €	2.287,94 €	28%
2800	1.986,91 €	2.265,06 €	14%
3000	1.891,71 €	2.356,46 €	25%
3200	1.871,03 €	2.285,91 €	22%
3400	1.980,77 €	2.324,08 €	17%
3600	2.065,90 €	2.319,30 €	12%
3800	1.982,02 €	2.343,85 €	18%
4000	1.815,74 €	2.213,95 €	22%
4200	1.863,43 €	2.147,86 €	15%
4400	1.810,02 €	2.225,87 €	23%
4600	1.745,92 €	2.086,17 €	19%
4800	1.889,43 €	2.159,32 €	14%
5000	2.397,73 €	2.919,52 €	22%
5200	2.307,44 €	2.891,36 €	25%
5400	1.981,71 €	2.339,60 €	18%
5600	2.169,05 €	2.375,88 €	10%
5800	2.086,40 €	2.686,95 €	29%
6000	2.264,74 €	2.669,85 €	18%
6200	2.301,17 €	2.848,63 €	24%
6400	2.446,42 €	2.597,98 €	6%
6600	2.067,63 €	2.504,10 €	21%
6800	2.220,95 €	2.623,64 €	18%
7000	2.076,65 €	2.477,61 €	19%
7200	2.219,01 €	2.646,53 €	19%
7400	3.207,22 €	3.205,55 €	0%
7600	3.269,08 €	3.159,84 €	-3%
7800	1.541,97 €	2.003,78 €	30%
8000	1.584,89 €	2.127,84 €	34%
8200	2.795,98 €	2.815,93 €	1%
8400	2.511,82 €	3.037,23 €	21%
8600	2.374,39 €	2.695,11 €	14%
8800	1.478,17 €	2.811,94 €	90%
9000	2.230,42 €	2.761,27 €	24%
9200	2.463,45 €	2.410,47 €	-2%
9400	2.687,57 €	2.945,57 €	10%
9600	2.385,75 €	3.061,06 €	28%
9800	2.442,28 €	2.673,78 €	9%
10000	1.666,74 €	1.954,49 €	17%

Rotterdam			
Distance to city center (m)	Ø (2011-2014)	Ø (2017-2020)	Change
200	2.156,53 €	4.344,81 €	101%
400	2.222,36 €	3.914,45 €	76%
600	2.393,73 €	3.639,67 €	52%
800	2.175,76 €	4.776,35 €	120%
1000	2.128,30 €	3.398,50 €	60%
1200	2.016,61 €	3.417,77 €	69%
1400	1.979,50 €	2.999,57 €	52%
1600	1.995,06 €	3.231,51 €	62%
1800	2.072,57 €	3.498,53 €	69%
2000	1.953,94 €	3.591,87 €	84%
2200	1.980,16 €	3.262,82 €	65%
2400	1.906,06 €	4.312,31 €	126%
2600	2.309,16 €	3.670,47 €	59%
2800	2.279,94 €	3.866,59 €	70%
3000	2.253,88 €	3.433,70 €	52%
3200	2.012,81 €	3.185,44 €	58%
3400	1.924,21 €	2.636,51 €	37%
3600	1.992,51 €	2.348,56 €	18%
3800	1.708,31 €	2.313,90 €	35%
4000	1.851,22 €	2.788,04 €	51%
4200	2.439,45 €	3.083,14 €	26%
4400	2.458,51 €	3.066,82 €	25%
4600	2.228,45 €	3.368,34 €	51%
4800	2.465,59 €	3.532,52 €	43%
5000	2.415,20 €	3.006,68 €	24%
5200	2.363,17 €	2.604,02 €	10%
5400	2.362,51 €	2.398,73 €	2%
5600	1.814,56 €	2.538,71 €	40%
5800	1.887,70 €	2.710,92 €	44%
6000	1.982,38 €	2.690,18 €	36%
6200	1.684,39 €	2.270,53 €	35%
6400	1.683,91 €	2.358,32 €	40%
6600	1.690,14 €	2.258,60 €	34%
6800	1.561,33 €	2.126,68 €	36%
7000	1.647,10 €	2.126,69 €	29%
7200	1.614,49 €	2.368,47 €	47%
7400	1.737,09 €	2.453,80 €	41%
7600	1.526,57 €	2.274,39 €	49%
7800	1.584,68 €	2.257,72 €	42%
8000	1.579,64 €	2.361,53 €	49%
8200	1.579,02 €	2.250,42 €	43%
8400	1.670,77 €	2.229,46 €	33%
8600	1.762,51 €	2.498,78 €	42%
8800	1.929,11 €	2.209,11 €	15%
9000	2.160,76 €	2.628,74 €	22%
9200	1.797,52 €	2.725,76 €	52%
9400	2.199,43 €	2.817,15 €	28%
9600	2.223,21 €	2.742,86 €	23%
9800	2.259,93 €	3.094,94 €	37%
10000	2.201,08 €	2.929,85 €	33%

