Erasmus
School of
Economics

Price effect of public transport

A research into the effect of high quality public transport on residential property values in a polycentric environment in the Netherlands.

Master Thesis Urban, Port and Transport Economics

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Abstract

Transportation is fundamental for any economic activity, however highly urbanized zones face severe congestion issues, decreasing the accessibility. Public transport infrastructure projects may relieve some of the pressure on accessibility in highly urbanized areas when implemented conform transit oriented development (TOD) guidelines. A discussion within this topic concerns the question whether or not residential properties are getting more expensive because of better accessibility, and whether this is good or not. Using the difference-in-differences method and data for residential properties in the Randstad, the Netherlands, the value uplift due to the introduction of the new metro E is researched. Properties located within 800 meters of any of the stations are found to increase in value due to the presence of the metro, controlling for both property and regional characteristics. However, the magnitude of the effect differs across regions and time periods.

Preface

For three years, I have studied the bachelor's course economics and business economics at the Erasmus university. During the master course, Urban, Port and Transport Economics, the focus within economic shifted towards the role of space. The occupation of both my parents falls within the public transport sector. The combination of my study and home fed interest have led to the idea of this research. The writing of this thesis was done in cooperation with the Province of Zuid-Holland, with whom I was an intern for six months. Unfortunately, the entire internship took place online, due to covid-19 regulations.

Nonetheless, I would like to express my sincere gratitude to Eric Terlien for the guidance during the internship, the sparring sessions and useful feedback. As well as providing me with a glimpse of what it is like to work at the PZH. Second, I would like to thank Meinard Eekhout for the assistance with the GIS analysis and other data modifications. From the university, I would like to thank Frank van Oort for the useful feedback along the way. Without their contributions, I would not have been able get where I am today.

Lastly, I would also like to thank my family for the support during my study, especially during the last six months.

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1. Introduction

The importance of a sustainable method of transportation in increasingly urbanized zones is gaining momentum due to increasing urbanization in the past decades. This urbanization trend is thought to increase in the coming decades, the European Commission estimates urbanized areas to make up 85 percent of the total world population by 2100 (OECD, 2015). In terms of growth of cities, urbanization has taken place in the Netherlands in a similar fashion as well, according to the PBL Netherlands Environmental Assessment Agency (Nabielek, Hamers, & Evers, 2016). Over the course of fourteen years, from 2000 to 2014, cities such as The Hague, Amsterdam and Utrecht have seen increases in population of over 60.000, with the expected population of cities rising from 7.5 million in 2018 to over 8 million in 2040. When comparing population densities across Europe, the urban landscape of the Netherlands exhibits lower and more spread out peeks in terms of density, compared to neighboring European countries (Nabielek et al., 2016). Urbanization trends are thus though to continue in both the near and distant future.

The urbanization trend also touches upon the idea that current public transportation projects must satisfy our future need of fast and reliable transportation. Choices now have to be made with the uncertainty of tomorrow. Costs related to these public transport projects are often well defined in terms of required materials, labor, maintenance and operation. However, the definition of benefits seems to be lagging behind. Clear benefits often mostly address ticket revenue. In order to make well substantiated choices regarding public transport projects, the benefits of public transportation must be further researched. This may lead to consider that infrastructure projects may even be financed through the promise of future revenues or increased property value through land value capture (Du, & Mulley, 2006; Medda, 2012). Therefore, mapping out both the costs and benefits of infrastructure projects is of great importance.

Beside the revenue and cost aspect, there are efficiency considerations to take into account, as well as possible congestion issues and limited availability of space. Public transportation provides transportation that requires less physical space on the road whilst offering capacity for more individuals, see figure C1 of the appendix (Botma & Papendrecht, 1991; Litman, 2014). As a result, available road systems can be used more efficiently, therefore addressing both efficiency and congestion while occupying limited space.

This research focusses on determining the effects of public transportation on property value uplift, but measured at a broader horizon than individual residential properties. The key concepts throughout the study are public transportation and accessibility. In order to define the relationships and dependencies between the concepts, they must be clearly defined. Public transportation has three characteristics that set it apart from other modes of transportation. First, vehicles are characterized by shared use, instead of personal use. Second, the routes are often predetermined and last, the users of public transportation do not own the means of transportation. Accessibility refers to the physical accessibility to and from the residential property to other locations, for work or leisure. The physical accessibility is determined by the time and cost of the travel (Henneberry, 1998). Public transportation can further be split up in different categories depending on modality, scope of operations and quality.

More specifically, this research aims to investigate the relationship between the presence of a light rail on residential property values in a polycentric environment by using a difference-in-differences (DD) method. The DD method compares the means of a treatment and control group before and after a certain treatment has taken place. With these four datapoints, the treatment effect can be determined. The DD method is widely used among similar researches (Agostini, & Palmucci, 2008; Mulley, Sampaio, & Ma, 2017; Wagner, Komarek, & Martin, 2017; Yen, Mulley, Shearer, & Burk, 2018). When comparing a light rail to a regular tram or bus, a light rail is considered to be a superior form of public transport. Where a tram would be situated at a 0-level, mixed in with other traffic, a light rail will often have a separate lane, or even be situated below or above ground. This does increase the expenses related to the construction of the light rail. However, it also ensures reliability and enables a higher frequency, which increases the transport capacity per hour. Besides these efficiency characterizations, a light rail often connects areas or cities at a regional level, while a regular tram or bus mostly connects places within a city. A light rail may be considered to be a combination of a tram and train, possessing characteristics of both. A light rail has many stops located close to each other within the city boundaries, relative to heavy rail. However, in suburban areas, distance between stops is significantly larger. This is graphically shown in figure C2 (Walker, 2010). The characteristics of the light rail set it apart from other public transport modalities, both in terms of daily operations and required investment.

Increased infrastructure costs to ensure reliability, speed and capacity are merely worth the investment if the provided capacity is well utilized. The concept of transit-oriented development (TOD) is increasingly important. TOD combines development of real estate projects with transit projects, instead of looking at the concepts separately. The definition of TOD slightly differs within literature, but the basic principle of real estate development around stations or development of stations to connect current and future real estate is present in all occasions (Curtis, Renne, & Bertolini 2016). TOD thus is important to better ensure the use of capacity by combining transport and real estate demands into a single project. This research concerns itself merely with the public transport dimension of TOD, as the concept itself is very broad.

This research estimates the effect of a high-quality light rail on property values in the province of South Holland, the Netherlands by investigating the metro E. This metro line connects Rotterdam and The Hague through suburban areas, operational since 2006. When estimating the effect using the DD method, it is important to control for other trends and effects at play. Two groups of controls are included in the research: property controls and regional controls. All controls added come forth out of previous research in which their relevance is already established. In other words, there are property and regional characteristics for which is determined that they have a significant effect on the value. The treatment and control group will be determined by actual distance rather than linearly from the stations. The actual distance is the distance travelled when using the available road system.

Possibly, there are multiple effects to be seen over time. The first effect may be caused due to announcements of plans of the light rail, as the commitment of the government acts as an incentive to private parties. Second, an effect may be observed at the moment that the light rail starts operations (Agostini, & Palmucci, 2008). After operations have started, it is possible that enhancements made over time also contribute to the value of the light rail, which may be reflected in the property values.

The paper is organized as follows. First, relevant literature will be discussed. Starting from general urbanization models, that form a basis for understanding property values in a spatial setting. From there, other spatial factors that influence property values are discussed, with a focus on connectivity via public transportation. The literature review will conclude with the main research question. Second, the methodology discusses the hypotheses, together with the general measurement method used. Third, a section is devoted to discussing changes made to the obtained datasets, as well as a brief elaboration on these data's origin. Fourth, regression results will be discussed, followed by relevant statistical tests. Lastly, there is a discussion on results and implications, which is followed by the conclusion.

2. Literature Review

Relevant literature for this research into the effect of public transport on property values includes an understanding of property values, beginning with urbanization models. Secondly, previous literature that connect public transport to property values is reviewed. The relation between employment and accessibility is also importance, as is the phenomenon of gentrification. The general context in which the public transportation firm operates is also of importance, both geographically and the modal split. Each of these subjects is discussed in a separate paragraph. All literature sources form the foundation of the context surrounding the central research question.

2.1. Urbanization models

At the basis of researching the effect of high-quality railway connections on its surroundings lie fundamental theories about urban spatial structures. One of the first approaches towards understanding spatial structures of urbanized zones was through the monocentric city model (Alonso, 1964). This model seeks to identify why cities form the way they do. Within this framework, people are thought to work in the central business district (CBD) and live at a given distance from the CBD. The further people live from the CBD, the more it costs them to travel, resulting in a lower willingness to pay for the land they live on. Land thus costs more when directly next to the CBD. Introducing income differences to the model shows that richer people tend to live further away from the CBD (Brueckner, 2011). This sorting mechanism does not only exist because of income differences, but also due to transportation (Gleaser, Kahn, & Rappaport, 2008). The reasoning here is that rich people have the possibility to use fast transportation, the car, while poor people do not have the means to make such an investment and are thus deemed to use public transportation. The most important assumption here is that public transport per kilometer is more expensive in use, in terms of both money and time, than the car, but does not require any investment up front.

There are three major assumptions tied to his model, which opens room for discussion. The first assumption concerns the extent to which all economic activities are limited to the CBD. Secondly, it is assumed the city has a radial road network, providing similar commuting times regardless of the location around the CBD, for equal distances. At last, the model assumes identical households, having similar preferences. Although none of the above stated assumptions are realistic, they are commonly found throughout economic models. Therefore, Alonso's model on spatial structures is a proper starting point to investigate property values in spatial structures.

One of the first models introducing polycentric structures is described by Howard (1946) covering the garden city, originally written in 1902. The garden city is a concept that integrates the big city and small villages. It was written in midst of the second industrial revolution. This period is mainly associated with the rise of mass production and worsening social and environmental problems in cities. Therefore, the work can be described as very progressive for its time. The garden city model has been very explicitly described. Centrally located in the garden city is a park, as well as all public buildings. Around this city center, plots of land are constructed around six radians to supply housing to 30.000 residents. At the outskirts of the city, shops, businesses and factories are situated, and moving further outwards, land is destinated for agriculture.

Following the garden city concept to explain and construct urban areas is the central place theory of Christaller (1933, 1966) and Lösch (1944, 1954). Christaller distinguishes between different order market areas, where higher orders markets supply a larger market area. Each center of an area represents a city, supplying the surrounding land with goods. Following Christaller's theory, a spatial pattern emerges, characterized by overlapping hexagonal areas, representing the market boundaries of each city. Lösch's approach is very much related to that of Alonso, however the approach is based on producers instead. The size of the market is determined by the cost of producing and transport. The market boundary is subsequently found when demand equals zero. Although the final result of both models is different, the spatial structure that is constructed is very much the same, hexagonal (see figure 2.1). The hexagonal structure ensures that the average distance from producer to consumer is minimal.

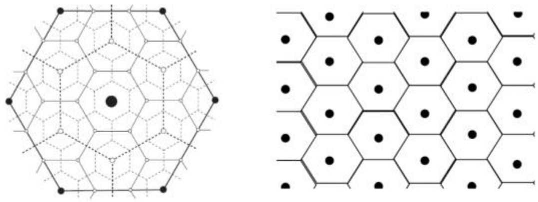

Figure 2.1: Market areas as constructed by Christaller (left) and Lösch (right).

Up to this point, the discussion of urbanization mainly focused on the construction of urbanized areas using models with an aggregated perspective. As economics is also very much a social science, dealing with human preferences and (un)rational behavior, it makes sense to review these spatial models from another, more individual point of view. A model solely containing space does not suffice when considering transport options for an individual on a daily basis. Hägerstrand (1970) approaches daily movements in a time-space concept, see figure 2.2 below. The model considers individuals movement over distance during the course of a day, starting and ending at home. The distance that can be covered depends on three constraints, determining the size of the prism, and the path within. With the introduction of newer modes of transportation, prisms are getting increasingly different. This trend is observed both within and between regions. The prism expands when available transportation can cover more distance. As example, the prism of an individual with a car is wider than for someone who only has access to a bicycle.

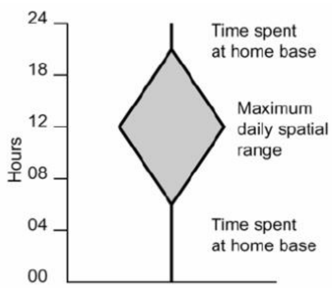

Figure 2.2: Daily time-space prism by Hägerstrand (L'Hostis, & Baptiste, 2006).

There is another theory concerning individuals and their daily movements with respect to time. Hupkes (1977) wrote about the law of constant travel time, which states that individuals are willing to spend a predetermined time commuting, regardless of the mode of transportation. As a result, faster modes of transportation do not decrease travel time, but instead increase the distance people are willing to commute, and therefore allow individuals to live further away from their work location. Over the years, faster mobility has thus increased the job potential – number of jobs – that can be reached within the average constant travel time of 75 minutes (Hupkes, 1982).

2.2. Public transportation and the housing market

The effect of improved accessibility on land value (property prices) has been researched thoroughly over the past decades. Researches have focused on a variety of transport systems across countries. The method often used to determine the effect of accessibility is the spatial hedonic price model, in which all characteristics of the properties are determined, after which is researched to what extent each determinant contributes to the given price of the real estate. Armstrong and Rodriguez (2006) applied this model to a commuter rail in eastern Massachusetts, using data containing 1.860 residential properties divided into seven municipalities, of which only four municipalities had access to the commuter rail service. Their results indicate that for properties located within the municipalities with access to the rail service, prices were up to 10 percent higher, but only if the property was located within 800 meters of the station. With every additional minute of drivetime, prices are expected to decrease by 1,6 percent.

Another method of measuring the effect is using a DD method (Puhani, 2012). The treatment effect (real effect) equals the observed effect minus the potential outcome, the outcome that would have occurred without treatment. In this case, the treatment is the availability of public transport over time. The control group can also consist out of a similar region not receiving the treatment. Propensity scores matching (PSM) can be used to find statistically identical regions (Yen, Mulley, & Shearer, 2019). The DD method is used in the next three papers discussed. Agostini and Palmucci (2008) reason that lower transport costs due to better accessibility explain the difference in property values. Their research focuses on the Santiago metro system in the years before operation of the metro line started. Results show that property values increased between 4 and 8 percent after the announcement of the construction and 4 to 5 percent after determining station locations, depending on the distance to the nearest station. A similar approach was conducted by Mulley, Sampaio and Ma (2017) for the introduction of a bus transit service. House prices were measured for houses close to bus stops and further away, both before and after the bus service started operating. Results indicate an increase of 7 percent for properties located within 800 meters from the stations.

However, not all researches find positive significant results. Wagner, Komarek and Martin (2017) find that property values decreased due to the introduction of a light rail in Virginia, United States. Property prices decreased by approximately 8 percent during construction and operational phase. This result is surprising as it opposes findings in similar academic literature. Within the paper, multiple reasons are given to explain the different outcome. First, the population density is significantly lower in the research area, and therefore the traffic density as well. The added value of the connection therefore decreases, resulting in decreased benefits, while residents are still faced with the full construction costs. Furthermore, the line did not connect local or regional high-density areas. This is of great importance, as demand for transportation is derived demand. In essence, this means individuals do not demand transportation for the transportation itself, but to reach a destination where the actual activity, such as work, takes place.

The differences in research outcomes can be explained by looking at the context of the research, which can be captured by introducing interaction terms into the model (Duncan, 2009). The main interaction term discussed by Duncan is the interaction between pedestrian quality and railway proximity. If the infrastructure is focused on pedestrians, station proximity is found to have a significant stronger impact, compared to for example car-oriented areas. Hess and Almeida (2007) also investigate the effect of accessibility on property values using the hedonic price approach. In doing so, several factors influencing this relationship are identified and grouped. Besides property characteristics, this refers to locational amenities and neighborhood characteristics, together forming the context. Examples of such amenities and characteristics are the distance to the nearest park, general location of the neighborhood, crime rates and median income level.

Property prices in datasets are built up by actual transactions. The final price is dependent on current demand and supply, as well as the ability of people to internalize developments into the price. Du and Mulley (2007) argue that there is no real property price change in the short term, as consumers are not able to internalize changes in their environment. Commercial entities, however, may be able to do this at a faster rate. Therefore, a discrepancy could exist between residential properties that are rented out (bought as investment) or owner occupied. Within the limits of this research, this cannot properly be controlled for as data on rent prices are not available, nor is it known whether or not a property is bought to rent out or not.

2.3. Modal split

The context matters to determine the extent to which a public transport line may influence its surroundings, and more specifically the property values. If public transport is not important at all, the effect may be minor compared to a location in which public transport is important (Hess, & Almeida, 2007). The terminology 'not important' leaves room for discussion. In this case, it refers to not having enough value to be of impact. This absence of impact can either be because the public transport line does not connect the proper regions, in which case the line itself has little to no value. The alternative case is that there are too many alternatives for consumers to choose from that, even if the public transport line itself is valuable, it will hardly be reflected due to the massive amount of competition it faces.

The modal split has changed over time, mainly because of technological developments and changing view on transit in relation to urban development. In the early twentieth century, urban development is thought to be development-oriented transit. During these times, private investors build transit to increase the value of their properties. In the period hereafter, the share of transit as transport mode decreased and the car became more important. Increasing congestion led to increasing demand for further development, which resulted in the current view on transit in relation to development: TOD (Dittmar, & Ohland, 2012). TOD was first mentioned by Calthrope (1993) laying out the foundation for a new urban design. Although this vision is shared by many, transit is not yet performing to its full extent, as it has not penetrated every aspect of development. As an example, standard parking ratios are often maintained regardless of the fact that TOD is in place (Dittmar, & Ohland, 2012).

Policy actions that can be undertaken to influence the modal choice of consumers are mostly limited to car taxation (Pucher, 1988). Higher car taxation then, of course, means a lower share of cars in the modal split. Simultaneously, the share of users for public transport depends mainly on supportive urban development (Pucher, 1988). A variant in which this supportive development became the main interest, is TOD. However, there is more to the process of modal choice than (financial) incentives. The choice between commuting by public transport or car is believed to be a social dilemma (Van Vugt, Van Lange, & Meertens, 1996). The two alternatives in the dilemma are argued to between the short term self-interest and long term collective interest. The prime example given concerns the choice to use a car. The self-interest (low travel times) outweighs the collective interest (less pollution) for each individual.

2.4. Employment

Arguably, public transportation connectivity does not only influence property values directly, but also via employment. The presence of jobs nearby may push up property values through land scarcity, which hints to a positive relation. However, without jobs in close proximity, longer commuting trips are necessary. Regardless, this connection between economic prosperity and connectivity is important to further research. This also touches the subject of gentrification, discussed in section 2.6. In general, national economic performance is calculated from the gross domestic product (GDP) and a set of economic indicators. The GDP is comprised out of individual contributions found in all jobs within a country. However, GDP itself is a limited measure, as it fails to include economic, social and personal well-being (Daly, & Posner, 2011). Economic well-being, as described within the holistic framework, includes factors such as employment, income and wealth, care work, creativity and innovation (de Leon, 2012). The more precise employment figures shed more light on how certain jobs are affected by public transport connectivity. This is especially interesting as employment is often clustered in specific regions, due to sector characteristics, employment pools, because of a preferable environment, natural resources or governmental legislation (Kloosterman, & Lambregts, 2001). This means that the value added of these jobs are also unevenly distributed over space. Fast and reliable transportation could support the rise of such clusters. Continuing this assumption, the introduction of high quality public transport affects property values through this employment effect. Arguably, fast and reliable transportation could also support diffusion instead. Regardless, the final effect is expected to be different per sector and region.

A research into the effect of public transport trip times on employment levels for the United Kingdom has shown a negative significant relationship (Johnson, Ercolani, & Mackie, 2017), thus stating that faster connections have a positive effect on the employment levels. This result is not unexpected, as the location is better accessible for people from other regions, therefore increasing the area with possible employees, given the law of constant travel time holds (Hupkes, 1982). Within Hupkes' paper, consumers are divided into two groups. Consumers either belong to the group that is dependent on public transportation, or the group who have alternative options, such as a private car. The relationship between fast public transportation and employment levels depend on the share of the population who depend on public transportation to be able to commute.

Going back to the century in which the first cities emerged, people worked close to their homes. Commuting as seen nowadays did not exist. Due to the introduction of faster modes of transportation, such as mass production of the car, people were able to live and work in different places, once again referring to the law of constant travel time (Hupkes, 1982). A major trend in commuting seen in the past decades, and likely to continue in the future, is the movement of residents from rural areas towards urbanized zones (OECD, 2015). However, within these urbanized zones, different trends can be observed. Where until recently there was a trend of the upper-middle class to move out of the high-density city center towards the suburbs, high income professionals are moving back into the city (Aguilera, Wenglenski, & Proulhac, 2009). This movements causes transit behavior called reverse commuting. The decision to live in the expensive city center is thought to be made up for by a variety of amenities related to the city center, captured in the consumer city phenomenon (Glaeser, Kolko, & Saiz, 2001). Trends seen in the UK between 1988 and 2015 include decreasing number of commuting trips, changing modal choice, increasing commuting distance and trip time, as well as greater variety when it comes to the time-of-day when the commuting takes place (Le Vine, Polak, & Humphrey, 2017).

