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From Transit to Transformation: How Light Rail is Driving Gentrification

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Contents

1. Introduction

In recent decades there has been a significant movement of people from rural areas towards urban areas in the Netherlands, mostly concentrated in large cities in the Randstad, resulting in high population growth and increased congestion in these areas. This trend has shown no signs of slowing down as of yet, which is why the government has planned to invest in public transport in urban areas, to help alleviate the congestion and improve liveability and accessibility in these areas (Rijksoverheid, 2019). Improving accessibility is particularly important for those with lower income, as a substantial percentage of the inhabitants of the four big cities in the Netherlands suffer from transport poverty (van der Bijl & van der Steenhoven, 2019). In this paper, neighbourhoods were examined in The Hague and Rotterdam, wherein approximately 20% of the population suffered from transport poverty. Improving accessibility via public transport is therefore vital for these areas, as suffering from transport poverty can aggravate poverty, since transport is vital in providing access to employment (Bastiaanssen et al., 2020). In their research they found that car ownership significantly increased the chance at employment especially for people who received welfare, showing the importance of transport access. They also found this relation for public transport, highlighting the importance of investing in public transportation for those who cannot afford a car.

This dilemma is also visible in Transit-oriented development (TOD). This development constitutes a synergy between transit and housing development intended to encourage residents to more frequently use public transit (Padeiro et al., 2018). TOD is widely viewed as an effective means of mitigating common urban problems, such as heavy traffic, noise pollution, air pollution, and urban sprawl (Cervero and Duncan, 2002). Yet, some studies argue that TOD causes gentrification in low-income neighbourhoods (Renne et al., 2016), which could negate the positive effects that TOD usually has. As the benefits of the additional accessibility that it offers will not benefit the low-income group that it was originally intended for as they would be forced out of their neighbourhoods due to increases in housing costs.

This thesis will focus on the relation between access to urban rail and gentrification in neighbourhoods in urban areas. By investigating this relation, it will be possible to give policy advice on whether TOD will also be accompanied by gentrification, which might lead to urban planners reconsidering implementing it. For example, when building a light rail line through a city, policymakers should, in an effort to prevent gentrification, ensure in advance that rents cannot be raised by large amounts so inhabitants will not be priced out of their neighbourhoods.

The research question of this paper is therefore:

What is the effect of access to light rail on gentrification in urban neighbourhoods?

To address this research question, a review of previous literature will be conducted, followed by a brief explanation of necessary concepts. Afterwards three hypotheses will be introduced to answer the research questions. In the methodology chapter, it will be outlined which methods are used to research the hypotheses. In the data section, an overview of the obtained will be given, as well as changes made to this dataset to perform the analysis. This will be followed by the results section where an overview will be given of the outcome of the conducted research. In the discussion section an interpretation of the results based on the knowledge obtained in the theoretical framework will be given. Finally, a conclusion to the hypotheses and the main research question will be presented, accompanied by recommendations for future research.

2. Theoretical framework

As stated by the research question *"What is the effect of access to light rail on gentrification in urban neighbourhoods?"* this study aims to investigate the impact of access to public transit on gentrification in urban neighbourhoods. To achieve this, first a clear definition of gentrification will be established, followed by an exploration of how the development of light rail may influence this process. Secondly, fundamental theory about urban spatial structures that shape individuals' location choices when selecting their place of residence will be explained, including an examination of how the construction of public transport infrastructure can impact urban areas. Afterwards, characteristics of gentrifiers, which can aid in identifying instances of gentrification within neighbourhoods will be explored based on the findings of previous literature on the effects of light rail development on gentrification in cities. Lastly, it is also important to determine whether the effects of constructing new rail lines are limited to local areas or whether they have a more widespread impact on the network.

2.1 Light rail in urban areas

As stated, it is important to first define gentrification. The phrase was first coined by Ruth Glass in 1964, who described it as follows:

"*The transformation of a poor neighbourhood in cities by the process of middle- and upper-income groups buying properties in such neighbourhoods and upgrading them"*.