	Tilburg		
Distance to city center (m)	Ø (2011-2014)	Ø (2017-2020)	Change
200	2.302,02 €	2.828,58 €	23%
400	2.157,66 €	3.184,22 €	48%
600	2.164,35 €	2.596,19 €	20%
800	1.978,63 €	2.511,48 €	27%
1000	1.931,30 €	2.377,65 €	23%
1200	1.885,28 €	2.297,44 €	22%
1400	1.793,19 €	2.198,55 €	23%
1600	1.845,95 €	2.214,92 €	20%
1800	1.874,24 €	2.319,09 €	24%
2000	1.851,47 €	2.242,47 €	21%
2200	1.861,23 €	2.352,43 €	26%
2400	1.894,59 €	2.354,91 €	24%
2600	2.007,72 €	2.456,39 €	22%
2800	1.747,23 €	2.131,96 €	22%
3000	1.998,48 €	2.315,03 €	16%
3200	1.880,67 €	2.151,73 €	14%
3400	1.890,23 €	2.258,33 €	19%
3600	1.928,76 €	2.156,32 €	12%
3800	1.802,21 €	2.170,57 €	20%
4000	1.865,62 €	2.203,24 €	18%
4200	1.889,76 €	2.375,34 €	26%
4400	2.050,89 €	2.702,87 €	32%
4600	2.149,08 €	2.572,59 €	20%
4800	2.685,02 €	3.008,95 €	12%
5000	2.158,53 €	2.617,03 €	21%
5200	1.950,15 €	2.400,36 €	23%
5400	1.970,91 €	2.252,39 €	14%
5600	1.910,30 €	2.355,10 €	23%
5800	2.007,85 €	2.320,81 €	16%
6000	2.098,27 €	2.354,10 €	12%
6200	2.007,95 €	2.235,95 €	11%
6400	2.019,94 €	2.312,86 €	15%
6600	2.092,92 €	2.236,57 €	7%
6800	2.156,72 €	2.371,29 €	10%
7000	1.936,05 €	2.302,66 €	19%
7200	2.101,22 €	2.393,94 €	14%
7400	2.069,97 €	2.263,77 €	9%
7600	2.080,34 €	2.250,35 €	8%
7800	2.087,29 €	2.344,36 €	12%
8000	1.892,33 €	2.295,35 €	21%
8200	1.997,95 €	2.229,47 €	12%
8400	2.029,22 €	2.125,78 €	5%
8600	2.041,72 €	2.421,60 €	19%
8800	2.022,96 €	2.271,60 €	12%

Appendix C – Descriptive Statistics Real Estate Price Data set (selected variables only)

	Mean	Median	Mode	Std. Dev.	Min	Max
Price (€)	312.689,40	260.000,00	225.000,00	193.901,70	45.000,00	1.497.500,00
Deflated price (€)	330.449,38	275.284,33	268.775,00	200.853,93	50.374,32	1.499.764,50
€/m^2	3.279,39	2.758,62	2.500,00	1.707,55	264,55	20.500,00
size	100,20	95,00	100,00	40,70	26,00	300,00
No. Rooms	3,80	4,00	3,00	1,44	1,00	19,00