On an ulterior thought, public transportation also fulfills an important role as governmental tool against social exclusion. The share of population dependent on public transport, due to lack of alternatives, often coincides with the poorest segment of the population. Local policy-makers therefore hold the key when it comes to connecting areas characterized by deprivation. However, if this relation is not properly understood by policy-makers, by-passing deprived areas is only aiding further deterioration of the area (Grieco, Turner, & Hine, 2000). Sufficient budgets are required to assist in the understanding of the relationship, consequently, the weakness here can be found in lacking budgets. This trend may also find its continuance in telecommunication infrastructure as well. In combination with the previously mentioned trend of working from home, social exclusion will further increase (Hine, Swan, Scott, Binnie, & Sharp, 2000). Public transportation thus fulfills different roles for different segments of the population.

The argument of social exclusion is also one that applies to newer high quality public transport lines. Especially for inter-city connections, questions come up regarding the target audience. As the more wealthy residents moved to suburban areas, they have the most to gain from fast access to downtown, where many of the jobs are located. The poor left behind around the city center have no use for a connection to the suburban areas. This observation was already done by Martin Luther King, Jr. (1969), albeit from a more racial perspective. More formally, this selective process of suburbanization is captured in a concept called spatial mismatch. In other words, it is the process of a regional distribution of residents based on income (Giuliano, 2005). On the other hand, there is literature stating transit is indeed able to overcome this physical separation. However, any transit-oriented solution is only applicable when physical distance, not racial differences, is the fundamental problem (Sanchez, 1999).

2.5. Network effects in a polycentric environment

Networks are systems of nodes and their connections, allowing for the exchange of information. A well-known network nowadays is the online social network, in which persons (nodes) are connected with one another, allowing for information sharing. However, many more networks exist, such as a physical transportation network, connecting location to each other. Networks often gain from increasing user counts due to increasing value of the service, take the internet as prime example here. The extent to which these network effects take place depend on the quality of the connections. If there are too many users, the network will become congested, and the positive network effect has the opposite effect. Networks thus transport information from one location to another, regardless of whether or not it was a conscious decision to do so. To clarify, think of the following example related to neighborhoods: Throughout a city, a road network is created for the purpose of commuting to the city center. Simultaneously, this network allows for the exchange of information between neighborhoods, which results in a spillover of effects in one region to all neighboring regions.

Network effects are undoubtfully of importance when considering a research that includes spatial elements. At the basis of network effects lies the gravity model of Newton, which states that every particle interacts with all other particles, where the size of this interaction is positively related to their masses and inversely to the distance between them. Applied to the spatial economic environment, this translates to the gravity model of spatial interaction. This model states that the potential of opportunity between locations is proportional to the size and inversely proportional to the distance between them (Zhu & Liu, 2004). The mathematical formula is stated below, where P represents the potential of interaction between regions; S the size of the given region; and D the distance between the regions. Depending on the subject of interest, S can refer to many variables. When considering international trade, S may be GDP. However, within the setting of this research, S is more likely to indicate population counts or jobs.

$$(1) \quad P_{ab} = \frac{S_a \times S_b}{D_{ab}}$$

Within the physical transportation network, both personal vehicles and public transport play an important role in connecting nodes by transferring information. Given the formula above, a better approximation of distance would be time, as distance by itself does not contain as much useful information. As example, traveling 100 kilometers by foot or by plane differs a great deal. Higher quality transportation – faster transportation – results in a higher potential of interaction. This fast exchange of information, even over large distances, makes it easier for nodes to align their actions. This is also observed when investigating the cities within the Randstad. Each city specializes in another cluster (Kloosterman, & Lambregts, 2001). Conform the specialization theory, this allows all cities to together create a larger output compared to a situation where all cities perform all activities (Smith, 1776). The observation that polycentric areas often specialize, leading to clusters is not restricted to the Randstad, but also seen in countries as China (Wang, Derudder, & Liu, 2019). Which city or region in the end specializes in a specific production process or service, depends on the production possibilities each region has in each of the products and services. Besides an increase in productivity due to specialization, economies of synarchy can also be achieved. This means that the combined output of entities is larger than the separate outputs summed up. The main message here is that communication between regions is required in order to be able to specialize and work together.

2.6. Gentrification

The term gentrification was introduced by Glass (1964) as the changing social character of neighborhoods as a result of a particular segment of the population that is being displaced. In other words, the poor segment of the population is pushed out by more wealthy residents, which changes the characteristics of a neighborhood. Originally, this was observed for the city of London. There are neighborhood characteristics that make them sensitive and vulnerable to gentrification. Most important is the fact that the properties were owned by the working class and the existing properties were split up to accommodate multiple families. This allowed for more wealthy classes to once again combine the previous subdivided properties into one, more expensive, property. A characteristic of gentrification itself is that, once started, it occurs at a very fast pace (Glass, 1964). Thus, nowadays gentrification is no new concept. The phenomenon also is not restricted to a country or continent, but it is observed around the world (Atkinson, & Bridge, 2004).

The phenomenon gentrification is thus more likely to occur in regions where relatively poor people live, as they can be outbid more easily. However, research has shown that the economy of a city also influences the effect of gentrification on the spatial morphology of a city. Take for example the extent to which gentrification is present in the Randstad, the Netherlands. The Randstad is a polycentric urbanized zone, including 4 of the 5 major cities of the Netherlands. Each of the cities differs relative to the others in terms of economic foundation. If the economy is mono-layered, which means that the economy depends on a single economic sector, the corresponding city is not expected to experience extensive gentrification. However, if an economy is multi-layered, thus depending on a range of sectors, gentrification is expected to have a widespread effect (Musterd, Hochstenbach, & Boterman, 2020). Within one polycentric area, differences in the extent to which gentrification plays a role exist. The Hague and Rotterdam are considered to be mono-layered cities, respectively depending on politic-bound activities and port operations.

Besides income and city characteristics, there are more characteristics that determine whether or not a region is vulnerable to gentrification. Thoughts go out to accessibility for all residents when originally planning the public transport network. However, too little attention is paid on the extent to which the introduction of public transport changes the land use (Revington, 2015). Interesting for this research in specific, is the effect from public transport stations on the extent to which gentrification happens. Kahn (2007) discusses the effect of public transport stations depending on two station types: 'walk and ride' stations and 'park and ride' stations. The typology depends on the modality mainly used to reach the station, either by foot or by car. Neighborhoods around walk and ride stations are found to be more vulnerable to gentrification than neighborhoods close to park and ride stations. The differences in property values between the two types of station found can partially be explained due to the higher level of negative external effects that are introduced by vehicle traffic, in comparison to pedestrian traffic.

In conclusion, gentrification is a phenomenon that has been around for decades, influencing city planning all over the world. There are characteristics that are important in evaluating whether or not regions are vulnerable to gentrification. These characteristics may present themselves at multiple levels, from national to local. Distinctive regional traits concern income differences and a city its general economic structure. Public transport stations also influence this vulnerability at a local level, in close proximity to the stations.

2.7. Research question

When considering property prices, there are many effects that play a role in the realization of the final sales price. Included in this is the accessibility effect of transportation. The focus in this research lies on the benefits from the proximity of a public light rail. Other effects at play have to be controlled for. First of all, when researching an effect on property values, it is important to know what drives property prices in general. Previous research has indicated several factors contributing to the development of residential property values. Besides property characteristics, for example size and number of rooms, there are other trends of importance. Prime examples are income levels, the interest rate, unemployment levels, the balance between demand and supply, see table B1 (Kranendonk, van Leuvensteijn, Toet, & Verbruggen, 2005: Spiegelaar, & Vrieselaar, 2020).

The urbanization trend causes cities to arise and grow, reforming the landscape. Reliable and fast transportation within and between cities is required to support further development and expansion of cities without deterioration of efficiency. Several theories have attempted to explain the spatial pattern in which cities or entities develop, as well as the link to individual movements in time. Following from the theory, the existing link between transportation and property values is undeniable. However, there are many interactions blurring the observed effect. These are the modal split, employment, network effects and gentrification. As well as remaining public and private transportation modalities. The theory discussed in section 2.1 to 2.7 form the foundation of the hypotheses.

Each hypothesis, as further elaborated on in the next section, focusses on a part of the research. Hypotheses are setup to either build towards the research question step-by-step. Each hypothesis fits into a sequence, following up on the previous hypothesis, building towards the next. All hypotheses together aim to answer the following question:

What is the effect from high quality public transportation on residential property values?

3. Methodology

Before the metro E was operational, a heavy rail connected the cities Rotterdam and The Hague. The transition from a heavy rail between the two cities was first proposed in 1998 (Gerritsen, 1998). Original plans state that both city centers should be connected via a light rail in 2010 latest. The existing heavy rail, the Hofpleinlijn, was already operating the route since 1908, exploited by the Dutch railway company NS. From 1977 onwards, under the service of the NS[1], trains operate at a 30-minute interval. The light rail operations, under the name Randstad rail, started in 2006. The investments for this line, amongst others, are partially driven by increasing pressure to relieve congestion on the existing road system around Rotterdam (Gerritsen, 1998). A schematic overview of the route of the metro E is presented below in figure 2.3.

The introduction on the light rail came at a cost, both for adjustments to the route as well as new and renewed stations along the path. In 2006, the E-line started operations after 8 years of planning and construction. Subsequent events of importance are the addition of stations in 2008 and 2010, including Rotterdam Central Station. In 2011, the route was extended to include more stops beyond Rotterdam Central Station. In 2015, the light rail saw minor quality enhancements due to additional capacity during morning rush hours, as well as a brand-new station in the city center of The Hague. These years thus mark influential moments and because of that, they are included in the analysis. A visual representation of these events and the years of measurement is shown in figure C3. As a result, there are six years included into the analysis: 1997, 2005, 2007, 2010, 2013 and 2017. Every year precedes an event as mentioned earlier, with the exception of 2017, which is the most recent year for which data was available.

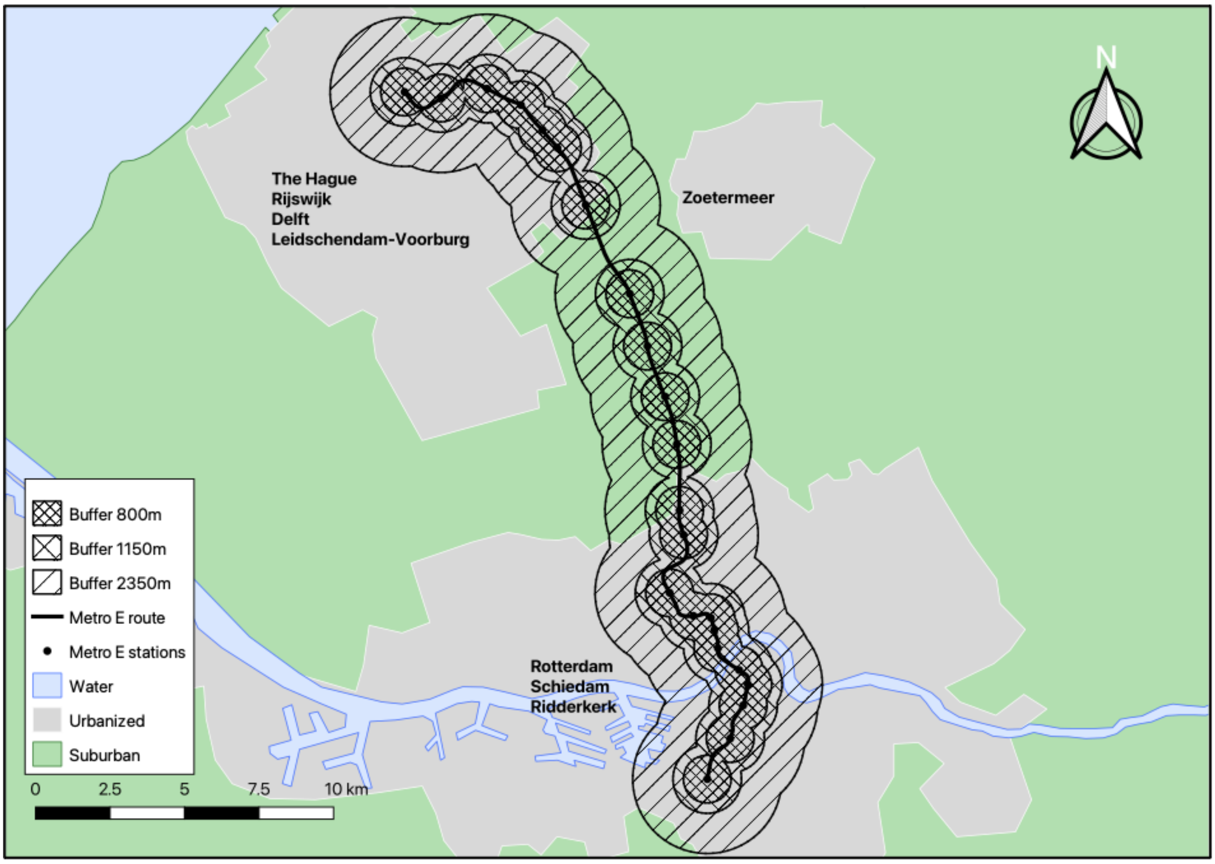

Figure 2.3: A schematic overview of the route and stations, including buffers of 800, 1150 and 2350 meters around each of the stations.

[1] The firm was called ZHESM, after South-Holland Electrical Railway Company. In 1917, the firm merged and became part of the firm that is still operational today: the NS.

3.1. Difference-in-differences

At the basis of this research lies the DD method. This method is widely used and considered to be one of the most important strategies to determine effects (Puhani, 2012). The method requires a minimum of two points in time, one before and one after the treatment. Additional points in time will aid to estimate the pre-treatment and post-treatment means. As a result however, serial correlation (or autocorrelation) must be taken into account (Clair, & Cook, 2015). Positive autocorrelation causes the standard error to be understated, where negative autocorrelation causes the standard deviation to be overstated (Bertrand, et al., 2004) Possible endogeneity is also a concern to take very seriously, as this causes estimates from the model to be biased.

Within this research, the differences are defined as follows: the first difference is the difference in residential property values across distance – meaning properties located close to and further away from the metro E station. And the second difference looks at the difference in value uplift over time – before and after the metro E started operations. First, the assumptions tied to the DD method are discussed, as well as the general mechanics of the method. Second, the drawbacks of the model are discussed, followed by possible solutions.

A DD model operates in two time periods: pre-treatment and post-treatment. Inherent to the method is that there will always be an unobserved outcome. Pre-treatment, all potential outcomes are known. However, post-treatment, this is not the case. For someone who is treated, it is impossible to know the potential outcome were he not treated. This is captured in the consistency assumption:

$$Y(t) = (1 - A) * Y^0(t) + A * Y^1(t).$$

Where A determines whether or not someone is treated. If someone is treated, $Y^0(t)$ will not be observed. Second, the potential outcome during the pre-treatment period is the same for both the treatment group and control group (Zeldow, & Hatfield, 2019). This first assumption is also referred to as the unconfoundedness assumption and it demonstrates the importance of finding a proper control group.

The second assumption, the counterfactual assumption (or parallel trend assumption) states that the treatment and control groups would have behaved similar without the treatment. For this assumption to hold, the control group should be as similar as possible to the treatment group. If this assumption does not hold, the final treatment effect (the DD estimator) will be over or understated. Mathematically, this is reflected in the following formula (Zeldow, & Hatfield, 2019):

$$E[Y^A(2) - Y^A(1)|A = 1] = E[Y^A(2) - Y^A(1)|A = 0]$$

For this research, this means that the value uplift because of inflation should be the same in both the treatment group and the control group.

The DD method provides an average treatment effect (ATE). There is one more requirement tied to the DD method, which is the SUTVA: stable unit treatment value assumption. This assumption states that the potential outcome of an individual should be unrelated to the treatment status of others (Delgado, & Florax, 2015). If this assumption is violated, causal effects can no longer be properly estimated. If the outcomes are coming forth from spatial interactions, SUTVA is violated. In other words, if the effects from the treatment spill over to the control group, effects are no longer properly estimated. As human interaction between regions is very unlikely to be of influence on property values, it is very unlikely that the price effect from the metro E will spill over to the control area.

The DD model is appealing due to the simplicity, intuitive interpretation and ability to get around endogeneity problems when comparing heterogenous individuals. However, the method also had its drawbacks. There are three main reasons why autocorrelation is of importance for the DD method (Bertrand, Duflo, & Mullainathan, 2004). First, DD estimations often use longer time series. Second, most dependent variables are typically positively autocorrelated. And last, the treatment variable changes itself very little over time (Bertrand, et al., 2004). A solution is suggested to deal with the autocorrelation problem. First, the data can be aggregated into two dimensions. With only one measurement before and after treatment, autocorrelation is no longer an issue. However, Angrist and Pischke (2008) offer a simple solution to the autocorrelation issue: remove the time series correlation by clustering at a higher level. Another, more complicated measure to counteract the autocorrelation would be to use an instrumental variable (Besley, & Case, 1994).

An issue with the method, not yet explicitly mentioned above, is spatial correlation. Delgado and Florax (2015) provide a new form of the DD method, including a local spatial interaction to account for spatial correlation. They look at including the spatially lagged term as removing an omitted variable bias. First, second or even higher order neighbors may be used for this interaction. The lagged spatial term is presented as follows. Delgado and Florax (2015) conclude that if spatial correlation occurs, the average treatment effect is in fact a function of its own direct effect, the size of the interaction and probability of treatment. Furthermore, they distinguish an average direct (ADTE) and indirect (AITE) treatment effect. Finally, the more local the spatial interaction is, the less likely it is the analysis will be affected.

3.2. C-squares

C-squares stands for concise spatial query and representation system. It allows for easy use and representation of spatial data (CSIRO, 2003). Any shape, given the fact that it is larger than the individual grid squares, can be reproduced. The smaller de squares, relative to the object, the more detailed and precise this reproduction will be. This method is more reliable in the representation of data than the minimum bounding polygon or minimum bounding rectangle method (Rees, 2003). To be useful, all grid squares have unique identifiers. The first digit describes in which global quadrant a grid square is located, after which the consequent digits describe the exact location in more detail. Using this, data can be related to a position on the world very easily.

The introduction of c-squares replaces older methods, such as the minimum bounding rectangle or minimum bounding polygon method for spatial indexing of data. Both of these methods do not support simple and fast text-based query operations, which is available for the c-squares. In the early stages of this method, it was mainly designed for marine data. Marine data rarely present itself in rectangles, for instance when gathering data around the perimeter of an island. The bounding rectangle will then return a huge rectangle, with a 'hole' – the island – in the data (Rees, 2003). However, the methods turns out to be useful in many other fields of work as well, including spatial economics.

The c-squares is useful to present visuals of the data. This tool helps to explain irregularities within the data, make links between variables and spatial effects, and visualize results. Besides this, using the c-squares enables faster and easier processing of data. As an example, the average number of properties within each of the grid squares in this research is 2.11. This means that the number of observations after aggregation in grid squares has more than halved. For larger sample sizes and more complete datasets, the gain is even more considerate. Whether or not omitting de details by aggregating data harms the quality of the research depends on the scale of the research. When performing a nationwide research comparing population densities, the grid squares may easily be multiple kilometers instead. Take for example a research from the PBL Netherlands Environmental Assessment Agency (Nabielek, et al., 2016), in which population density growth is depicted on a grid of two by two kilometers. As long as the grid is (significantly) smaller than the object that is replicated, there are no restrictions to size other than data availability. Interestingly, grid squares are fairly uncommon within urban academic literature.

For this research, grid squares are predetermined at 100 by 100 meters. Grid squares are preferable over other types of polygons, such as areas based on neighborhood borders or postal codes, as these often are shaped irregularly. These irregular shapes make determining the center point of gravity more difficult, which is easily done for a square. The center point of gravity is of importance as it serves a purpose in determining which grid squares lay within the area of interest. The exact steps taken in this process are described in the fourth section: data. Aggregating the data into the grid sections also decreases the possible distorting effect from outliers on the final result, however this only hold for grid squares for which there are two or more observations. Finally, as previously mentioned, the spatial data can be processed faster, as less calculations are required due to the lower number of observations – while still taking the unique properties into account.

Another effect of aggregating data is that all squares are now taken into account with the same weight. A grid square with 1 observation thus weighs de same as a grid square with 23 observations. Within this research, this resulted in a better balance between observations within the treatment group and control group. Within a city, properties are located closer to each other. Assuming that the probability of a property being sold is equal, there will be more observations within the city.

All property data that is used in this research has some type of spatial identification. In the data section, an elaborate explanation will be given on how this is done. In short, however, the identification is used to determine to which grid section a specific property belongs. This is visually show in figure 3.1 below. The first map shows the (hypothetic) properties of interest that have been sold. The first step is to overlay the grid, after which all attributes of the properties can be aggregated. The geographical information is no longer required, because the center point of gravity of each grid square can be used instead.