Glass adds that gentrification also comes with changes in characteristics of the neighbourhoods affected and that once started, the pace at which the neighbourhoods gentrify occur is generally fast. Since 1964, a lot of research has gone into this topic, and many new theories discussing the causes and consequences thereof have been conducted. Smith (1987) added that an important characteristic of gentrification is that aside from the social and economic changes in the affected areas, there is also a physical change in the housing stock. New residents do not move into run-down houses or slumps, rather they renovate existing houses or move into newly built houses in the neighbourhoods. These improvements to the housing stock have the side effect of making the supply of houses unaffordable for the original poorer residents of the neighbourhoods.

To gain an understanding of how public transportation investments and accessibility influence gentrification, housing prices and location choices of people, it is important to first explore fundamental economic theories. The main way gentrification occurs is through increased housing and rent prices in inner cities, which results in the original residents getting priced out of their neighbourhoods and being forced to move away. While public transit is often seen as a positive force for urban development and accessibility, without policies and planning it contribute to gentrification.

To understand how this relation can occur, it is important to first study the consequences of investments into public transport. Where the influence on the neighbourhoods around the lines invested in are of interest. The changes herein are mostly caused by the increase in accessibility that the residents in these areas experience due to the new and improved infrastructure. Accessibility is a concept that is given different interpretations, but in this context, it means the opportunity to use transportation facilities that are necessary to reach desired locations at suitable times (Geertman & van Eck, 1995). It depends on both the opportunities the network and transportation options provide, as well as the person's mobility (Moseley, 1979). The latter refers to their personal ability to move, meaning that there are also differences in accessibility for those living on the same street. For example, one person might have physical limitations hindering their accessibility, such as a disability preventing them from walking long distances, or a lack of funds preventing them from using certain modes of transport. Many people, for instance, are unable to afford a car or a train ticket. Improved accessibility can be achieved by increasing the area residents can reach in a reasonable amount of time or reducing the costs associated with certain trips, so that the travel options available can be taken by a larger number of people. Improvements in accessibility through these means could, therefore, cause the network of the residents to increase as the area they can reach within a reasonable timeframe increases. Allowing them to reach more services and potential places of work.

A possible result of these increases due to investments in new light rail systems is that it could affect the prices of property in neighbourhoods, as increased accessibility is theorised to increase the land value, which would result in higher house prices. The logic behind this effect is that according to the land rent theory, the price of land is based on its connectivity to services and goods.

2.2 Monocentric city model

To comprehend how investments in public transport might have an influence on this relation, it is important to start by considering how property prices are decided and how people take their decisions concerning residency. As mentioned before in the introduction, a large part of the population of the big cities in the Netherlands, earns a lower income and suffers from transportation poverty. Economic models can help understand why there is a concentration of people who suffer from this phenomenon in the big cities. The first economic models describing these price mechanics and urban land theory were thought of in the 60's and 70's of the previous century (Alonso, 1964; Mills, 1972 & Muth, 1969). Together, the theories described in these papers resulted in the monocentric city model. An important aspect of this model is that it describes places where work is concentrated, called a central business district (CBD), around which people decide to live. People want to live as close as possible to the CBD, as the travel costs are lowest there. As a result, the land prices are highest around these areas, gradually reducing the further away from the CBD, which causes an equilibrium in which the higher travel costs are compensated by lower land prices. Due to this equilibrium, wealthier consumers end up living further away from the CBD, as they consume more land. Meaning they benefit more from the lower land prices than the poorer people, as they consume more of it and therefore get more compensation for the higher transportation costs. Following this logic, investments in public transportation can influence this dynamic, as improved accessibility can increase the attractiveness of living further away from the CBD. This is because the travel costs to the CBD decrease, meaning that the equilibrium changes and the influence of distance on the land prices decreases. Therefore, these investments can make living further away from the CBD more affordable for those with a lower income. At the same time, however, this could also lead to the opposite effect where wealthier individuals move towards the centre, increasing housing prices and displacing the poorer residents living there now.