N=169.361

Appendix D – In- and Outcommuting Quotients 2014

	2014							
	Outcommuting				Incommuting			
	City - Sub	City - Other	City-City	Home	Sub - City	Other - City	City-City	Home
Amsterdam	0,17	0,07	0,09	0,67	0,27	0,16	0,12	0,45
s-Gravenhage	0,20	0,09	0,18	0,54	0,29	0,14	0,14	0,43
Amersfoort	0,21	0,16	0,24	0,39	0,24	0,23	0,17	0,35
Apeldoorn	0,09	0,20	0,14	0,58	0,15	0,29	0,11	0,45
Arnhem	0,16	0,19	0,19	0,45	0,30	0,26	0,13	0,32
Breda	0,14	0,17	0,21	0,47	0,22	0,24	0,14	0,39
Dordrecht	0,26	0,11	0,24	0,40	0,30	0,17	0,13	0,40
Eindhoven	0,19	0,15	0,14	0,52	0,24	0,30	0,13	0,33
Enschede	0,08	0,24	0,07	0,61	0,10	0,34	0,03	0,53
Groningen	0,07	0,20	0,07	0,66	0,20	0,30	0,02	0,48
Haarlem	0,33	0,06	0,29	0,32	0,41	0,11	0,11	0,37
Heerlen	0,24	0,11	0,24	0,42	0,40	0,18	0,14	0,28
's-Hertogenbosch	0,09	0,22	0,22	0,47	0,16	0,35	0,17	0,32
Leeuwarden	0,04	0,22	0,07	0,68	0,17	0,32	0,04	0,46
Leiden	0,27	0,08	0,28	0,37	0,37	0,13	0,17	0,33
Maastricht	0,09	0,10	0,20	0,61	0,24	0,15	0,17	0,45
Nijmegen	0,11	0,22	0,17	0,50	0,24	0,25	0,08	0,44
Rotterdam	0,21	0,11	0,14	0,54	0,28	0,23	0,10	0,39
Sittard-Geleen	0,09	0,18	0,27	0,46	0,18	0,30	0,15	0,37
Tilburg	0,13	0,17	0,20	0,50	0,20	0,20	0,15	0,44
Utrecht	0,20	0,12	0,22	0,46	0,29	0,23	0,18	0,30
Zwolle	0,06	0,26	0,12	0,57	0,11	0,46	0,06	0,38
Ø	*0,16*	*0,16*	*0,18*	*0,51*	*0,24*	*0,24*	*0,12*	*0,39*

Appendix E – Literature review process

Several search engines were used to perform the literature review. In fact, most of the search requests were performed with Google Scholar. VU Libsearch, Scopus and Web of Knowledge have also been used, but in a lower frequency.

This four-step systematic approach was used to conduct the literature review:

1. Search

Several keywords and key terms were searched in the academic search engines mentioned before. To achieve a general overview of the topic, some general keywords were chosen to start with the process. Some of these keywords were:

- *Commuting (Netherlands)*
- *ICT*
- *Population density (Netherlands)*
- *Real estate prices (Netherlands)*
- *Urban settlement behavior*
- ...

The first indicator to decide which paper to read was the number of citations. Followed by that, the abstract and conclusion part were the first things I read when I started to read a paper. That helped me to get a broad overview of the paper and saves me from spending time on irrelevant results that may found their way through the search engine with my keywords but is irrelevant for my research.

2. Collect

Subsequent to the first step, articles that were relevant to my research were saved to a citation manager (Zotero) and tagged with their main information and a short summary of abstract and conclusion.

3. Analysis

Part of the analysis was to read the papers collected. While doing so, all relevant information was retrieved and put into a literature matrix to be able to narrow these information into the main area of interest. With the help of this literature matrix, a good overview of the topic was guaranteed.

4. Repeat until finalization

To be sure about a sufficient amount of literature collected, the first three steps were repeated until a sufficient amount of information, objectives, results, pros and cons, etc. were gathered.