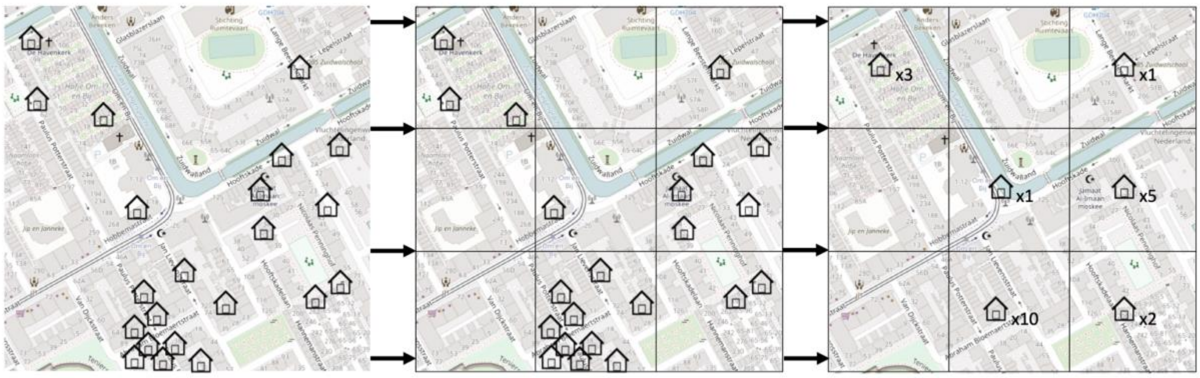

Figure 3.1: Visual representation of aggregation of properties using the c-squares.

3.3. Alternative methods

The section alternative methods includes both alternatives to the design of the model, as well as the design of the control group. Comparable models are the comparative interrupted time series (CITS), the difference in difference in differences model and the multilevel regression. Available alternative methods regarding the determination of the control group are matching or the use of synthetic controls. In the next section, these alternatives are reviewed, starting with the models.

The DD method as discussed earlier is in fact a simplification of the CITS model (Somers, Zhu, Jacob, & Bloom, 2013). This is because the DD design determines whether the treatment group deviates from the mean of the comparison group. The CITS model introduces an additional control for trends within the control and treatment group. It first measures the deviation from the established trend for the treatment group and control group. Second, it determines whether the treatment group has deviated more relative to the control group. A basic DD design is given by:

$$Y = \alpha + \beta_1 Treatment + \beta_2 Post + \beta_3 Treatment * Post + \beta_n X + \varepsilon.$$

Where post is a dummy taking on value 1 after treatment, and 0 otherwise. The CITS model also includes the following to capture the trend.

$$+ \beta_4 Time \text{ } and \text{ } \beta_5 Time * Treatment$$

Where time captures the pre-treatment trend (Clair, & Cook, 2015). Due to the introduction of the pre-treatment trend in both the treatment and control group, the CITS is able to make better projections in the long term. Besides this, the estimates are more realistic, since the standard deviation is increasing for longer-term effects, which is not the case of the DD method (Somers, et al., 2013).

However, this model does impose additional data requirements. Data has to be available for four or more moments in time to properly estimate the pre-treatment trend (Somers et al., 2013). Unfortunately, this research is setup using only 6 moments in time, of which only two measurements are taken before treatment: 1997 and 2005. This means that there are not enough data observations to determine a pre-treatment trend. This method, regardless of its advantages, cannot be applied for this reason.

There is yet another simplified version of the CITS model: the simple interrupted time series (ITS). The DD model experiences threats to its validity due to possible exogenous events occurring at the same time as the treatment of interest. For the ITS model, any event that occurs causes a threat to the validity due to the one-group design. Besides this, it is argued that the ITS is unfit for estimating causal effects (Shadish, Cook, & Campbell, 2002). Mainly this is due to the fact that the method is unable to rule out the effect of other developments (Clair, & Cook, 2015). The additional drawbacks of the ITS model compared to the DD model make clear that this is not a suitable substitute.

A more extensive variant of the DD method is the difference-in-difference-in-differences method (DDD). According to Clair and Cook (2015), this design captures additional variation, and thus better isolates the treatment effect. The use of an additional control group helps addressing the selection bias. For the regular DD model, any events that occurs to the treatment group only will lead to biased estimates. With the DDD model, there is an additional safeguard as there is an additional control group present. To lead to bias estimates, events must thus solely occur within the treatment group, relative to both controls. By definition, the odds of obtaining biased estimates are thus smaller for a DDD design than for a DD design. However, the method is still susceptible for exogenous events. Delgado and Florax (2015) argue that there are also disadvantages to using a DDD design, especially in regard to a spatial research. First, dividing the sample into more groups is inefficient for smaller samples. And second, increasing the groups will result in many betas, of which some do not make sense. In short, they conclude a DDD design is not optimal within a spatial setting.

Another method to consider as substitute for the DD is the multilevel regression. The use of a multilevel regression is thought to be justified when data has a hierarchical structure (Mulley, & Tsai, 2016). For example, when considering properties, higher hierarchies may be a neighborhood, city, province, country or even continent, based on the scope of the research. The number of hierarchies that can be in place are thus not limited, however, the most common design uses two levels, which has a two-level nested data structure. For example, level one includes the individual property, where level two reflects the grid square in which the property is located. Assuming properties that are located close to each other are more alike, properties within the treatment area could be more alike compared to properties in the control group. As a result, using a regular DD design will underestimate the standard errors, and thus possibly overestimate the significance (Mulley, & Tsai, 2016). Concluding, the variation in property values is found to be captured better with the use of a multilevel regression, compared to the DD method (Yen, et al., 2019).

However, within this research, properties are aggregated into the grid squares instead. The multilevel regression would have been able to examine the individual properties within their neighborhood instead. Arguably, this would have been the better choice. However, controlling for spatial effects at a higher scale can also be done by introducing fixed effects into the regression, which is the chosen solution within this research. Any regional effect that is constant over time will then be omitted, and as a result does not induce a bias to the model. The introduction of a fixed effects model is introduced in section 5.2 for this particular reason. The main reason for using the fixed effects solution comes forth from the decision to utilize grid squares. Due to this aggregation, it is questionable whether or not the model can suffice in the sample size requirement for accurate estimation (Hox, 2013). When the number of groups in the second level is lower than 50, the standard errors are found to be estimated too low (Maas, & Hox, 2015). If grid squares were not used however, this method would be appropriate. At the very least, this debate confirms the importance of doing extensive robustness checks for the DD model used in this research. Besides this, the choice of the control area is arguably more influential (Yen, et al., 2019). The next two paragraphs discuss the alternatives for the determination of the control area.

Within the DD literature, a control group can be setup in different ways. First of all, the control group can be distance based, which is the form also used in this research. Through literature, a catchment area is determined, all observations within the scope of the research that fall outside of this catchment area are assigned to the control group. This method relies on the assumption that the properties are actually similar due to the close proximity. Testing this is difficult, because it is not clearly defined what attributed of the properties should actually be the same for them to form a proper control. The distance based construction relies on literature to determine the size of the catchment area. Distance-based controls can either be formed with a continuous variable, measured from the stations of interest, or with the creation of buffers with set distances. The latter one is used in this research, computed from the actual continuous data. The zones that are created differ from 0 to 800 meters, 800 to 1150 meters, 1150 to 2350 meters and 2350 to 5000 meters. Within the data section, this will be further elaborated.

Alternatively, the control area can be constructed by using matching. This is an approach to counter the selection bias between the treatment and control group in a more objective manner (Yen, et al., 2019; Caliendo, & Kopeinig, 2008). Applied to the current research, the goal is to find a property with similar characteristics – for example a property with the same number of rooms and floors, sold in the same year, both with the same attributes – that is not located within the treatment area. This property can than serve as a control for the specific property that is located within the catchment area of the metro E. This requires an extensive database of properties that may serve as control. A method that uses this logic is called the propensity score matching (PSM). An example for this matching principle can be found in a research determining the price effect of sea level rise (Bernstein, Gustafson, & Lewis, 2019). All properties have differing attributes and a chance of experiencing a flooding. Within the paper, all properties are matched based on their attributes. The only differing variables then are the chance of flooding and value of the house. The effect of a flooding can be determined because the relationship between them is isolated using matching principles.

Lastly, there is the option of creating a synthetic control area. Within this framework, a synthetic version of a region is constructed with the use of characteristics from other regions. Abadie and Gardeazabal (2003) reconstructed the Basque Country without terrorism by using other Spanish regions. They then could use the synthetic Basque Country as a control for the actual Basque Country to see the economic cost within the region. This method was created as the Basque Country did not have a natural counterparty it could be matched with. The synthetic Basque Country was tested against historical data so see whether the two behaved the same. In fact, this method can be viewed as a special case of matching, where the control area is first constructed to fit the treated party.

3.4. Hypotheses

Each of the hypothesis will be answered through a regression analysis. Due to the changing nature of the hypothesis, each focusing on a subsection of the research question, each regression will be slightly different. Below, the hypothesis with their respective regression analysis are reviewed.

1. <u>The Base Effect</u>

Hypothesis one concerns itself with the introduction of high quality public transport into an area where previously none was available. The argument here is that increased accessibility is a preferable characteristic of an area, decreasing the time spend traveling, or increasing the range that can be reached within a timeframe. This assumed positive relation between accessibility to public transportation and property values is considered to be the base effect. Following this reasoning, the first hypothesis reads as follows:

H1: The introduction of high quality public transportation increases local property values

The first analysis hypothesizes a very stylized reality. Each of the grid squares will be given a zone value of either 0 or 1 for each year of the analysis. The 0 indicates that the center point of gravity of the grid square is not located within the catchment area of an E-line station. Hence, the 1 indicates that the center point of gravity is located within the catchment area. The catchment area of the station depends on the transport modality that is used to reach the station. Research into multimodal transport with train, tram & metro and bus as main transport modality, shows that cycling and walking are the main forms of pre-transport. For the Netherlands, the combination of cycling and walking is especially important, accounting for (respectively) 62, 56 and 83 percent of all movements between the residence and train, tram or metro and bus. Following this research determining the catchment area of public transport stations, the threshold is set at 2350 meters (van der Blij, Veger, & Slebos, 2010), which corresponds to the average distance for cyclists.

The opening of the metro E took place in 2006. The break of the difference-in-differences estimator is thus set at 2006. Years 1997 and 2005 will consequently be given a 0 for the time estimator, and the four remaining years will be given a 1. The hypothesis states that properties within the catchment area – zone value 1 – experience a more rapid increase in price than those outside the catchment area. The regression analysis for square statistic i for year t equals:

$$(1) \quad \begin{aligned} Value_{it} &= \beta_0 + \beta_1 Time_{it} + \beta_2 Zone_{it} + \beta_3 DID_{it} + \beta_4 dCategory_{it} + \beta_5 Constructionper_{it} \\ &+ \beta_6 Isolation + \beta_7 MaintenanceIN_{it} + \beta_8 MaintenanceOUT_{it} + \beta_9 Houseview_{it} \\ &+ \beta_{10} Garden_{it} + \beta_{11} Heating_{it} + \beta_{12} Attic_{it} + \beta_{13} Loft_{it} + \beta_{14} Parking_{it} \\ &+ \beta_{15} nRooms_{it} + \beta_{16} nFloors_{it} + \beta_{17} nBalconies_{it} + \beta_{18} nDorms_{it} + \varepsilon_{it} \end{aligned}$$

2. <u>The Proximity Effect</u>

It is unlikely that the base effect is uniformly distributed over the area around stations. First of all, properties must be within a certain distance to the station for residents to use it. Second, properties closer to the station may benefit even more than those located further, but within the maximum catchment area, away. Therefore, the second hypothesis reads as follows:

H2: The base effect increases with declining distance to the station

Assumed by the second hypothesis, is that properties located close to the stations will benefit even more in terms of value uplift. To test this hypothesis, the catchment area cannot simply be labeled as within or outside the catchment area, as was the case for hypothesis 1. Public transport relies on other modalities to bring passengers to the stations. Walking and cycling together make up for the majority of passengers, ranging between 56 and 83 percent of all movements, depending on the main modality (KiM, 2014). Therefore, it makes sense to divide the catchment area in zones that distinguish walking from cycling. As a result, there will be three categories within the catchment area, one for walking, walking and cycling, and cycling. These categories have the respective distances of 800, 1150 and 2350 meter as measured from the station (van der Blij et al., 2010). The measurement will largely remain the same, however all grid squares will now receive a value from 0 to 3 depending on the distance from the station to the center of the square. The second regression equals:

$$(2) \quad Value_{it} = \beta_0 + \beta_1 Time_{it} + \beta_2 Zone_{it} + \beta_3 DID_{it} + \beta_4 Propertycontrols_{it} + \varepsilon_{it}$$

3. The Usage Effect

The base effect is thought to depend on the quality of the public transportation line. A light rail connecting two major cities, being employment hotspots and offering many amenities, has more value to people than a line connecting relatively small villages. Therefore, the third assumption combines this quality measure and the base effect. The use of the public transport line indicates to what extent people find the line to be useful, which thus acts as a proxy for quality. The third hypothesis reads as follows:

H3: The base effect increases with usage of the public transport line as a whole

Hypothesis three concerns itself with the use of the transportation line. A station that is used by many people every day is more valuable, indirectly for businesses. If all stations along a line are used a lot, the entirety of the line becomes more valuable, which may also be reflected in the value uplift of surrounding properties. A newly introduced line will never be functioning at full capacity, as the infrastructure is likely to be constructed for decades to come, as creating infrastructure that can only suffice in current demand is therefore not viable. To control for this, the daily number passengers is introduced as a first control variable. The third regression equals:

$$(3) \quad Value_{it} = \beta_0 + \beta_1 Time_{it} + \beta_2 Zone_{it} + \beta_3 DID_{it} + \beta_4 Propertycontrols_{it} + \beta_5 Passengers + \varepsilon_{it}$$

4. The Employment Effect

Roads and other physical infrastructure is constructed to support transport in two directions. As a result, the introduction of infrastructure introduces two effects. On one hand, a region is better connected to all other places, making it more attractive for consumers to live. On the other hand, the region is more easily reachable from all of those other places as well, which makes it a more beneficial location for firms. The attraction of firms may further increase the property values, as land is increasingly scarce. There are two sectors which are thought to affect the property values even more: education and retail/ restaurants. These two groups are included in the analysis separately. Consequently, the fourth hypothesis reads as follows:

H4: The base effect increases with number of jobs in the area

To control for influences from employment, the number of jobs in each grid squares are also measured. The accessibility of jobs may influence the value of properties. An increase in jobs due to the introduction of a light rail may be viewed as an indirect effect from the introduction of the light rail. However, to determine the direct effect only, this must be controlled for. The fourth regression equals:

$$(4) \quad Value_{it} = \beta_0 + \beta_1 Time_{it} + \beta_2 Zone_{it} + \beta_3 DID_{it} + \beta_4 Propertycontrols_{it} + \beta_5 Passengers + \beta_6 Jobs\_educ_{it} + \beta_7 Jobs\_retail_{it} + \beta_8 Jobs\_other_{it} + \varepsilon_{it}$$

5. Regional Effects

Within the real estate environment, there is more than just one spatial effect that influences the property values. These spatial effects can either be positive (amenities) or negative (disamenities). Amongst the amenities are proximities to other modalities of transportation, such as busses, trains, trams or the highway. Other amenities are the distance to employment and retail hotspots, parks and other recreational green zones. Disamenities include high air pollution levels, noise and close proximity to industrial land (Powe, Garrod, & Willis, 1995). These amenities and disamenities have a significant influence on the decision-making process of consumers when it comes to buying a house. Consequently, the fifth hypothesis reads as follows:

H5: Property values are influenced by multiple spatial effects

While controlling for real estate related influences, use of the metro E and job-related effects, there are more factors that must be controlled for to obtain unbiased estimates. Hypothesis five states that there are four proximity related factors that influence property values, namely distance to: highways, regular and other high quality public transportation and recreational green zones. These spatial effects represent amenities or disamenities for consumers. By introducing the nearest distance to each of these locations, the effect is controlled for. The fifth regression equals:

$$(5) \quad Value_{it} = \beta_0 + \beta_1 Time_{it} + \beta_2 Zone_{it} + \beta_3 DID_{it} + \beta_4 Propertycontrols_{it} + \beta_5 Passengers + \beta_6 Jobs\_educ_{it} + \beta_7 Jobs\_retail_{it} + \beta_8 Jobs\_other_{it} + \beta_9 Highways_{it} + \beta_{10} Other\_PT_{it} + \beta_{11} Green\_zones_{it} + \varepsilon_{it}$$

6. <u>The Locational Effect</u>

Light rails are often connecting urbanized zones through suburban areas. I anticipate the effect for stations within urbanized areas to differ to those in suburban areas. Suburban areas are more likely to depend solely on such a light rail than residents in urbanized zones, which may be reflected in the effect on property values. The sixth hypothesis reads as follows:

H6: The degree of urbanization around the station influences the base effect.

Furthermore, there are differences between stations that influence the base effect. One objective measures to determine the degree of urbanization is population density. To see whether different type of areas effect the extent to which the base effect is visible, stations are divided among three different categories. There are three categories of degree of urbanization: a highly urban, an urban and a suburban environment. The factor around which this division is made is population density. A graphical representation can be found in figure C5. The regression analysis does not differ from before. However, the data is analyzed in three separate groups. In the analysis, only the catchment area from any of the three options stated above is compared to the total reference group. This analysis is repeated for all three options. The regression equals:

$$(6) \quad Value_{it} = \beta_0 + \beta_1 Time_{it} + \beta_2 Zone_{it} + \beta_3 DID_{it} + \beta_4 Propertycontrols_{it} + \beta_5 Passengers + \beta_6 Jobs\_educ_{it} + \beta_7 Jobs\_retail_{it} + \beta_8 Jobs\_other_{it} + \beta_9 Regionalcontrols_{it} + \varepsilon_{it}$$

7. <u>Partial Effects</u>

All previous analyses consider the effect of the introduction of a light rail to be one effect. However, there are multiple effects to be distinguished. Events to distinguish are the announcement and start of construction, start of operation, and further enhancements, connections and quality changes, made down the road. As brought up by Agistini and Palmucci (2008), a part of the total effect can be found within the announcement period. Therefore, the last hypothesis reads as follows:

H7: The base effect consists of five consecutive effects.

Hypothesis 7 assumes that five consecutive effects make up the total effect on property values that is observed from the introduction of a light rail. By changing the years that are included into the analysis, it is possible to observe the contribution of each separate effect. The regression formula does not change, only the years that are included into the dataset. For each effect, two years are taken into account to see whether or not a significant increase in property values is observed, relative to the control group. The specific effect and years used are shown below in table 3.1.

$$(7) \quad Value_{it} = \beta_0 + \beta_1 Time_{it} + \beta_2 Zone_{it} + \beta_3 DID_{it} + \beta_4 Propertycontrols_{it} + \beta_5 Passengers + \beta_6 Jobs\_educ_{it} + \beta_7 Jobs\_retail_{it} + \beta_8 Jobs\_other_{it} + \beta_9 Regionalcontrols_{it} + \varepsilon_{it}$$

Event	**Years included**					
1. Announcement investment	1997	2005				
2. Opening light rail		2005	2007			
3. Connection to Rotterdam central station*			2007	2010		
4. Connection to Slinge				2010	2013	
5. Quality increase**					2013	2017

*Table 3.1: Overview of the regressions. *The connection to Rotterdam Central Station includes adding three more stations, see figure C3. ** Quality increase refers to a new (separate) stop at the Hague central station and more capacity in the form of higher frequencies.*

4. Data

The data that is used in this research is obtained from three separate sources. First, the property data, in the form of transaction values and all relevant property characteristics, are obtained through the NVM, a cooperation of Dutch estate agents and appraisers. The second dataset is obtained from the national employment register. This so-called LISA-dataset contains information on employment per establishment as well as the corresponding spatial location. Lastly, there are several controls to account for due to the spatial angle of this research. The data layers for these controls are obtained from the regional governmental institution, the province of Zuid-Holland (PZH). Each of the datasets will be reviewed separately regarding quality and all data modifications are reported and discussed. A complete overview of all data modifications is shown in figure C4.

4.1. NVM dataset

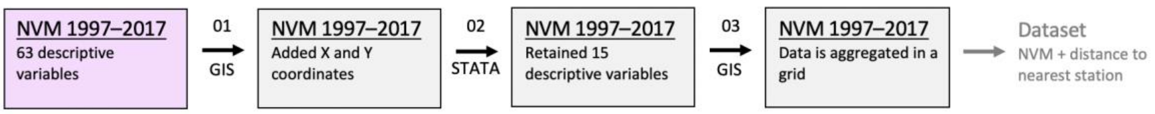

Figure 4.1: The transformations concerning the NVM data.

Figure 4.1 shows four datasets, set apart by three data modifications done with the help of STATA or geographical information systems (GIS). Each of these modifications will be discussed stepwise. First of all, the NVM dataset is comprised of sale prices of residential properties, as well as property characteristics described by a total of 63 variables. Data for the years 1997, 2005, 2007, 2010, 2013 and 2017 consist out of well over 168.000 observations. All data is registered by autonomous real estate agencies that took part in a cooperation to create this data. As not all agencies release all property characteristics, part of the data is incomplete. The first step aims to include proper localization measures.

Step 1: *All raw data is geocoded with the help of GIS in order to determine an X and Y coordinate. In the original dataset, localization is done by country, city, street name, number and postal code. However, x and y coordinates are required for the analysis. 2.241 observations are omitted due to incorrect or geocoding results.*

After including the proper variables to determine the location of the properties, the NVM dataset contains 126 variables, inflated due to the geocoding process. Only a part holds relevant information that can be used to answer the research question. The second step aims to take away unusable variables, as well as create two explanatory variables and delete observations that contain faulty information.

Step 2: *Observations that contain information that seems impossible have been omitted. Firstly, all 6.376 observations without a surface area are omitted. Second, observations with transaction prices lower than €50.000 or a surface area smaller than 20m^2 are omitted. Third, properties with a value higher than 1.500.000 are omitted due the unique characteristics of such properties. Lastly, properties with a price per square meter below 300 or above 10.000 are also omitted due to their excessive nature. These set boundaries result in a loss of another 1.186 observations. From the original dataset, 15 descriptive variables are included in the dataset. These control variables describe the property through its attributes.*

Box three thus contains a selection of variables and observations that are used in the analysis. 158.702 observations and 18 variables remain: the coordinates, a year variable and fifteen variables that contain information on the properties. To utilize the data, all observations have to be aggregated into a 100x100 meter grid, which is the purpose of step 3.

Step 3: *All observations are plotted on a map of the province South-Holland. As follows from the setup of the research, the only* grid squares *that are of interest, are the squares which center point of gravity lies within a 5km radius from the metro E. Any observations that lie outside of this region are dropped consequently. All observations within this range are aggregated into the grid. Each grid square is referred to by an identification number (C-number) and the center point of gravity of each* grid square *is used in any of the future distance measures. The aggregation affects the variables differently. Variables x and y are omitted, as they are no longer useful. The variables category, price and view are averaged if there are multiple observations in the same* grid square *in the same year. The year variable remains unchanged. This is also shown in table 4.1*

Variable	Aggregated in grid
X and y coordinates	(C-number)
Year	
Price	Average
Category and construction period	Average
Scores for maintenance and isolation	Average
presence of nice view, a garden, heating, an attic, loft and parking	Average
Number of rooms, floors, balconies and dorms.	Average

Table 4.1: Aggregation of the NVM variables into a 100x100m grid.

Box 4 shows the dataset of the NVM data that has been aggregated into the grid. Due to the fact that some grid squares have multiple properties within them, the number of grid squares is lower than the number of properties in earlier datasets. The total number of observations that remains for all six years is 27.802. Grid squares differ from 1 to 23 observations. However, in 51.14% of the observations, a grid square only contains 1 observation. The variable category now shows the percentage of apartments in the given grid square. The construction variable indicates the average age of the buildings within the grid square. All variable indicating whether or not a property has an attribute consequently show the percentage of properties with the given attribute. The count – room, floor, balcony and dorm – variables show the average number of the grid square. The next step towards a functional dataset is calculating the distance between each of the grid squares to the nearest station of metro E.

4.2. PZH data layers

The PZH has a lot of data layers that can be used with GIS software. All data layers that are used are briefly reviewed. The discussion of the data layers is split up in two sections. First the road network and metro stations data is reviewed followed by three data layers that are used as control: green zones, public transport stops and highway data.

1. <u>Road network and metro stations</u>

Figure 4.3: The transformations concerning the PZH data layers.

A linear measurement (as the crow flies) to determine the time it takes to travel from one location in a city to another is not optimal. Geographical characteristics of regions largely determine the actual route and thus the length of the trip. In order to increase the validity of the research, the route determinations are done via the road network. The routes that are sought-after are the shortest routes, in length, from any of the previously mentioned grid squares to the station of the metro E that lies closest by. For this, two datasets are required. First the data containing the positions of the stations of metro E and second the available road infrastructure.

Step 4: *Both the center point of gravity of all of the grid squares and the locations of the stations are known. Through a nearest neighbor analysis in GIS, with the neighbor being the metro station, each of the grid squares can be matched with their respective station. For each square, this method thus yields a distance between closest station and the center point of gravity of the respective square of the grid. This analysis is done for all unique grid squares, meaning the same square will be appointed the same distance, regardless of the year.*

The second box thus contains distance information on each of the grid squares to the nearest station, as well as the station name and station ID. These distances will later be used to place grid squares into zones surrounding the stations, instead of the absolute distance itself. However, obtaining the distances does allow for flexible creation of zones. The distance data has to be matched with the already obtained NVM data during step 1 to 3.

Step 5: *Both the NVM dataset and the distance dataset are structed to provide information based on uniquely identified grid squares. Therefore, the data can be matched based on this identification.*

Box three thus contains both the NVM information on residential properties and the distances to the nearest station, including station identification. The next step in the process is including not only property, but also regional controls to the dataset. This will be done in step 6 and 7. First, however, there are two remarks to be made about the road network in advance. The remarks are tied to possible challenges that arise when performing an analysis over time.

First, the infrastructure used in determining the routes is one that includes pedestrian and bicycle routes. However, in Holland, most road infrastructure is made for both car and bike. Therefore, the routes that are made are fairly similar for cars. The main analysis therefore mainly interest pedestrian and bike transport, but with some caution may also be used for car transport.

Second, and more important, the road network that is used is from recent years. As not all roads available nowadays were also available in 1997, this may pose a problem. Considering this is important. Roads infrastructure has expanded over the years, thus creating more alternative routes that may be faster. Therefore, the time it took to get from a square of the grid to a station in 1997 may be underestimated. However, route length does not determine travel time alone. In order to accurately take this in consideration, average traffic speed must be known as well. Assuming the speed of pedestrian and cycling traffic has remained similar over the past two decades, it could be that the travel times for earlier years in this analysis are underestimated. What this means for the results will be discussed in a later section.

2. Green zones, highways, remaining public transport and other data

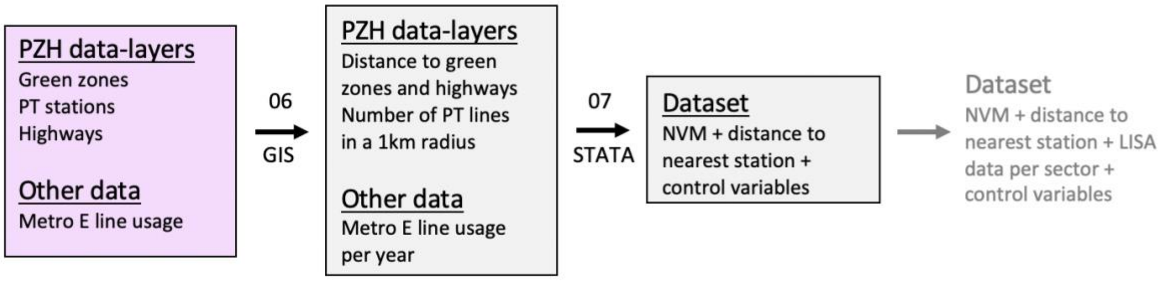

Figure 4.4: The transformations concerning the PZH data layers.

There are several controls to add to the regression analysis. This includes data from the PZH and line usage data. The line usage data was obtained for several dates between 2005 and 2018 from the RET (H. Kranenburg, personal communication, July 30, 2020). Another measurement for November 2001 was obtained via a report from the local government (Stadsgewest Haaglanden, 2001). The passenger numbers are given for multiple years at differing months. Therefore, the number of passengers that is used in this research is recalculated. For each of the six years in the analysis, the number of passengers is calculated for January first. This is done by either linear interpolating between two given datapoints, or linear extrapolation. Controls from the PZH include nearby recreational green zones, highway proximity and access to other forms of public transport. Both the data layer for highways and other high quality public transport stations are fairly straight-forward and do not require changes. The data layer for green zones does require further elaboration.

The data layer itself is a very detailed map of all sort of green zones. First of all, all green zones that do not serve any public recreational purpose are omitted, such as personal gardens, green road verges and land with agricultural or construction purposes. Park size is thought to be important in determining the added value of green zones (Brown, Schebella, & Weber, 2014). Two parks mentioned in their paper are of interest: community parks and large urban parks. These parks are respectively 120.000 to 200.000 square meters and more than 200.000 square meters. The goal therefore is to filter out all green areas that do not meet this requirement. However, due to the degree of detail, this is easier said than done. Zones are separated from one another by streets and paths for pedestrians and cyclists, as well as by typology – grass or woodland. A large forest or dune is thus cut up in smaller parts. Setting the requirement of at least 120.000 square meter would omit all data.

With GIS, buffers can be created around all zones. These buffers of 4 meters are designed to cross footpaths and bicycle paths up to small road. This measure is determined by the looking at the road profile for access roads in a 30km/h environment, which is 7.60 meters (Gemeente Den Haag, 2015). This width is comprised of one-way car access, and two-way bike and pedestrian access. The road width can differ slightly per municipality, although there are recommended national standards. If buffers overlap, the square footage of the separate zones is summed up, after which the original size requirement can be applied. However, this creates a new problem, as zones now may be connected through small patches of green. For example, two smaller green areas of 60.000 square meters may be connected through a series of trees that are planted in a street, and thus be taken into account for the analysis. To prevent such a thing from happening, the size requirement will be fulfilled in three steps.

First, smaller sized green zones are removed from the map using two tools: the ratio of surface-circumference must be larger than 5. The use of the ratio has two effects, omitting shapes based on their form and size. The ratio is lower for declining surfaces and is lower for more stretched out surfaces. This removes all strips of green zones that are shaped as a line, as well as smaller green zones, see figure C6. As an example, a perfectly round green zone of a 10 meter radius will have a ratio of 5, this means all green zones smaller than this will be omitted. However, a strip of land with width of 2 meters and a length of 2.5 kilometers will have a surface-circumference ratio of only 1. The underlying goal is to remove strips of green zones that are unfit to serve as recreational zone. The second, possibly unnecessary, tool deletes all green zones smaller than 1.300 square meters to be 100 percent certain no wrong mergers take place.

The second step is placing the previously mentioned 4 meter buffers around the remaining zones. Third, the surface of the zones from which the buffers overlap will be summed up, after which the original size constraint can be tested. The remaining zones are then either given the label community park or large urban park based on the size. After this process, all data layers are ready to be used for the GIS analysis in step 7.

Step 7: *The highway and the green zone data layers will be treated in a similar fashion. First, the data layers are plotted on the map. From each of the grid squares containing NVM data, the linear distance to the nearest point of the highway, nearest community park and large urban park are calculated. A location close to a highway may have a bilateral effect, positive due to increased accessibility and negative due to negative externalities such as noise.*

The variable other PT lines is included as the number of public transport lines, measured at stations, that are within a 1 kilometer radius from the center point of gravity of each square in the grid. A line with multiple stations will thus only be taken into account once. This analysis is repeated for high quality public transport and regular public transport, which will be taken into account separately in the analysis.

4.3. LISA dataset

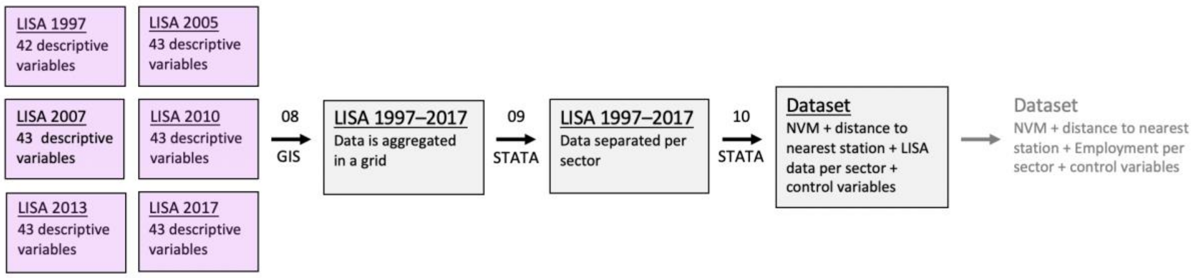

Figure 4.6: The transformations concerning the LISA data.

The LISA dataset contains information on employment levels, where each observation represents a firm. For each firm, there are more than 40 variables measuring the firm location, size of the establishment, sector in which the firm operates and employee counts. For the province of South-Holland, the six years included in the analysis contain 496.301 observations, of which 215.664 are unique. This information is graphically represented by the 6 purple boxes in figure 4.6. In order to use the data, observations have to be aggregated into the grid in a similar fashion as done with the NVM data.

Step 8: *With the use of GIS, all observations are plotted on the map of the province South-Holland. Observations that are located within the same square of the grid in the same year are aggregated. The boundaries of the grid are similar to those used for the NVM data, in a radius of 5 kilometer around the metro E line. Similar to the NVM data, variables change due to this aggregation. For the LISA variables, this means summing the number of firms and their respective employee counts. There is one variable that is created during this process: sector. This variable contains values 1, 2 and 0, referring respectively to jobs in the sector schooling, catering and retail, and other. For a detailed breakdown of this variable from the original data, see table B2.*

Variable	Aggregated in grid
X and y coordinates	(C-number)
Year	
Sector	
Number of firms	Sum
Total number of jobs	Sum
Number of fulltime jobs	Sum
Number of part time jobs	Sum

Table 4.2: Aggregation of the LISA variables into the 100x100m grid.

The aggregated LISA dataset contains 82,905 observations (grid squares) containing the variables mentioned under step 8. However, in this state is it impossible to merge the data with the NVM data as there are multiple entries for each square statistic for each year, due to the addition of the sector. Therefore, the dataset has to be separated into three distinct datasets, each containing the data for one specific sector.

Step 9: *Using Stata, the dataset can be split up depending on the sector. The variable names have to be adjusted in order to properly merge the data. In other words, all variables have to have some sort of sector identification: 'Total number of jobs' will thus change to 'Total number of jobs_1' for sector 1, 2 for sector 2 and 0 for sector 0.*

Step 10: *After the datasets have been separated, each of the datasets can be merged with the NVM dataset based on the grid square identification number. All grid squares for which no NVM data is available will be omitted as it has no use in the analysis. From the total of 27.802 grid squares, 7.022 grid squares have no employment record in any of the sectors in the specified year, thus employment equals zero.*

4.4. Final dataset

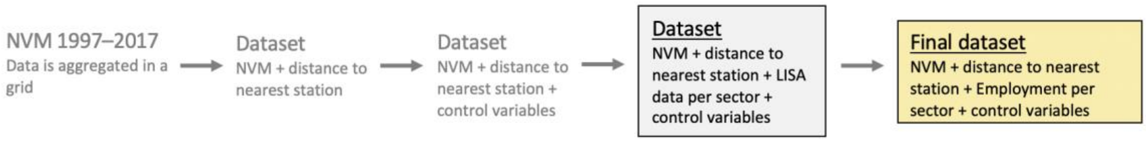

Figure 4.7: The final dataset.

The final dataset obtained in this process is shown in the yellow box in figure 4.7 above. It contains all main variables required for the analysis, as well as LISA data, property and regional controls. In the next section, the data is split up in four categories: general variables, LISA variables, NVM variables and regional variables. The descriptive statistics per category are shown below. These figures will be shortly reviewed before continuing to the result section.

In table 4.3 below, station ID and distance to the nearest station only show 13,812 entries. This is because of the fact that these variables are only calculated for the catchment area, not the control group, resulting in the shown number of observations. The number of properties within one grid square differs from 1 to 23, the first one of which makes up just over half – 51.14% – of all observations. The station type describes the station its environment in three categories: highly urban, urban and suburban.

Variable	Obs.	Mean	Std. Dev.	Min	Max
Year	27,802	2009	5.858	1997	2017
Number of properties	27,802	2.109	1.728	1	23
Average price per m^2	27,802	2046	772.0	349.7	8281
Station ID	13,812	14.75	8.902	1	34
Distance to nearest station (m)	13,812	1639	861.0	13.58	4018
Average passengers per day	27,802	1889	1409	6710	41833
Station type	27,802	.9636	1.127	0	3

Table 4.3: Descriptive statistics of the main variables.

Table 4.4 describes the number of jobs in a grid square. As previously mentioned, there are 7.022 grid squares that have no value for any of the sectors, which explains the fairly high standard deviations compared to the mean values that are presented.

Variable	Obs.	Mean	Std. Dev.	Min	Max
Number of jobs in					
- education	27,802	1.0990	7.4994	0	165
- in retail and catering	27,802	3.2214	16.321	0	466
- other sectors	27,802	19.509	79.390	0	4414

Table 4.4: Descriptive statistics of the LISA data.

Table 4.5 describes all of the NVM control variables that are taken into account. There are different types of controls to be distinguished. The original construction period has three values indicating whether a property was built before the second world war, between the second world war and 1990, or after 1990. The aggregated variable thus indicates the share of apartments from each period. The isolation and maintenance variables present the average score for all properties in a specific grid square. Following these variables, there are dummies indicating the presence of a certain attribute and count variables indicating the average number of attributes that are present in a grid square.

Variable	Obs.	Mean	Std. Dev.	Min	Max
Construction period	27,802	1.816	.7769	1	3
Isolation score	27,802	1.605	1.642	0	5
Maintenance inside score	27,802	6.976	1.065	1	9
Maintenance outside score	27,802	7.063	.8266	1	9
Category (apartment dummy)	27,802	.5534	.4790	0	1
House view	27,802	.3326	.4231	0	1
Garden	27,802	.4810	.4530	0	1
Heating	27,802	.9493	.1861	0	1
Attic	27,802	.0485	.1948	0	1
Loft	27,802	.0869	.2572	0	1
Parking	27,802	.2240	.3909	0	1
Number of rooms	27,802	4.443	1.509	0	26
Number of floors	27,802	2.033	.9228	1	7
Number of balconies	27,802	.4883	.5027	0	3
Number of dorms	27,802	.1193	.3060	0	2

Table 4.5: Descriptive statistics of the NVM data.

Lastly, the descriptive statistics of the regional controls retrieved from the PZH. For each grid square, the number of (high quality) public transport lines within a 1 kilometer radius is calculated, as well as the distance to the nearest highway and park. These linear distances are measured in meters, disregarding the road infrastructure and geographical characteristics of the land. A distance to the nearest park of 0 means that the center point of gravity of the grid square is located within a green zone.

Variable	**Obs.**	**Mean**	**Std. Dev.**	**Min**	**Max**
Number of high quality PT	27,802	3.393	3.819	0	26
Number of regular PT	27,802	4.943	3.297	0	22
Distance to nearest highway (m)	27,802	25823	2077	.9331	8012
Distance to nearest park (m)	27,802	14323	964.9	0	4862
Distance to nearest large park (m)	27,802	16478	1030	0	4896

Table 4.6: Descriptive statistics of the regional controls.

5. Results

The result section focusses on the regression output that is obtained from the analysis. All hypotheses will be reviewed, as they are set up to determine the effect of the metro E on property value stepwise, however, the main focus will lie on hypotheses 5, 6 and 7. The result discussion will consist out of multiple sections. First, an observation of the results, followed by an interpretation of the main coefficients and coefficients which behave differently than expected. Second, the hypotheses will either be rejected or not rejected. The following section is devoted to robustness checks of the analysis, as well as other relevant statistical tests. This includes running the regression with log-transformed variables, using grid square fixed effects, and only taking squares into account that include more than one property. Two used statistical tests are the Chow test and VIF. The Chow test allows for easy comparison between coefficients within one regression and the VIF checks for possible influence from multicollinearity – highly correlated independent variables within the model. The concluding section is aimed at the main results and possible implications of the findings in this research.

5.1. Answering the hypotheses

Regression results for hypotheses 1 to 4 are summarized in table 5.2. Hypothesis 1 suggested a stylized reality in which no regional controls are taken into account, and there is a singular zone of 2350 meter around all of the stations. Variables time and zone give a sense of property value, regardless of the presence of the metro E. Results indicate properties have indeed become more expensive over time, which is to be expected. Interestingly, properties within the 2350m zone are found to be more expensive than the control area (5000 meter distance, excluding the catchment area). However, the most important coefficient in this analysis – the difference-in-differences estimator– does not yield any significant result. In the appendix, the complete regression output can be found under regression A1, this table shows the property controls to the full extent. All control variables are grouped into property and regional characteristics, similar to the research from Armstrong and Rodríguez (2006).

The variables category, construction period, loft and number of floors are found to have a negative and significant effect. For the category variable this makes sense, as the variable indicated whether or not properties are an apartment or ground-bound property, of which the latter one is more valuable. The negative effect of number of floors may be interpreted as saying that properties of the same surface are more valuable with less floors, which is likely. The loft variable stands out, as having a loft is said to decrease the property value, which is the opposite of what was expected[2]. Maintenance and property view, the presence of an attic and parking, and the number of rooms, balconies and number of dorms all are found to have a significant positive effect. These controls all behave as expected. Lastly, the controls for isolation, the presence of a garden and heating are not found to have any significant effect. Possibly, the expected positive effects are absorbed into other variables within the model. For example, the isolation score and build period (correlation +0.5010). For the heating variable, the lack of effect may be due to data distribution, as 90.56 percent of all grid squares observations have the same value – heating present in all properties.

The result found for the difference-in-differences estimator are not significant for a 2350 meter catchment area. However, the significance of the coefficient is highly dependent on the size of the catchment area. Changing the catchment area to include all properties within 1150 meters returns a positive and significant DD estimation, with a P-value of 0.022. Decreasing the size of the catchment area further to 800 meters also yields a positive and significant effect, showing a P-value of 0.004. Based on the findings, the base effect, stating that the introduction of high quality public transport increases local property values, is not rejected for a catchment area of 800 and 1150 meters. This conclusion is drawn from the fact that a significant coefficient is found for the difference-in-differences

[2] For the loft variable, 87.8% of all grid squares do not have this attribute.

estimator. Regarding this conclusion, it is worth to again emphasize that there is as strong relationship between the measurement of an effect and the size of the catchment area.

It is likely that the effect found under hypothesis 1 is not equally distributed over distance. Therefore, the proximity effect suggests that the 2350 meter zone should be divided into three zones, measuring respectively 0 to 800 meters, 800 to 1150 meters and 1150 to 2350 meters. The results of this analysis can be seen under column 2 of table 5.2. Regarding the zone variable, only the third zone is found to be significantly more expensive than the control area. Zone 1 and 2 present no significant difference from the control. The most interesting change has happened to the difference-in-differences estimator. As with the zone variable, two out of the three zones find no significant influence, however for zone 1 there is a positive and significant relation. This indicates that the introduction of the metro E has increased property values within an 800 meter distance around the stations, relative to the control region. The property control variables undergo no changes of any significance compared to the first analysis, see table A1, column 2.

To determine whether the coefficients for the DD estimation of zone 1, 2 and 3 differ from each other significantly, a Chow test is used. The result shows that zone 1 is significantly different from zone 2 and 3, and the control. Zone 2 and 3 do not differ from each other, nor the control group. The result thus indicate a significant difference among the zones, see table 5.1. As the hypothesis assumes differences among regions, it cannot be rejected based on this result.

DD coefficient zones	**1**	**2**	**3**	**0**
1				
2	0.050**			
3	0.005***	0.605		
0	0.007***	0.944	0.499	

Table 5.1: P-values determining the odds of the coefficients being similar.

Hypothesis 3, the usage effect, predicts that there is a positive relation between the number of passengers that use the metro E and the residential property values surrounding the stations. Column three shows an almost identical regression as before, but now controlling for the number of passengers across the line for each year of the analysis. Introducing this control affects the coefficient found for time and the constant, but not the significance of these and other coefficients. The coefficient for passengers shows the added value per passenger, which ranges between 6710 and 41833.

Based on the results of the regression, the third hypothesis is not rejected. However, there is a basis for debate. The passenger count variable is highly correlated to the year variable: 0.8736. Because of this, the effect shown under the passengers-variable may be partially taking over the time effect, instead of showing the actual effect due to the increase in passengers. Running a VIF test indicates there is no reason to fear interference from multicollinearity. This is because none of the variables show a VIF-value higher than 10 (rule of thumb). The value returned for time and passenger counts is 2.06 and 1.44 respectively. The mean VIF is found to be 2.32.

Including employment numbers aim to control for any price increases in property values in two ways: scarcity of ground to build on and amenities. This is what is stated in the employment effect of hypothesis 4. Properties values may be positively influenced due to a lower supply of residential properties and the presence of retail and restaurants and bars nearby are thought to be favorable. The variables under employment distinguishes two types of job presence that are anticipated to be wanted in the neighborhood: education and retail and catering. Education is not found to have a significant effect on property prices. This means that within grid squares with educational firms – schools – properties are not necessarily more expensive. This may be due to the widespread and even distribution of schools across the Randstad. If all regions have schools available on a reasonable distance, no property will be significantly influenced.

Retail and catering does show a positive and significant relationship with property values. The large coefficient, compared to all other jobs, may be explained through geographical placement of retail, restaurants and bars: the city center. It is not unimaginable that this location effect is also taken into account by introducing the job counts per grid square. Lastly, job presence in general seems to have a positive and significant effect on property values. This result is to be expected as individuals tend to try to live close to their work, as traveling back and forth each day is also very costly.

The employment effect, as stated in the fourth hypothesis, thus is not rejected. However, there are differences per sector. Just as there are sectors that influence property values positively, there may be sectors that yield the opposite effect, although large firms in industrial sectors – such as Shell – are most likely located in designated zones, further away from residential areas.

	(1)	(2)	(3)	(4)
VARIABLES	H1	H2	H3	H4
Time				
1	509.2***	509.1***	365.6***	365.0***
	(11.22)	(11.22)	(12.23)	(12.20)
Zone				
1 (~800)		34.43	33.37	19.42
		(22.41)	(22.38)	(22.35)
2 (~1150)		21.90	21.52	8.668
		(23.50)	(23.45)	(23.51)
3 (~2350)	60.31***	85.83***	85.23***	73.74***
	(14.31)	(18.21)	(18.18)	(18.14)
Difference-in-differences				
Zone 1 (~800)		72.01***	70.28***	70.44***
		(26.71)	(26.42)	(26.27)
Zone 2 (~1150)		1.974	4.146	3.835
		(28.29)	(27.96)	(27.94)
Zone 3 (~2350)	11.44	-14.56	-12.50	-11.65
	(17.01)	(21.52)	(21.38)	(21.27)
Passengers			0.00874***	0.00865***
			(0.000336)	(0.000334)
Employment				
Education				0.322
				(0.513)
Retail and catering				1.006***
				(0.232)
Other				0.671***
				(0.0773)
Constant	578.5***	581.8***	466.4***	474.7***
	(55.02)	(54.98)	(55.20)	(55.07)
Observations	27,802	27,802	27,802	27,802
R-squared	0.309	0.310	0.327	0.333
Multiple zones	No	Yes	Yes	Yes
Property controls	Yes	Yes	Yes	Yes
Regional controls	No	No	No	No

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5.2: Regression results for hypotheses 1 to 4.

The study to the effect of the metro E in a spatial setting cannot ignore other regional spatial effects in its region. For instance, other forms of transportation have not at all been taken into account. The regional effect suggests controlling for such interactions. Results including regional controls are shown in the first column in table 5.4 below, or – for the complete regression – table A2.

Including the regional controls for access to other public transport and highways and the distance to green zones, all three zones are found to be significantly more expensive than the control, unlike previous regression results. However, the difference-in-differences estimator for all three zones remains fairly similar: only for zone 1 there is a positive and significant result. Changes for employment coefficients include a (weak) 90% significant positive effect of education on property values. As for property controls, loft is no longer negatively associated with property values and better isolation does seem to be positively associated, which is as expected. The difference-in-differences estimator results are graphically shown in figure 5.1 below. The results are shown for a part of the route to serve as example; however, they apply to the entire route.

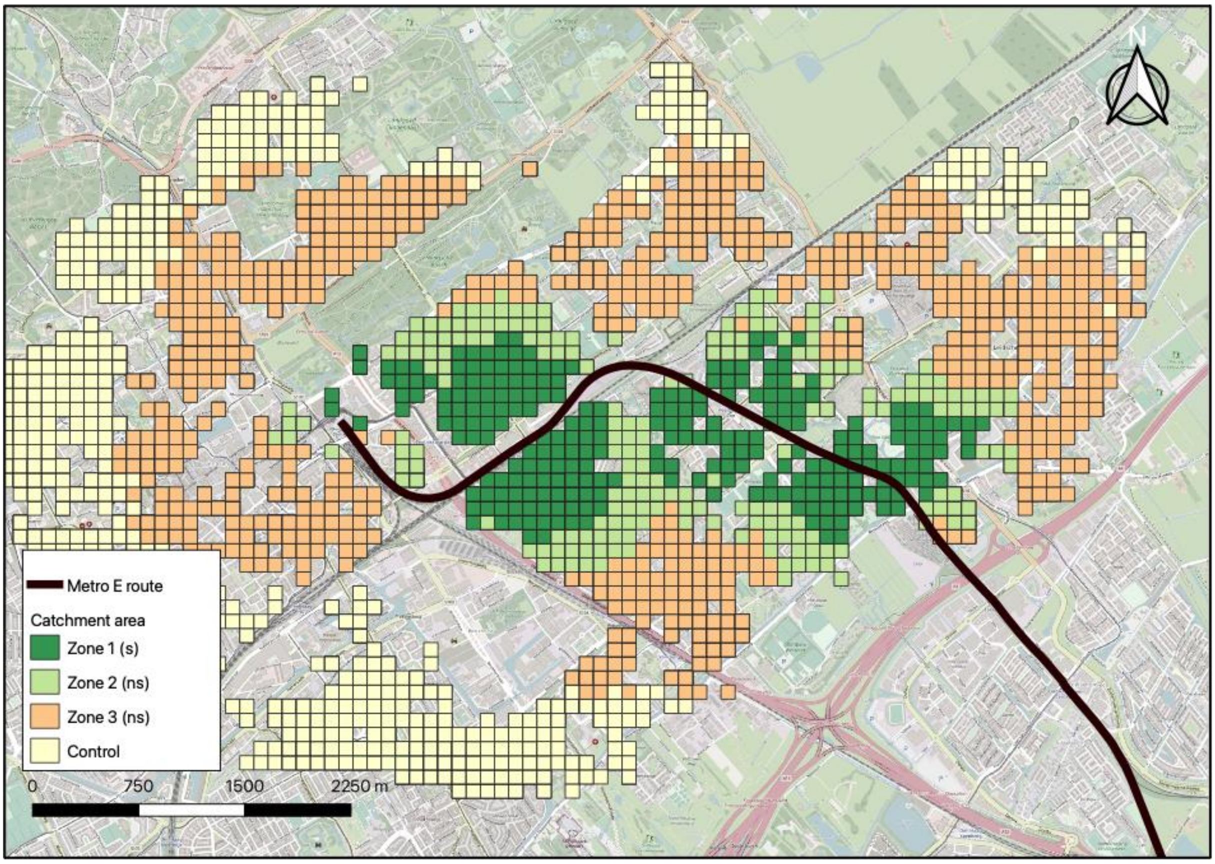

Figure 5.1: Graphical representation of the difference-in-differences estimator from hypothesis 5 using c-squares. The zones either significantly differ from the control (s) or do not significantly differ from the control (ns).

The new regional controls behave somewhat unexpected. The coefficients found for highways and parks are positive and significant, this means that property values increase with distance. In other words, the further away, the higher the property value. For highways, this makes sense as there may be two effects at play: accessibility and negative externalities. Given the positive coefficient, the latter is superior. The coefficient for large parks is negative and significant, meaning property values close to large recreational green zones are considered to be more valuable, which is in accordance with other scientific literature. The negative coefficient of the park variable may be explained through the setup of the research. If the closest park is in fact a large park, the distances measured for park and large are equal. This results in a high correlation between park and large park of 0.8593.

However, a negative relationship between high quality public transport and property values is strange, as it deviates from earlier research (Hess, & Almeida, 2007; Yen et al., 2019). Besides this, it also contradicts with the clear and positive effect for both regular public transport and the metro E, the main focus in this research. A possible explanation for this result is the city planning. A high number of high quality public transport alternatives are mostly found in city centers, while regular public transport is more evenly spread out over the region. This coincides with the fact that both the city planning of Rotterdam and The Hague is following a more traditional structure where the wealthy live on the edge of the city while the poor live near the city center, where high quality public transport is abundantly present to connect downtown offices.

For the results, it is again interesting to know whether or not the effects from each of the zones significantly differs from each other. This is done by performing a Chow test, which states the odds of the coefficients being equal, see table 5.3. The significance shown in the bottom row can also be observed from the regression result in table 5.4. The result shows that only zone 1 differs significantly from any of the other zones.

Consequently, the fifth hypothesis is not rejected. This conclusion can be drawn from the fact that the included regional controls seem to significantly influence the property values. Besides this, all three zone coefficients have changed and are now estimated to be positive and significant. Another improvement of the model can be seen in the explanatory power, which has increased from 0.333 to 0.397 due to the addition of regional controls.

DD coefficient zones	**1**	**2**	**3**	**0**
1				
2	0.0834*			
3	0.0098***	0.5921		
0	0.009***	0.776	0.667	

Table 5.3: P-values determining the odds of the coefficients being similar.

The base effect behaves differently under different sets of circumstances. Up to this point, the only differentiation has presented itself in the form of three zones surrounding the station and the control variables for both property characteristics and regional influences. Hypotheses 6 and 7 aim to further break down the relationship between the introduction of the metro E and neighboring property values. Hypothesis 6 does so by distinguishing three different types of environment: a highly urban, an urban and a suburban environment. Hypothesis 7 does so by dividing the effect over time, into 5 partial effects. The regression output for hypothesis 6 in shown in table 5.4, for hypothesis 7, see table 5.6.

VARIABLES	(5) H5	(6) H6a suburban	(7) H6b urban	(8) H6c highly urban
Time				
1	367.0***	389.1***	372.4***	369.8***
	(11.51)	(12.37)	(12.34)	(12.42)
Zone				
1 (~800)	93.13***	107.6**	182.6***	420.3***
	(23.46)	(42.74)	(30.46)	(57.36)
2 (~1150)	55.20**	51.33	88.74**	397.4***
	(23.75)	(34.12)	(36.36)	(53.56)
3 (~2350)	121.6***	69.30***	67.39**	305.0***
	(17.93)	(25.14)	(28.06)	(32.79)
Difference-in-differences				
Zone 1 (~800)	69.98***	117.5**	-4.799	280.3***
	(26.83)	(47.72)	(34.22)	(65.77)

(table continues on next page)

Zone 2 (~1150)	7.945	80.77**	-76.04*	132.6**
	(27.88)	(39.57)	(41.14)	(62.49)
Zone 3 (~2350)	-8.904	8.616	-77.67**	51.54
	(20.68)	(28.73)	(31.82)	(37.08)
Passengers	0.00876***	0.00737***	0.00757***	0.00847***
	(0.000315)	(0.000362)	(0.000367)	(0.000384)
Employment				
Education	0.812*	1.248	0.927	0.473
	(0.453)	(0.779)	(0.590)	(0.510)
Retail and catering	0.716***	0.456*	-0.274	0.408
	(0.218)	(0.254)	(0.277)	(0.261)
Other	0.578***	0.240**	0.609***	0.332***
	(0.0686)	(0.121)	(0.110)	(0.0619)
Constant	829.3***	1,065***	940.3***	854.3***
	(54.26)	(65.73)	(65.21)	(67.18)
Observations	27,802	19,005	18,607	18,170
R-squared	0.397	0.417	0.407	0.433
Multiple zones	Yes	Yes	Yes	Yes
Property controls	Yes	Yes	Yes	Yes
Regional controls	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5.4: Regression results for hypotheses 5 and 6.

The output for the locational effect is shown in columns 2, 3 and 4 of table 5.2. The research is setup so that each of the subsamples are compared to the entirety of the control group. As a result, the coefficients may become more extreme. Before, the catchment areas considered were made up of a mixture of highly urban, urban and suburban environments, which also holds true for the control. However, for hypothesis 6a, we are comparing only suburban regions to a mixture of controls areas. This makes it impossible to say something about the values of properties within the catchment areas of stations in suburban areas relative to the control group in the suburban area. However, it does allow for easy comparison of coefficients between all three subdivisions of hypothesis 6, as the control group used in each of the analyses is the same. A visual representation of all zones is shown in figure C5.

Relative to the control group, properties in highly urban areas show the highest base value within the catchment area, as the coefficients for zone are higher than those for suburban and urban regions. In other words, properties within zone 1 of the highly urban areas are more expensive than properties in zone 1 of suburban areas. Again, the difference-in-differences estimator is the most interesting variable to interpret. For suburban areas, a positive and significant effect is found for zones 1 and 2. For urban environments, two negative and significant relationships are found for zone 2 and 3. And lastly, for properties in highly urban areas, positive and significant coefficients are found for zone 1 and 2, similar to suburban regions. The results of the difference-in-difference estimations are graphically represented in figure 5.2 below.

The negative coefficients in the urban environment regression are somewhat surprising, however they can be explained. Most likely, this negative effect follows from the sample that is taken and compared to the mixed control. This results in lower average property values in urban environments, thus explaining the results. However, including other regional – neighborhood – characteristics is required to provide a decisive answer. Remaining control variables do not show any noteworthy changes.

Environment type:
Suburban

Station name:
Meijersplein

Environment type*:*
Urban

Station name:
Blijdorp

Environment type:
Highly urban

Station name:
Rotterdam Central Station

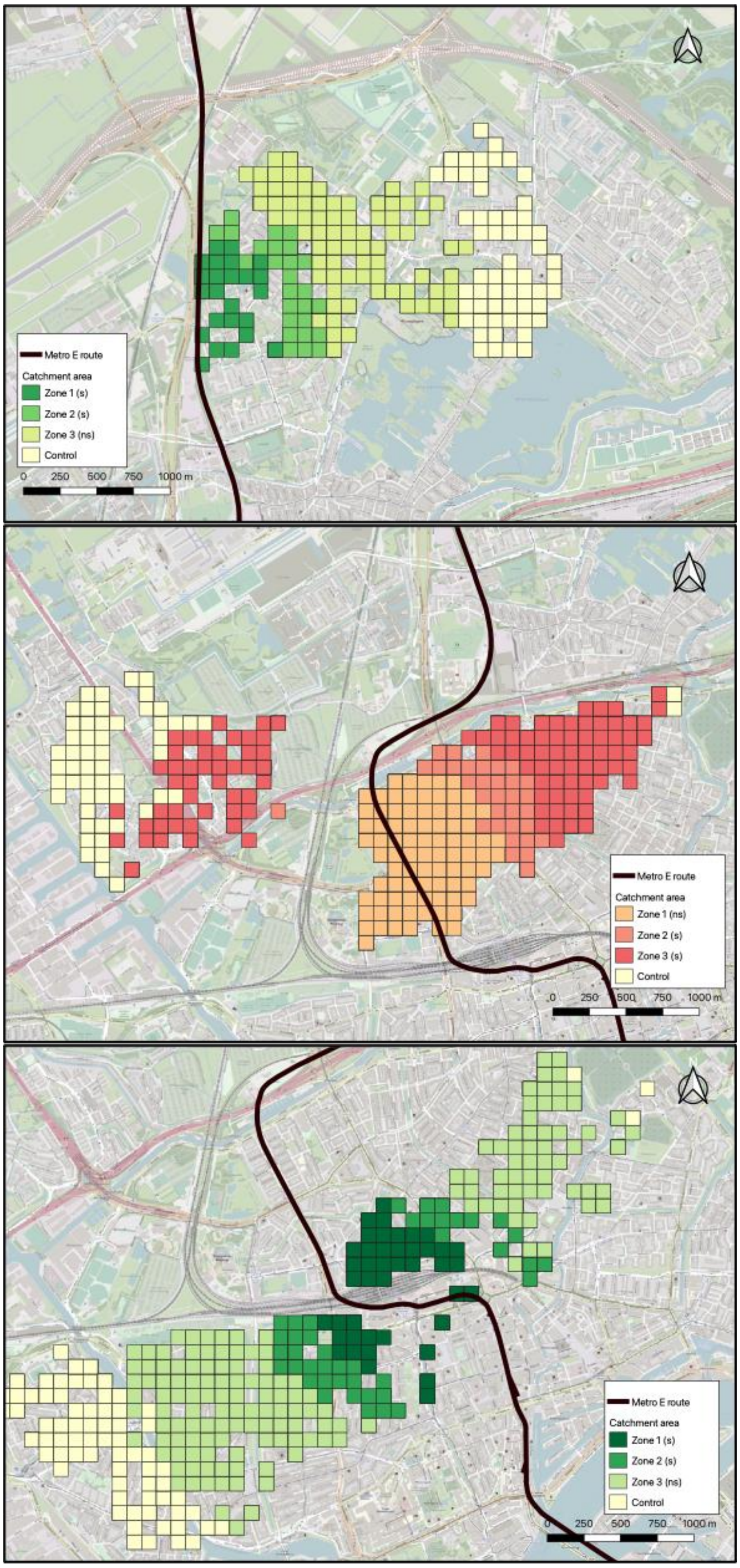

Figure 5.2: A graphical representation of the difference-in-differences estimator from hypothesis 6 using c-squares. Colors are applied given based on the coefficient

The locational effect hypothesis assumes the probability of a higher base effect for suburban regions, as these regions are more likely to depend solely on the metro E compared to urbanized zones that have access to multiple forms of high quality public transport. To compare the obtained coefficients across regressions, they must first be put into a single regression, after which a Chow test can be run to determine whether the difference are significant. The result for this test is stated in table 5.5 below. The P-value shows the likelihood that the two coefficients found for the difference-in-differences estimator for zone 1 for any given two pairs are the same. As an example, the odds of the coefficients for suburban and highly urban environment, 117.5 and 280.3 are the same, equals 4.53 percent. This means that with 95 percent certainty, I can conclude that the coefficients are different from each other. Based on this result, H6 is not rejected.

Difference		Test	F-value	P-value
Suburban	Urban	$\beta_{suburb} - \beta_{city} = 0$	4.34	0.0372
Suburban	Highly urban	$\beta_{suburb} - \beta_{city\ center} = 0$	4.01	0.0453
Urban	Highly urban	$\beta_{city} - \beta_{city\ center} = 0$	14.78	0.0001

Table 5.5: Chow test results between all three categories for the zone 1 coefficient of the DD estimator.

Lastly, hypothesis 7 divides the entirety of the effect – 20 years of time – in shorter periods to allow for better understanding of when the added value of metro E is reflected in property values. The results of the regressions are presented in table 5.6 below. There are 5 periods to distinguish: the announcement, opening (start of operation), connection to Rotterdam Central station, the extension to Slinge and quality improvements, such as additional capacity. The first deviant coefficients are found under the time variable for the time period 2007-2013. It seems that the general trend of property values was decreasing at the time, which can be explained by the global financial crisis that occurred in 2007 and 2008, followed by the European debt crisis. With this in mind, the coefficients are behaving as expected. Almost all zone coefficients show a positive and significant coefficient, with the only exception being zone 2 for the time period 2005 to 2007. This positive relationship between the zone and control similar to previously found coefficients. All property controls are behaving as expected. For the regional controls, controls for highways and recreational green remains unchanged. However, for regular public transport and high quality public transport, coefficients do change, where high quality public transport now shows a positive and significant relationship and regular public transport turns out to be insignificant.

The main variable, the difference-in-differences estimator, shows several interesting outcomes. Across the metro line, properties located in zone 2 around the station underwent a notable decrease in value compared to the control group for the announcement period. This is remarkable to say the least, as zone 1 and 3 do not seem to differ significantly from the control at all.

For the opening, no significant results are found, which is surprising. The start of operations namely reflects the moment in time at which the metro E actually started exercising the added value (connecting regions). It has to be mentioned that the operation of the metro E faced some issues early on, including derailments that may have influenced the value negatively.

VARIABLES	(9) H7a 1997-2005 Announcement	(10) H7b 2005-2007 Opening	(11) H7c 2007-2010 Rotterdam	(12) H7d 2010-2013 Slinge	(13) H7e 2013-2017 Quality
Time					
1	903.5***	166.3***	-37.13***	-191.2***	577.6***
	(13.73)	(13.63)	(14.02)	(14.43)	(15.05)
Zone					
1 (~800)	91.99***	108.6***	92.43***	196.7***	142.0***
	(20.65)	(25.09)	(25.11)	(24.41)	(25.89)
2 (~1150)	85.92***	30.16	49.68**	46.68*	53.24**
	(21.70)	(23.37)	(24.60)	(27.26)	(26.99)
3 (~2350)	98.54***	103.8***	101.2***	90.65***	110.6***
	(20.07)	(17.95)	(19.08)	(20.29)	(20.52)

(table continues on next page)

Difference-in-differences					
Zone 1 (~800)	-25.22	-27.42	118.9***	-46.05	166.1***
	(29.91)	(33.70)	(33.60)	(34.08)	(38.17)
Zone 2 (~1150)	-91.67***	7.307	10.96	-2.766	110.1***
	(30.66)	(33.03)	(36.10)	(37.28)	(40.67)
Zone 3 (~2350)	-21.51	-12.30	-8.114	11.01	80.55***
	(26.23)	(25.58)	(27.28)	(27.89)	(28.84)
Employment					
Education	0.266	0.173	-0.190	0.107	1.394*
	(0.596)	(0.521)	(0.542)	(0.636)	(0.746)
Retail and catering	0.687**	0.875***	0.686**	0.441	0.666**
	(0.325)	(0.329)	(0.335)	(0.302)	(0.310)
Other	0.365***	0.656***	0.612***	0.440***	0.598***
	(0.0777)	(0.106)	(0.133)	(0.105)	(0.106)
Constant	601.2***	1,333***	1,409***	1,337***	948.1***
	(80.69)	(87.83)	(91.17)	(92.09)	(85.24)
Observations	8,077	10,710	10,083	8,547	9,642
R-squared	0.582	0.387	0.387	0.404	0.475
Multiple zones	Yes	Yes	Yes	Yes	Yes
Property controls	Yes	Yes	Yes	Yes	Yes
Regional controls	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5.6: Regression results for hypothesis 7.

For the time period 2007 to 2010, in which 4 stations including Rotterdam Central station were added, the first positive and significant coefficient is found for zone 1. Zones 2 and 3 once again do not show any price increases due to the presence of the metro E. The value of the metro E, in terms of connectivity, increased by a lot due to the connection to Rotterdam central station, which may explain the observed results. The connection to Slinge, similar to the opening of the metro E, does not yield any significant coefficients. This connection is different in a way as there was already a metro operating in the area, which was passed on from one line to the other. This suggests the added value of the connectivity was already present before the metro E took over the service, which would explain why there is no significant influence measured.

The last timeframe shows the changes between 2013 and 2017. Most notably, for the first time, all coefficients for the difference-in-differences estimator are found to be positive and significant. This result implies that the majority of the added value of the metro E was transferred to property values seven to ten years after it started operating. The effect seems to be larger, as distance to the station decreases, which is in accordance with other academic literature. Splitting up the 20-year time period into five shorter periods allows for a better understanding of the timing of the value uplift. When investigating the effect of the value uplift for current and future residents, this knowledge is essential. Arguably, this makes properties around the metro E inaccessible for the lower income segment of population. However, this only holds for the period from seven to ten years after the start of operations. Before this, no significant value uplift occurs across all zones and how the property values are affected in the long term – ten to twenty years and longer – is not clear. Further research is required to determine the exact long term effect on property values.

The difference-in-difference estimations for the years 1997 to 2005, 2007 to 2010 and 2013 to 2017 are also graphically presented below in figure 5.3. The other two time periods have been omitted because no significant results were obtained for the difference-in-differences estimate.

Timespan:
1997 to 2005

Measurement of:
Announcement

Timespan:
2007 to 2010

Measurement of:
Connection to Rotterdam

Timespan:
2013 to 2017

Measurement of:
Quality enhancements

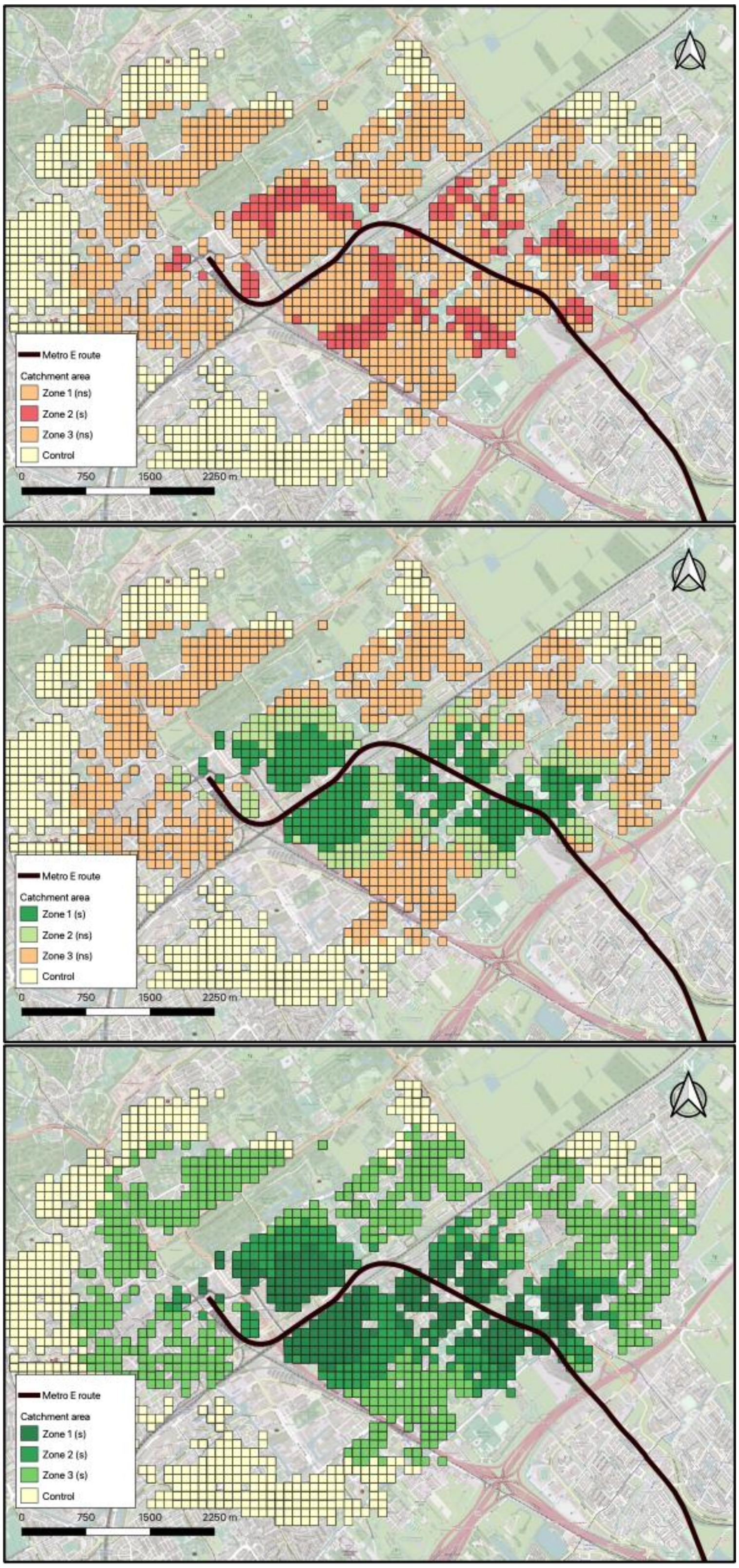

Figure 5.3: A graphical representation of the difference-in-differences estimator from hypothesis 7 using c-squares. Colors are applied given based on the coefficient

In table 5.7 below, the hypotheses and corresponding result is summarized. All hypotheses are found to not be rejected based on the evidence provided from his research. Arguably, there are a few comments to be made. First of all, whether or not a significant effect is found for hypothesis 1 highly depends on the size of the catchment area. However, by creating catchment areas through literature, the chosen sizes are considered to be properly substantiated. For hypothesis 3, there is a high correlation between the year variable and the number of passengers. However, following from the VIF test, this is not worrying. The employment figures in hypothesis 4 indicate that the effect from employment is highly dependent on the type of employment. More industries can be identified to further break down the effect – for example by introducing knowledge intensive jobs separately. Finally, the effects per subsample of the data, as divided in hypothesis 6, have a very small probability of being similar. However, the obtained results are found to differ significantly at a 5% or 1% significance level.

	Hypothesis	Rejected	Notes
1	Base effect	No	For an 800 and 1150 meter catchment area
2	Proximity effect	No	
3	Usage effect	No	High correlation with variable year
4	Employment effect	No	Effect differs per sector
5	Regional effects	No	
6	Locational effect	No	Effects only have a very small probability of being similar
7	Partial effects	No	

Table 5.7: Outcome per hypothesis, summarized.

5.2. Robustness and relevant statistical tests

In order to see whether or not the obtained results are actually robust, there are several data modifications that can be implemented. The results for these robustness checks are shown below in table 5.8 and regression A4.

First of all, 14.217 grid squares only capture 1 property for a given year. This may cause interference as outliers can influence the measured effect. To check whether this is happening, the regression is run again, only containing grid squared with 2 or more observations. The regression result for the DD estimation can be compared to the result in column 1, which shows the results discussed earlier this section. The significance for the DD estimation changes slightly, but all previous results still stand regardless.

Second, fixed effects at a grid square level can be used to control for all factors that are constant over time. The results for the fixed effects regression are shown in column 3. As expected, the coefficients for zones 1, 2 and 3 are omitted from the regression. The DD estimation shows a significant and positive effect at 1%, similar to the result obtained before.

Third, most descriptive variables for property characteristics show a right-tailed distribution. This is to be expected, as there are more properties with 2 rooms than there are with 15 rooms. This logic holds for most property characteristics, such as floors, balconies or dorms. The standard deviation, on which the significance is based, is calculated assuming a normal distribution. To approach this normal distribution, the natural logarithms can be calculated for each of these variables, after which the regression can be run again. The results for the logged regression are shown in column 4 below. Regression A4 shows which variables are logged in order to come to this result. Again, all of the coefficients are found to be similar as before. Merely the significance has dropped slightly – the DD estimation is now significant at a 5% level.

Lastly, a regression is ran without the observations linked to the central stations of Rotterdam and The Hague. Over the years, these stations undergone substantial renovation within the timespan of this research. For Rotterdam central station, renovation took place between 2010 and 2014. For The Hague, renovation occurred between 2010 and 2016. Locally, improvements to infrastructure can lead to price fluctuations. The results of the regression without these locations is found under regression 18 in table 5.8. The renovations thus have not introduced a bias into the earlier found coefficients. Based on all of the results in table 5.8, the regression output obtained for hypothesis 5 and all successive regressions are considered to be robust.

VARIABLES	(14) H5 – all obs.	(15) H5 – 2+ obs.	(16) H5 – grid square Fixed effects	(17) H5 – with logs	(18) H5 – excl. central stations
Time					
1	367.0***	305.7***	336.2***	0.234***	368.8***
	(11.51)	(13.32)	(8.620)	(0.00600)	(11.86)
Zone					
1 (~800)	93.13***	96.32***		0.0453***	100.4***
	(23.46)	(28.21)		(0.0143)	(24.23)
2 (~1150)	55.20**	60.41**		0.0266*	50.98**
	(23.75)	(28.68)		(0.0152)	(24.55)
3 (~2350)	121.6***	159.2***		0.0519***	73.79***
	(17.93)	(22.58)		(0.0104)	(18.61)
Difference-in-differences					
Zone 1 (~800)	69.98***	76.67**	90.30***	0.0365**	65.87**
	(26.83)	(31.67)	(20.42)	(0.0155)	(27.68)
Zone 2 (~1150)	7.945	40.33	33.33	0.00550	12.28
	(27.88)	(33.61)	(22.93)	(0.0167)	(28.87)
Zone 3 (~2350)	-8.904	-34.75	6.728	-0.0153	-24.88
	(20.68)	(25.82)	(17.71)	(0.0113)	(21.51)
Constant	829.3***	397.0***	944.9***	6.827***	979.0***
	(54.26)	(80.50)	(61.35)	(0.0464)	(57.10)
Observations	27,802	13,585	27,802	27,802	24,817
R-squared	0.397	0.439	0.334	0.415	0.391
Multiple zones	Yes	Yes	Yes	Yes	Yes
Property controls	Yes	Yes	Yes	Yes	Yes
Regional controls	Yes	Yes	Yes	Yes	Yes
Number of groups			9,622		

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5.8: Alternative regression formats for hypothesis 5.

A VIF test has quickly passed in section 5.1, at the discussion of hypothesis 3. A complete overview of the result of this VIF test is shown below in table 5.9. A complete overview is given because of the expectation that multicollinearity between variables is to be anticipated. It is likely that some property characteristics are correlated to each other, for example the maintenance score of a property on the inside and outside.

Variable	VIF	Variable	VIF
Time 1	2.06	Category	3.97
Zone 1	4.09	Build period 1945 – 1990	1.47
2	3.77	Build period 1991 – now	2.56
3	3.81	Isolation	2.11
DD zone 1	4.00	Maintenance inside	2.23
2	3.77	Maintenance outside	2.26
3	3.99	House view	1.14
Passengers	1.44	Garden	1.95
Jobs education	1.01	Heating	1.06

(table continues on next page)

Jobs hospitality	1.04	Attic	1.07
Jobs other	1.08	Loft	1.2
Distance highway	1.39	Parking	1.28
Distance park	4.48	Number of rooms	2.21
Distance large park	4.11	Number of floors	3.95
High quality PT	1.53	Number of balconies	1.32
Regular PT	1.60	Number of dorms	1.18
Mean VIF	2.32		

Table 5.9: The VIF score for all variables included in hypothesis 5.

5.3. Remarks in regard to the theory

The results shown above are still exposed to some effects mentioned in the theory section. For instance, what part of the effect is actually caused by network effects? And how does gentrification affect the results, as this is not accounted for within the result. The next section discusses these aspects with regard to the results, based on literature.

First of all, there are geographical elements that are not taken into account within the model. Both Rotterdam and The Hague have a unique geographical urban structure (Nabielek, & Hamers, 2015). In Rotterdam, Originally, the port of Rotterdam was located within the city, but in recent decades, the port and city have separated slowly. The northern part of the city has been more successful in maintaining and attracting (port related) knowledge intensive firms. Because of this, there is a difference between residents of the northern and southern part of the city. The majority of the southern part is made up from social-rented properties, while the northern part is relatively wealthy. Besides the physical separation, the river Maas, this creates an even bigger social gap between inhabitants of both regions (Doucet, 2010). For the Hague, there is a historical division between properties built on sand or peat, where the upper part of society was generally living on sand grounds, also creating social distance. This is still clearly visible when looking at income levels in the city (Nabielek, & Hamers, 2015).

The property value uplift is said to be because of two reasons, both the network effect and the transport system itself (Mulley et al., 2017). It is difficult to determine the exact contribution of each of these two effects. For example, the central station of Rotterdam has been renovated completely. Together with this change, the local government has greatly invested in the surrounding area. The result is a successful transition of a lagging neighborhood to a prominent area within the city. The network effect represents the added value through connectivity that the line has to offer. In table 5.8, the regression is performed without the Rotterdam Central Station. The results show that the effect measured before remains, indicating it was not biased by the renovation of the station.

Furthermore, the gentrification aspect of the cities Rotterdam and The Hague is not yet properly reviewed. To include this in the model, additional variables are required to proxy for gentrification. As suggested by Glass (1964), this could be neighborhood characteristics that describe whether or not a neighborhood is vulnerable to gentrification, or distinctive social traits of the residents. However, the cities Rotterdam and The Hague are expected to face limited influence from gentrification trends. This follows from a research into the changing social geographies in the Randstad between 2007 and 2015 (Musterd et al., 2020). This research argues that for the region Rotterdam and The Hague, the neighborhoods alongside the city centers is mostly made up from the lower income segment. More wealthy neighborhoods are found to be situated at six to ten kilometers from the city center. This could also be related to the historical geographical layout as mentioned before. It can thus be concluded that sorting of individuals based on their characteristics – income for example – has not changed significantly over time in the area of interest.

6. Conclusion

Over the course of fourteen years, from 2000 to 2014, cities such as The Hague, Amsterdam and Utrecht have seen increases in population of over 60.000, and – within the Netherlands – the share of residents living in cities is expected to increase with 6.7 percent to 8 million in 2040. This shift emphasizes the importance of fast and reliable transportation, especially in highly urban areas. The proposed mode of transport: public transportation. This research has estimated the effect of a high-quality light rail on property values in the province of South Holland, the Netherlands by investigating the metro E. This metro line connects Rotterdam and The Hague through suburban areas.

There are four fundamental theories regarding urban spatial structures that formed the basis of this research. The monocentric city model from Alonso (1964) forms the starting point. Polycentric structures introduced by Howard (1946) were further developed within the central place theory by Christaller (1933, 1966) and Lösch (1944, 1954). A more recent addition to the literature of these aggregated models is the daily time-space prism by Hägerstrand (1970), including individual characteristics. At last, human commuting behavior in reviewed in the form of the constant travel time by Hupkes (1982).

The residential value uplift has been researched thoroughly in the past decades. Most of these researches have used the difference-in-differences method to determine an effect. There seems to be a general consensus that public transportation increases property values.

The research introduced seven hypotheses. The first five hypotheses gradually add components to the model. For example, public transport may also influence property values indirectly via employment, rather than direct. Hypotheses six and seven aim to break down the complete model to gain a better understanding of the obtained effect. The obtained effect may increase or decrease with the relative importance of public transport in the area. It is important to realize that all connectivity within a region also introduces the exchange of information – spillover effects. Combining the literature and hypotheses, the main research question that is answered holds:

What is the effect from high quality public transportation on residential property values?

The method used to answer this question is a difference-in-differences (DD) method. This method is widely used and considered to be one of the most important strategies to determine effects (2012). This methodology is used in conjunction with c-squares – concise spatial query and representation systems. Alternative methods to the DD method are the CITS and ITS method (comparative interrupted time series and simple interrupted time series). A further development of the DD method is the difference-in-difference-in-differences (DDD) method. Lastly, the multilevel regression poses an alternative to the use of the DD method. The DD method was preferred over the alternatives because of the additional data requirements of the alternatives.

The determination of the control group was also found to be of importance. For this research, a distance based method is chosen over matching or the creation of a synthetic control. Within distance based methods, a simple and advanced form exist. The simplified form uses linear distances, whereas the advanced form used the road network to calculate distanced. Within this research, the latter is used for most distance calculations.

There are three institutions from which the majority of the data is obtained. Residential property data is obtained from the NVM, a cooperation of Dutch estate agents and appraisers. The employment data is obtained from LISA, the main employment register for the Netherlands. And lastly, there are several data layers that were obtained from the Province of Zuid-Holland (PZH). The years included in the analysis are 1997, 2005, 2007, 2010, 2013 and 2017. These years were chosen based on historical events associated with the metro E. The revised dataset contains 158.702 residential properties, distributed over 27.802 grid squares. Of these grid squares, there are 13.812 unique observations, as some grid squares appear in multiple years. The data is modified with the use of GIS (geographical information system) and STATA.

The results are presented per hypothesis and in conjunction answer the research question. The base effect from hypothesis one indicates that properties in general have indeed become more expensive over time. This general trend is important to identify and the outcome is unsurprising, given yearly inflation rates. Noticeable results are observed for the loft variable, as the presence of a loft is found to have a negative effect on the property value. This contradictory result may be explained because of data distribution, as almost 88 percent of all observations do not have a loft. The controls isolation, presence of a garden and heating are not found to have a significant effect on the property price. This is surprising as they were expected to have a positive effect. Possibly, the effect is already absorbed by other property characteristics in the model. The result obtained for the DD estimator is highly dependent on the size of the catchment area. In conclusion, however, the hypothesis is not rejected.

Hypothesis two distinguishes three zones within the maximum catchment area: respectively 0 to 800 meter, 800 to 1150 meter and 1150 to 2350 meter. A positive and significant result is solely found for the smallest catchment area (zone 1). Zone 1 significantly differs from the control as well as the bigger catchment areas.

Hypothesis 3 introduces passenger counts into the model. This does not change any of the previously found coefficients or significances. The passenger count itself is found to be significant and positive, however it is highly correlated to the year variables. This means that it may be over-estimated because it may partially take over the time effect.

Hypothesis 4 introduces employment data into the model. Property values may be positively influenced due to a lower supply of residential properties – shops and offices take up physical space – and the presence of retail and restaurants and bars nearby are thought to be favorable. Surprisingly, education is not found to have a significant effect on the property prices. This may be due to the widespread and even distribution of schools across the region. Retail and catering, as expected, is found to be positively associated to property values.

Hypothesis 5 completes the model by introducing regional controls. Including controls for the distance to highways, recreational green zones and availability of other forms of public transportation does not change the significance of any of the DD estimators from hypothesis 4. For highways and green zones, the coefficient is negative. This means that the larger the distance between a property and a highway or green zone, the higher the property value. This is logical for the highway variable because of the negative externalities that may be experienced. However, for the green zone variable, this is the opposite of what was expected. The negative coefficient for parks can be explained by another regional control: large green zones. The coefficient for large green zone is negative, which means that the closer a property is located to the park, the higher the value. The most striking observation from the regional controls is found for the accessibility of other high quality public transportation, which is found to be negative. Possibly, city planning is the cause of this result. Both Rotterdam and The Hague have a classical distribution of residents, where the wealthier residents live on the edge of the city and the poor residents live in neighborhoods around the city center. However, most high quality public transportation, such as trains, are present in the city centers. This inverse geographical relation may have led to the observed result.

Hypothesis 6 divides the complete dataset in three categories based on the location of the station. The station is either located in highly urban environments, urban environments or suburban environments. All subsamples are compared to the same control area, which consists out of a mixture of all these environments. For suburban and highly urban environments, a positive and significant effect is found in zones 1 and 2 (between 0 to 1150 meter). For urban environments, a negative and significant effect is found for zones 2 and 3. These negative coefficients are surprising, but can be explained. Five out of the seven stations that are taken into account for the urban environment are situated in the southern part of Rotterdam. This neighborhood is lagging behind compared to the northern, more wealthy part of Rotterdam. However, the most important observation to make is that in each of the subsamples, zone 1 has increased in price the most (or had the smallest decrease), followed by zone 2 and then zone 3 compared to the control area.

Hypothesis 7 divides the complete dataset over time rather than distance. There are five time periods to distinguish. The time variable, as discussed previously, is expected to be positive due to constant inflation. However, for the time period 2007 to 2010 and 2010 tot 2013, it is found to be negative. This means that the general trend for property prices was decreasing at that time. This makes sense given the global financial crisis, which was followed by the European debt crisis. For the time period 1997 to 2005, a significant and negative price decrease relative to the control is observed for zone 2. No causes for this significant decrease can be derived from the model. A similar increase is obtained for zone 1 in the time period 2007 to 2010. This increase may be due to the new connection to Rotterdam Central Station; however, it is unclear why this effect does not affect zone 2 and 3. For the period 2013 to 2017, a positive and significant effect is found for all three zones. This coincides with increased capacity during the rush hour and the opening of two renovated stations: The Hague and Rotterdam central station. The positive effect is also found to be largest in zone 1, followed by zone 2 and then zone 3.

To be certain that the obtained results are robust, the regression analysis is repeatedly performed under different circumstances. First, the analysis is ran only containing grid squares with two or more observations. Second, fixed effects are implemented to account for all unobserved factors that stay constant over time. Third, natural logarithms are introduced to estimate the standard errors more accurately. Lastly, the analysis is performed without the central stations Rotterdam and The Hague because of the renovation of these stations. For all analyses, a similar result is found for the DD estimations, which is positive and significant for zone 1, and not significant for zones 2 and 3.

Recommendations for future research mainly relate to the methodology. First of all, a more complex method can be used, such as the CITS, to more accurately take time trends into account. Second, the use of a higher order fixed effect can be implemented to account for regional characteristics. The main example is presented in Rotterdam. The southern part of the city is considerably less wealthy, which is assumed to interfere with the coefficients for the results for urban environments found under hypothesis 6. Alternatively, as this research is written during a period in which covid-19 is greatly affecting daily commuting behavior, further research could focus on how this influences the established effects within this research.

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8. Appendix

8.1. Appendix A: Regression results

VARIABLES	(1) H1	(2) H2	(3) H3	(4) H4
Time				
1	509.2***	509.1***	365.6***	365.0***
	(11.22)	(11.22)	(12.23)	(12.20)
Zone				
1 (~800)		34.43	33.37	19.42
		(22.41)	(22.38)	(22.35)
2 (~1150)		21.90	21.52	8.668
		(23.50)	(23.45)	(23.51)
3 (~2350)	60.31***	85.83***	85.23***	73.74***
	(14.31)	(18.21)	(18.18)	(18.14)
Difference-in-differences				
Zone 1 (~800)		72.01***	70.28***	70.44***
		(26.71)	(26.42)	(26.27)
Zone 2 (~1150)		1.974	4.146	3.835
		(28.29)	(27.96)	(27.94)
Zone 3 (~2350)	11.44	-14.56	-12.50	-11.65
	(17.01)	(21.52)	(21.38)	(21.27)
Passengers			0.00874***	0.00865***
			(0.000336)	(0.000334)
Employment				
Education				0.322
				(0.513)
Retail and catering				1.006***
				(0.232)
Other				0.671***
				(0.0773)
Property controls				
Category	-350.3***	-350.9***	-346.8***	-365.5***
	(19.17)	(19.17)	(19.07)	(19.13)
1945 ≥ Build period ≥ 1990	-151.2***	-150.3***	-149.4***	-147.3***
	(9.600)	(9.627)	(9.519)	(9.489)
Build period ≥1991	-44.72***	-44.70***	-51.95***	-52.96***
	(14.89)	(14.90)	(14.75)	(14.70)
Isolation	1.844	2.004	-1.024	-0.979
	(3.424)	(3.424)	(3.395)	(3.385)
Maintenance inside	105.7***	105.7***	107.6***	106.5***
	(5.928)	(5.925)	(5.882)	(5.872)
Maintenance outside	28.18***	27.91***	36.40***	36.01***
	(7.904)	(7.898)	(7.901)	(7.873)
House view	238.4***	238.2***	236.6***	239.8***
	(10.35)	(10.34)	(10.23)	(10.20)
Garden	17.34	17.37	21.99	25.64*
	(14.51)	(14.51)	(14.41)	(14.39)

(table continues on next page)

Heating	15.76	15.66	-1.299	1.591
	(23.64)	(23.62)	(23.57)	(23.51)
Attic	93.59***	94.77***	97.95***	100.6***
	(24.98)	(24.97)	(24.71)	(24.69)
Loft	-36.95**	-36.78**	-9.462	-7.921
	(16.26)	(16.26)	(16.18)	(16.17)
Parking	422.9***	422.7***	412.2***	407.0***
	(13.11)	(13.11)	(13.06)	(13.04)
Number of rooms	77.82***	77.74***	76.49***	76.04***
	(4.544)	(4.546)	(4.507)	(4.501)
Number of floors	-101.5***	-101.8***	-99.84***	-100.8***
	(9.384)	(9.385)	(9.321)	(9.311)
Number of balconies	104.2***	103.7***	103.3***	104.4***
	(10.07)	(10.07)	(9.953)	(9.932)
Number of dorms	58.35***	58.93***	47.17***	50.36***
	(14.76)	(14.76)	(14.52)	(14.50)
Constant	578.5***	581.8***	466.4***	474.7***
	(55.02)	(54.98)	(55.20)	(55.07)
Observations	27,802	27,802	27,802	27,802
R-squared	0.309	0.310	0.327	0.333
Multiple zones	No	Yes	Yes	Yes
Property controls	Yes	Yes	Yes	Yes
Regional controls	No	No	No	No

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A1: The complete regression result for hypotheses 1 to 4.

VARIABLES	(5) H5	(6) H6a suburban	(7) H6b urban	(8) H6c Highly urban
Time				
1	367.0***	389.1***	372.4***	369.8***
	(11.51)	(12.37)	(12.34)	(12.42)
Zone				
1 (~800)	93.13***	107.6**	182.6***	420.3***
	(23.46)	(42.74)	(30.46)	(57.36)
2 (~1150)	55.20**	51.33	88.74**	397.4***
	(23.75)	(34.12)	(36.36)	(53.56)
3 (~2350)	121.6***	69.30***	67.39**	305.0***
	(17.93)	(25.14)	(28.06)	(32.79)
Difference-in-differences				
Zone 1 (~800)	69.98***	117.5**	-4.799	280.3***
	(26.83)	(47.72)	(34.22)	(65.77)
Zone 2 (~1150)	7.945	80.77**	-76.04*	132.6**
	(27.88)	(39.57)	(41.14)	(62.49)
Zone 3 (~2350)	-8.904	8.616	-77.67**	51.54
	(20.68)	(28.73)	(31.82)	(37.08)
Passengers	0.00876***	0.00737***	0.00757***	0.00847***
	(0.000315)	(0.000362)	(0.000367)	(0.000384)
Employment				
Education	0.812*	1.248	0.927	0.473
	(0.453)	(0.779)	(0.590)	(0.510)
Retail and catering	0.716***	0.456*	-0.274	0.408
	(0.218)	(0.254)	(0.277)	(0.261)
Other	0.578***	0.240**	0.609***	0.332***
	(0.0686)	(0.121)	(0.110)	(0.0619)
Regional controls				
Distance highway	0.0312***	0.0245***	0.0391***	0.0477***
	(0.00212)	(0.00236)	(0.00246)	(0.00258)
Distance park	0.105***	0.110***	0.0956***	0.0922***
	(0.00626)	(0.00744)	(0.00653)	(0.00723)
Distance large park	-0.251***	-0.259***	-0.228***	-0.275***
	(0.00553)	(0.00675)	(0.00568)	(0.00633)
Number of high quality PT	-5.845***	-47.87***	-20.90***	-27.41***
	(1.160)	(2.102)	(1.745)	(1.586)
Number of regular PT	6.715***	37.79***	0.886	26.40***
	(1.423)	(2.377)	(1.672)	(2.196)
Property controls				
Category	-356.0***	-411.5***	-363.4***	-333.3***
	(18.11)	(22.43)	(22.14)	(22.77)
1945 ≥ Build period ≥ 1990	-144.8***	-209.7***	-114.4***	-127.0***
	(9.329)	(11.82)	(11.27)	(12.12)
Build period ≥1991	-32.52**	-73.12***	-9.289	-1.117
	(14.32)	(16.83)	(17.22)	(17.72)
Isolation	6.503**	6.570*	6.943*	8.283**
	(3.273)	(3.596)	(3.910)	(4.062)

(table continues on next page)

Maintenance inside	97.49***	93.94***	84.36***	98.78***
	(5.546)	(7.149)	(6.879)	(6.881)
Maintenance outside	30.62***	16.87*	28.48***	21.22**
	(7.521)	(9.319)	(9.284)	(9.405)
House view	222.4***	235.9***	223.7***	198.7***
	(9.717)	(11.36)	(11.73)	(12.19)
Garden	-8.900	-81.04***	-14.22	-15.70
	(13.77)	(16.90)	(16.52)	(17.01)
Heating	-14.13	-26.26	2.866	-24.31
	(22.52)	(27.18)	(26.54)	(29.31)
Attic	105.9***	99.73***	122.0***	124.3***
	(23.83)	(26.35)	(29.66)	(32.40)
Loft	2.511	-17.54	34.70*	-20.83
	(15.49)	(16.54)	(19.59)	(20.60)
Parking	362.5***	354.6***	348.1***	359.4***
	(12.50)	(13.09)	(14.99)	(15.94)
Number of rooms	40.13***	41.20***	40.46***	22.29***
	(4.233)	(5.057)	(5.174)	(5.039)
Number of floors	-60.68***	-64.53***	-66.83***	-19.63*
	(8.945)	(10.85)	(10.96)	(11.31)
Number of balconies	95.43***	78.10***	85.64***	95.00***
	(9.389)	(11.55)	(11.22)	(11.70)
Number of dorms	46.77***	58.61***	69.00***	51.80***
	(13.92)	(14.62)	(17.68)	(18.51)
Constant	829.3***	1,065***	940.3***	854.3***
	(54.26)	(65.73)	(65.21)	(67.18)
Observations	27,802	19,005	18,607	18,170
R-squared	0.397	0.417	0.407	0.433
Multiple zones	Yes	Yes	Yes	Yes
Property controls	Yes	Yes	Yes	Yes
Regional controls	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A2: The complete regression results for hypotheses 5 and 6.

VARIABLES	(9) H7a 1997-2005 Announcement	(10) H7b 2005-2007 Opening	(11) H7c 2007-2010 Rotterdam	(12) H7d 2010-2013 Slinge	(13) H7e 2013-2017 Quality
Time					
1	903.5***	166.3***	-37.13***	-191.2***	577.6***
	(13.73)	(13.63)	(14.02)	(14.43)	(15.05)
Zone					
1 (~800)	91.99***	108.6***	92.43***	196.7***	142.0***
	(20.65)	(25.09)	(25.11)	(24.41)	(25.89)
2 (~1150)	85.92***	30.16	49.68**	46.68*	53.24**
	(21.70)	(23.37)	(24.60)	(27.26)	(26.99)
3 (~2350)	98.54***	103.8***	101.2***	90.65***	110.6***
	(20.07)	(17.95)	(19.08)	(20.29)	(20.52)
Difference-in-differences					
Zone 1 (~800)	-25.22	-27.42	118.9***	-46.05	166.1***
	(29.91)	(33.70)	(33.60)	(34.08)	(38.17)
Zone 2 (~1150)	-91.67***	7.307	10.96	-2.766	110.1***
	(30.66)	(33.03)	(36.10)	(37.28)	(40.67)
Zone 3 (~2350)	-21.51	-12.30	-8.114	11.01	80.55***
	(26.23)	(25.58)	(27.28)	(27.89)	(28.84)
Employment					
Education	0.266	0.173	-0.190	0.107	1.394*
	(0.596)	(0.521)	(0.542)	(0.636)	(0.746)
Retail and catering	0.687**	0.875***	0.686**	0.441	0.666**
	(0.325)	(0.329)	(0.335)	(0.302)	(0.310)
Other	0.365***	0.656***	0.612***	0.440***	0.598***
	(0.0777)	(0.106)	(0.133)	(0.105)	(0.106)
Regional controls					
Distance highway	0.0157***	0.0296***	0.0343***	0.0289***	0.0278***
	(0.00290)	(0.00305)	(0.00316)	(0.00322)	(0.00345)
Distance park	0.0692***	0.109***	0.109***	0.103***	0.131***
	(0.00897)	(0.00876)	(0.00920)	(0.00989)	(0.0101)
Distance large park	-0.196***	-0.267***	-0.277***	-0.253***	-0.288***
	(0.00773)	(0.00788)	(0.00818)	(0.00853)	(0.00880)
Number of high quality PT	-13.28***	-15.55***	-12.25***	-7.845***	4.717**
	(1.748)	(1.470)	(1.597)	(1.729)	(2.036)
Number of regular PT	9.892***	9.948***	9.750***	7.438***	-3.631
	(2.092)	(1.952)	(2.139)	(2.257)	(2.336)
Property controls					
Category	-288.2***	-388.6***	-378.8***	-368.5***	-422.9***
	(25.30)	(27.72)	(28.79)	(28.83)	(29.55)
1945 ≥ Build period ≥ 1990	-71.35***	-136.7***	-147.6***	-170.5***	-274.6***
	(12.73)	(13.18)	(13.74)	(14.28)	(15.85)
Build period ≥1991	4.218	-65.68***	-65.13***	-97.39***	-238.3***
	(20.03)	(21.35)	(23.54)	(22.03)	(22.11)
Isolation	-6.760	-10.98**	-13.13**	-0.351	11.07**
	(5.044)	(4.629)	(5.263)	(4.956)	(5.127)
Maintenance inside	72.45***	106.3***	109.6***	98.59***	95.06***
	(9.135)	(9.834)	(8.584)	(7.342)	(7.871)

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Maintenance outside	33.55***	37.02***	31.11**	41.31***	90.60***
	(11.00)	(13.66)	(12.53)	(11.83)	(11.65)
House view	124.2***	135.3***	137.3***	115.9***	127.4***
	(18.44)	(14.40)	(14.17)	(14.02)	(15.07)
Garden	-12.46	-27.53	6.713	54.80**	27.01
	(20.54)	(21.58)	(22.44)	(21.71)	(21.24)
Heating	-26.39	-33.41	12.78	61.00*	17.85
	(41.85)	(36.14)	(32.60)	(31.34)	(33.85)
Attic	46.06*	95.08***	156.7***	139.9***	182.8***
	(27.54)	(34.71)	(41.98)	(43.04)	(40.21)
Loft	28.69	-5.678	-41.53*	-26.54	0.156
	(23.66)	(22.07)	(22.29)	(23.81)	(27.82)
Parking	361.8***	445.9***	442.6***	404.3***	407.6***
	(19.42)	(20.02)	(20.61)	(18.94)	(18.56)
Number of rooms	27.59***	42.87***	47.08***	43.19***	63.99***
	(6.250)	(6.553)	(6.673)	(6.839)	(7.083)
Number of floors	-70.59***	-100.8***	-85.69***	-94.96***	-131.3***
	(11.12)	(13.47)	(14.88)	(15.59)	(15.35)
Number of balconies	7.596	22.89	13.55	-2.878	4.374
	(14.16)	(14.76)	(14.83)	(14.39)	(14.89)
Number of dorms	11.48	0.600	-8.123	30.71	35.55
	(21.48)	(20.92)	(21.17)	(21.40)	(22.19)
Constant	601.2***	1,333***	1,409***	1,337***	948.1***
	(80.69)	(87.83)	(91.17)	(92.09)	(85.24)
Observations	8,077	10,710	10,083	8,547	9,642
R-squared	0.582	0.387	0.387	0.404	0.475
Multiple zones	Yes	Yes	Yes	Yes	Yes
Property controls	Yes	Yes	Yes	Yes	Yes
Regional controls	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A3: The complete regression output for hypothesis 7.

VARIABLES	(14) H5 – all obs.	(15) H5 – 2+ obs.	(16) H5 – Grid square Fixed effects	(17) H5 – with logs	(18) H5 – excl. central stations
Time					
1	367.0***	305.7***	336.2***	0.234***	368.8***
	(11.51)	(13.32)	(8.620)	(0.00600)	(11.86)
Zone					
1 (~800)	93.13***	96.32***		0.0453***	100.4***
	(23.46)	(28.21)		(0.0143)	(24.23)
2 (~1150)	55.20**	60.41**		0.0266*	50.98**
	(23.75)	(28.68)		(0.0152)	(24.55)
3 (~2350)	121.6***	159.2***		0.0519***	73.79***
	(17.93)	(22.58)		(0.0104)	(18.61)
Difference-in-differences					
Zone 1 (~800)	69.98***	76.67**	90.30***	0.0365**	65.87**
	(26.83)	(31.67)	(20.42)	(0.0155)	(27.68)
Zone 2 (~1150)	7.945	40.33	33.33	0.00550	12.28
	(27.88)	(33.61)	(22.93)	(0.0167)	(28.87)
Zone 3 (~2350)	-8.904	-34.75	6.728	-0.0153	-24.88
	(20.68)	(25.82)	(17.71)	(0.0113)	(21.51)
Passengers (log)	0.00876***	0.00973***	0.00873***	0.0578***	0.00839***
	(0.000315)	(0.000382)	(0.000228)	(0.00270)	(0.000326)
Employment					
Education (log)	0.812*	0.470	3.223***	-0.00390	1.014*
	(0.453)	(0.524)	(1.082)	(0.00301)	(0.558)
Retail and catering (log)	0.716***	0.756***	-0.442	-0.00607***	0.547**
	(0.218)	(0.249)	(0.849)	(0.00220)	(0.233)
Other (log)	0.578***	0.664***	0.181	0.0236***	0.690***
	(0.0686)	(0.113)	(0.130)	(0.00153)	(0.114)
Regional controls					
Distance highway (log)	0.0312***	0.0355***		0.0181***	0.0224***
	(0.00212)	(0.00263)		(0.00202)	(0.00217)
Distance park (log)	0.105***	0.118***		0.0532***	0.112***
	(0.00626)	(0.00751)		(0.00491)	(0.00633)
Distance large park (log)	-0.251***	-0.244***		-0.148***	-0.236***
	(0.00553)	(0.00646)		(0.00472)	(0.00562)
Number of high quality PT (log)	-5.845***	-0.983		-0.0293***	-9.328***
	(1.160)	(1.414)		(0.00266)	(1.525)
Number of regular PT (log)	6.715***	7.534***		0.0269***	-0.480
	(1.423)	(1.835)		(0.00327)	(1.439)
Property controls					
Category	-356.0***	-210.6***	-203.6***	-0.167***	-385.9***
	(18.11)	(25.08)	(26.76)	(0.00825)	(19.33)
1945 ≥ Build period ≥ 1990	-144.8***	-104.4***	125.0***	-0.0248***	-156.7***
	(9.329)	(11.68)	(18.92)	(0.00451)	(9.712)
Build period ≥1991	-32.52**	-36.48*	228.9***	0.0387***	-41.10***
	(14.32)	(20.77)	(31.35)	(0.00640)	(14.90)
Isolation	6.503**	26.88***	23.26***	0.00375***	5.814*
	(3.273)	(5.333)	(3.270)	(0.00145)	(3.342)

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Maintenance inside	97.49***	104.1***	91.92***	0.0528***	89.06***
	(5.546)	(7.574)	(5.542)	(0.00274)	(5.976)
Maintenance outside	30.62***	45.68***	-7.045	0.0101***	28.58***
	(7.521)	(10.83)	(7.515)	(0.00377)	(7.997)
House view	222.4***	231.5***	170.5***	0.123***	233.6***
	(9.717)	(13.84)	(10.69)	(0.00431)	(10.11)
Garden	-8.900	116.7***	103.2***	0.0101*	-39.38***
	(13.77)	(21.02)	(13.96)	(0.00598)	(14.57)
Heating	-14.13	-90.18***	-7.779	0.0290**	0.664
	(22.52)	(32.71)	(21.02)	(0.0113)	(22.99)
Attic	105.9***	70.96*	-9.720	0.0353***	111.6***
	(23.83)	(40.35)	(25.13)	(0.0104)	(24.35)
Loft	2.511	-11.34	16.25	-0.00279	19.43
	(15.49)	(27.46)	(16.19)	(0.00715)	(15.72)
Parking	362.5***	344.9***	104.6***	0.143***	357.8***
	(12.50)	(19.52)	(16.73)	(0.00521)	(12.44)
Number of rooms (log)	40.13***	31.31***	-24.80***	0.0196**	45.41***
	(4.233)	(6.018)	(5.241)	(0.00852)	(4.555)
Number of floors (log)	-60.68***	19.37	1.127	-0.0179**	-84.06***
	(8.945)	(12.21)	(11.69)	(0.00766)	(9.420)
Number of balconies (log)	95.43***	142.8***	109.7***	-0.0511***	87.16***
	(9.389)	(13.42)	(9.888)	(0.00505)	(9.913)
Number of dorms (log)	46.77***	17.85	33.98**	-0.0504***	62.14***
	(13.92)	(24.77)	(14.74)	(0.00539)	(14.11)
Constant	829.3***	397.0***	944.9***	6.827***	979.0***
	(54.26)	(80.50)	(61.35)	(0.0464)	(57.10)
Observations	27,802	13,585	27,802	27,802	24,817
R-squared	0.397	0.439	0.334	0.415	0.391
Multiple zones	Yes	Yes	Yes	Yes	Yes
Property controls	Yes	Yes	Yes	Yes	Yes
Regional controls	Yes	Yes	Yes	Yes	Yes
Number of groups			9,622		

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A4: Alternative regression options adopted into the model. All variables where (log) is noted are only logged in regression number 17.

8.2. Appendix B: Tables

Tabel 3.1 Variabelen ter verklaring van de reële huizenprijsontwikkeling in Nederland[a]

	Van Els en Vlaar (1996), MORKMON-III	De Vries en Boelhouwer (2004)	PwC (2004)	OESO (2004)	Brounen en Huij (2004)
Instituut	DNB	OTB	PwC	OESO	EUR
Korte-termijnvergelijking					
Reëel beschikbaar inkomen		X	X	X	
Reële (hypotheek)rente		X	X	X	X
Historische huizenprijsontwikkeling		X	X		
Reëel financieel gezinsvermogen				X	
Werkloosheid					X
Woningvoorraad, volume				X	
Reële investeringsprijs van woningen	X				
Krapte op de woningmarkt					X
Rendement aandelenbeurs					X
Seizoen	X	X			X
Afwijking lange-termijnniveau (ecm)	X	X	X	X	
Lange-termijnvergelijking					
Netto-rentelastenquote		X			
Reëel beschikbaar inkomen	X		X	X	
Reële rente	X		X	X	
Reële huurprijs	X				
Woningvoorraad, volume				X	
Reëel gezinsvermogen				X	
Tijdsbasis	Kwartaal	Halfjaar	Kwartaal	Jaar	Kwartaal
Steekproefperiode	1980-1993	1975-2002	1970-2003	1970-2002	1985-2003
Verklaringsgraad (R^2)	0,84	0,75 en 0,76	n.b.	0,76	0,73

[a] Brounen en Huij (2004) verklaren de *nominale* huizenprijsontwikkeling.

Table B1: Explanatory variables used in previous research investigating the development of house prices (Kranendonk, van Leuvensteijn, Toet, & Verbruggen, 2005).

Sector 1 (education)		**Sector 2 (retail and catering)**		**Sector 0 (other)***	
Subsector name	**LISA-ID**	**Subsector name**	**LISA-ID**	**Subsector name**	**LISA-ID**
(Special) primary education	8520	Retail	471, 472, 474, 475, 476, 477, 478		
Secondary education (vmbo, havo, vwo)	8531	catering	5610, 5630		

*Table B2: Configuration of the sector variable created from the LISA dataset. *The sector ‘other’ includes all subsectors except those assigned to sector 1 or 2.*

8.3. Appendix C: Figures.

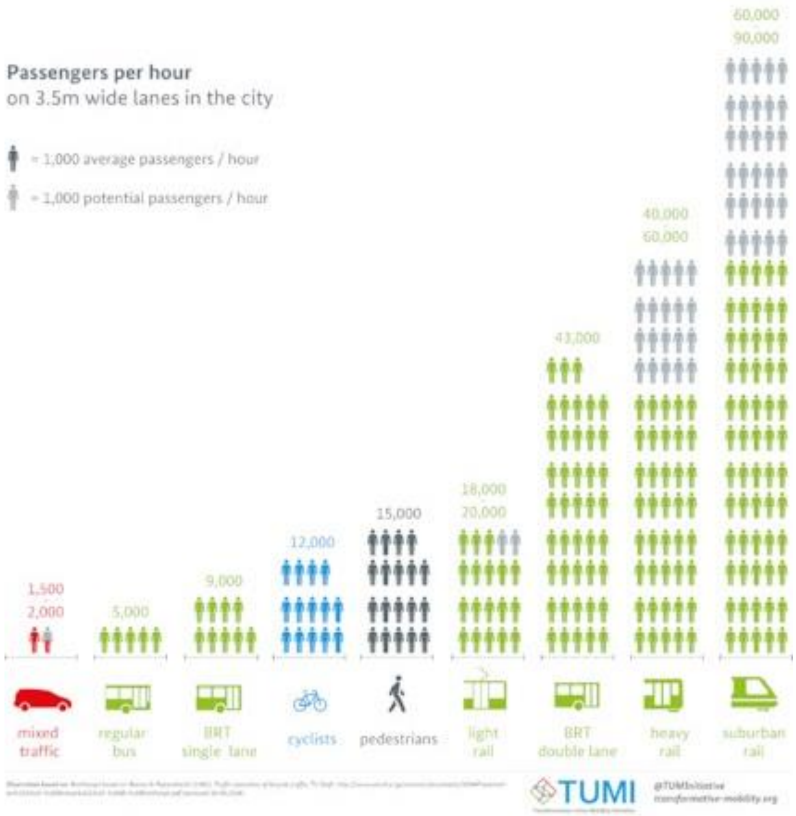

Figure C1: The passenger capacity of different transport modes (Botma & Papendrecht, 1991).

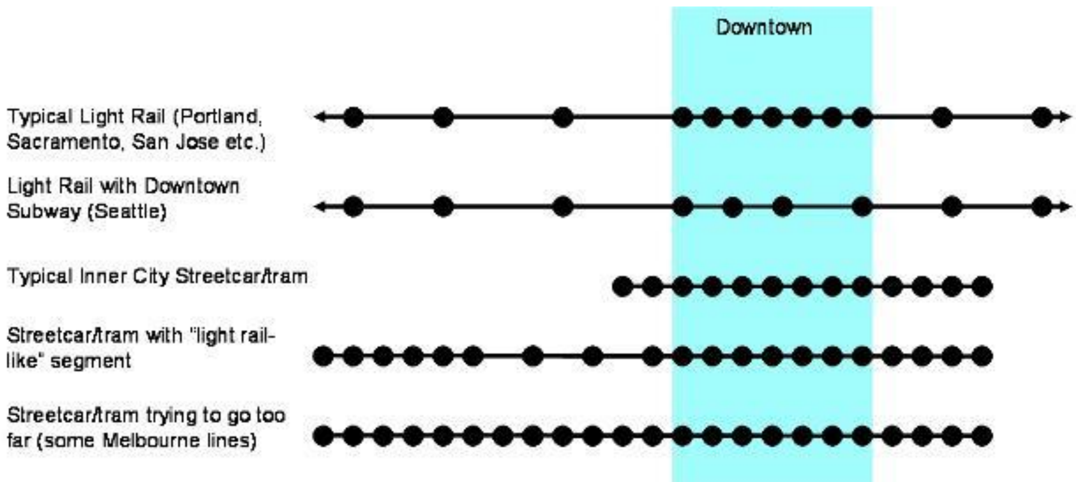

Figure C2: Public transportation structures (Walker, 2010).

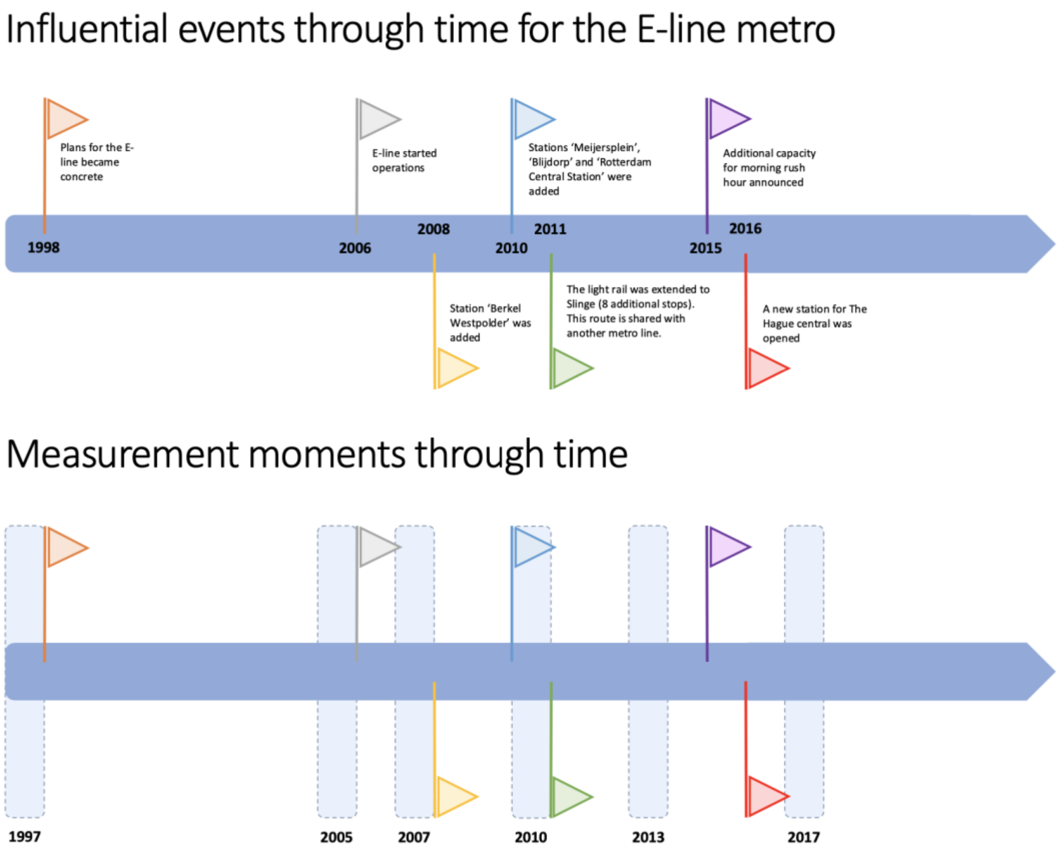

Figure C3: A timeline of main events, which form the basis of the years chosen for the analysis.

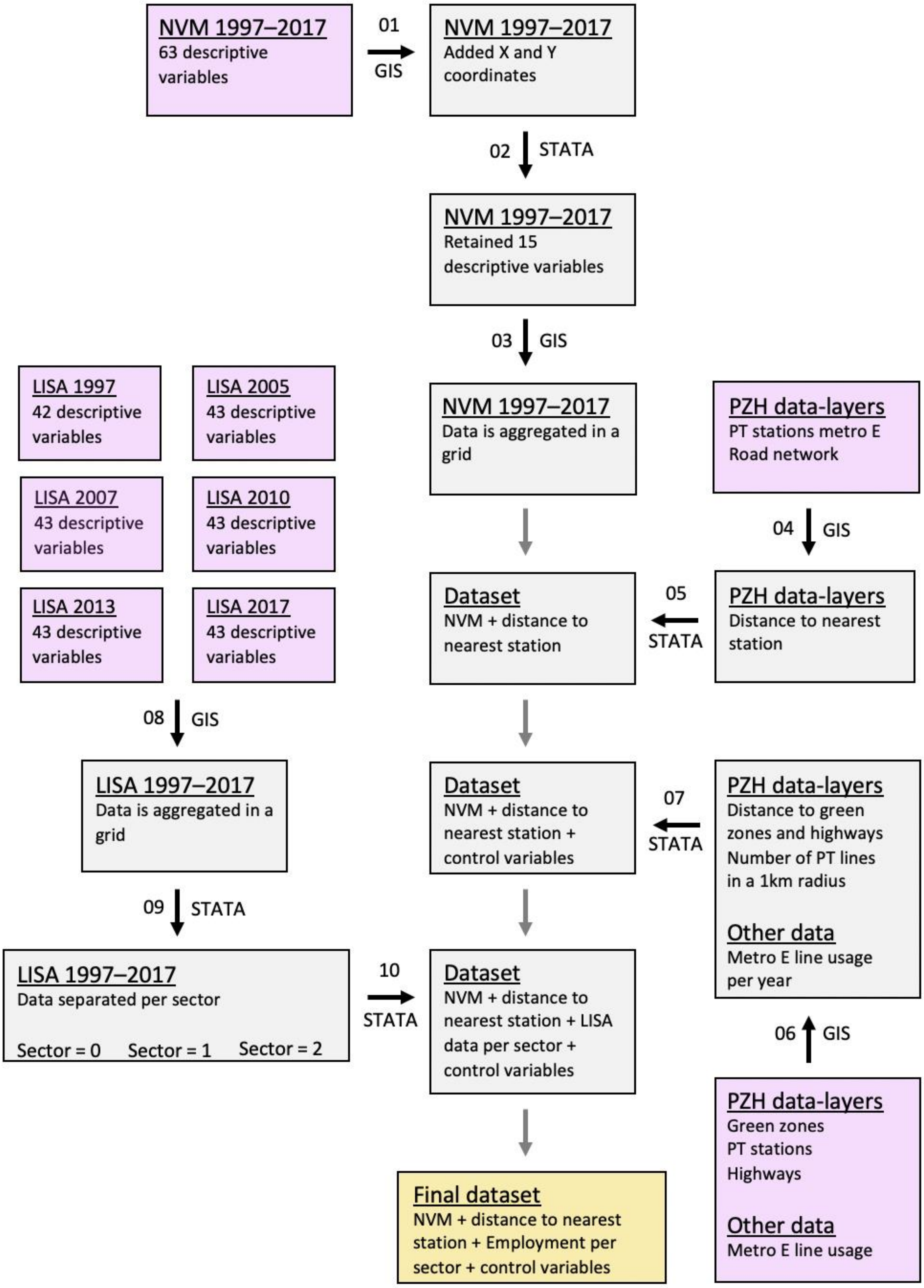

Figure C4: The data flow chart. Purple boxes reflect obtained datasets, grey boxes are intermediate datasets, and the final dataset is shown in yellow.

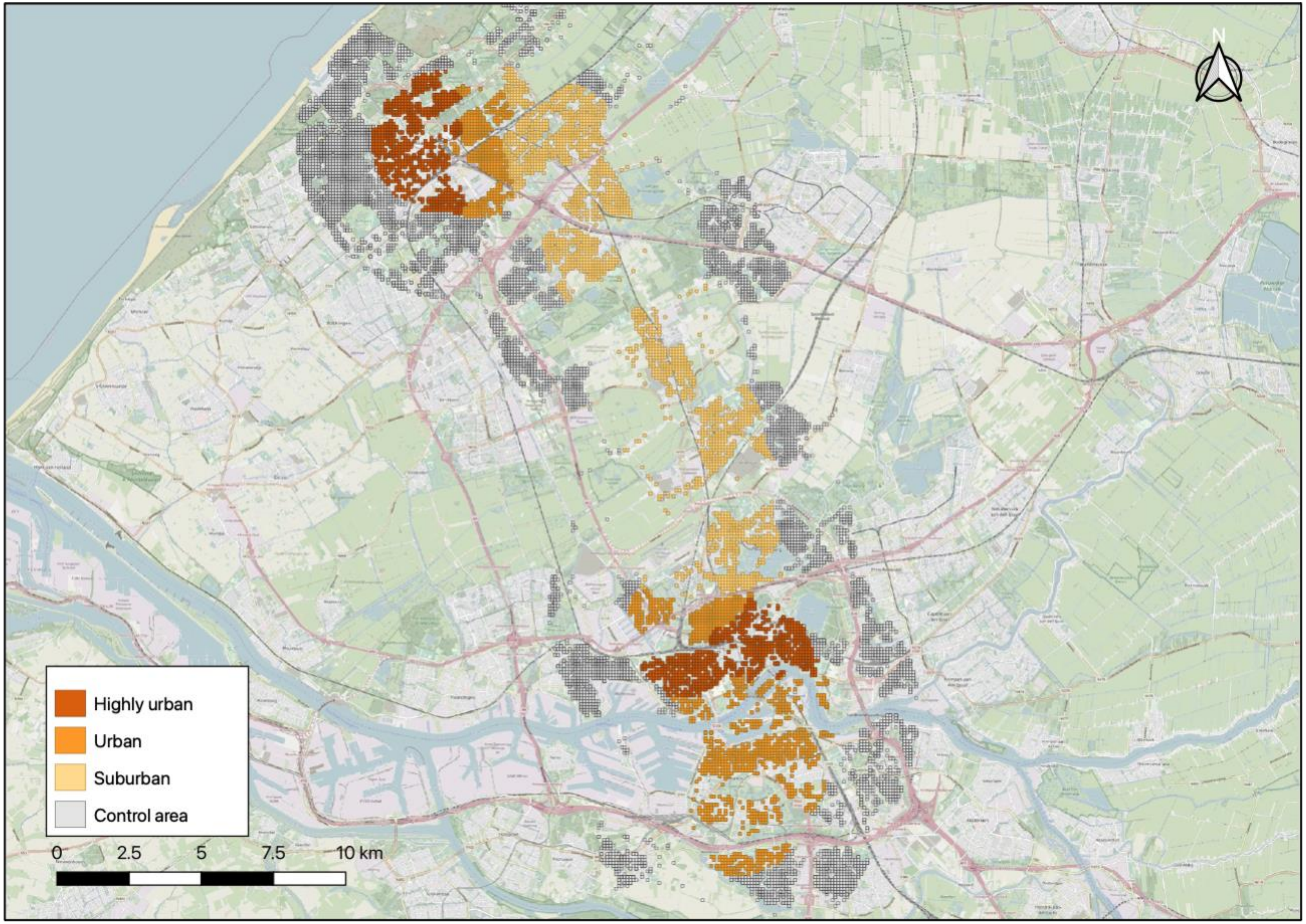

Figure C5: All grid squares by degree of urbanization.

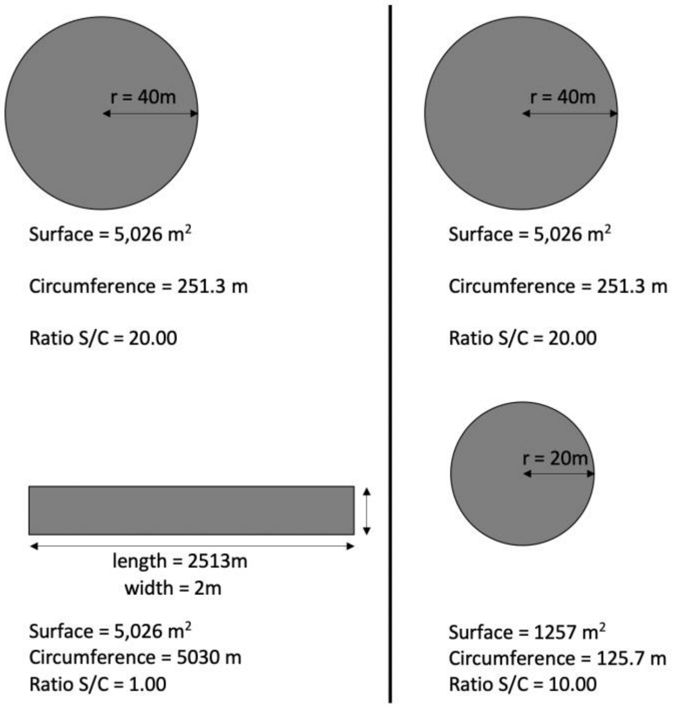

Figure C6: Graphical representation of the surface-circumference measure.