2.3 Polycentric model

While this model does explain why a high proportion of the population who have a lower income live in cities, there are problems with applying it to modern cities. This is because, as the name suggests, it tries to model monocentric cities and a large part of modern cities and urban areas are polycentric in nature, in the USA, for example 75.9% of the employment in metropolitan areas was over three miles away from the CBD (Glaeser et al., 2008). In addition, the researchers mention the income elasticity of demand for land seems to be overstated in the monocentric city model. In this paper it is mentioned that this elasticity is likely to only be around 0.25. While this still explains some of the sorting mechanic theorized by the monocentric city model, it cannot explain the whole phenomenon.

In a polycentric urban area, the price of housing is still influenced by the location, but the exact mechanics are more complicated. Someone might, for example, live in Rotterdam and work in the CBD in the Hague instead of Rotterdam. According to the monocentric model, this person would then either move to the Hague in an equilibrium or work in Rotterdam, but real-life situations show that this is not always the case. Since the monocentric model cannot explain such a scenario, this has been researched extensively in the past decades and this concept has been coined “excess commuting” (Viguie & Faere, 2015). Hamilton (1982) was the first to research this concept and describes it as commuting in excess of economic theory. In practice this means commuting from one job centre to the other, as according to the monocentric city model this is an inefficiency, as the commuter could suffer less total transportation and rent expenses by moving. While the topic has since been researched in great detail, resulting in new methods to measure the amount of cross commuting (Van Ommeren & Van der Straaten, 2005), there is still no consensus on the exact reasons and the impact of the possible causes on the amount of excess commuting. In a literature review on the existing literature on the commuting excess (Ma & Banister, 2006) the main factors causing this inefficiency were listed. They mention multiworker household as a large contributor, meaning couples wherein both partners work, often do not work in the same centre. In other words, often one of the partners needs to partake in excess commuting. In addition, job changes increased inefficiency in commutes, due to the high costs associated with moving. Meaning that if the turnover on the job market is high, average transportation costs increase, leading to higher inefficiencies. Due to reason such as these, there is an increased importance of a large network for individuals to areas and good accessibility to areas outside of the nearest CBD, as in practice many people are not employed in the nearest CBD. Which is something that can be clearly observed in reality, as many people decide not to move when their place of employment changes. Partly because of the monetary costs associated with moving, but also because of the social network that they have built up in their current city, which makes moving undesirable unless the commute takes too long.

Since, as mentioned, the monocentric city model is not realistic for a lot of modern cities, Glaeser et al. (2008), offer an alternative for the concentration of lower income populace in city centre, namely, the presence of public transportation in cities. Private cars require a larger investment than public transportation, meaning that among poor people there are more who are dependent on public transportation. This results in them sorting into places where there is more access to this, which is usually in inner cities. The suburbs of cities on the contrary are usually very car oriented, meaning that the wealthier individuals, who do not depend on public transportation tend to move there. It is important to note that this is research into American cities, where there is a more pronounced difference between suburbs and the inner city, so this effect could be smaller in the Netherlands. It is also added that there is less centralization of the poor in cities on the west coast, because of a lower level of public transportation (Glaeser et al., 2008), meaning that for this sorting to appear, it is required that there is sufficient public transportation in the city. Additionally, the connectivity of the network should also be worse in neighbourhoods further away from the inner city, which motivates those that depend on it to move towards the city centre.

2.4 Housing prices

Based on these benefits public transport provides to residents in inner cities, where construction of new lines usually takes place, it is likely that property value increases as investments into public transit are made. As government bodies are interested in the returns of investments on public transport expenditures, a large body of research already exists on the effect that transport infrastructure has on land value. When studying the research papers that have been written about this subject, it becomes clear that that the theory that land becomes more desirable and expensive due to increased connectivity is indeed empirically validated. Literature reviews into papers written about this subject in an effort to investigate this relationship have shown that generally land values do indeed increase when investments into transport access are made (RICS, 2002; Smith, Gihring & Litman, 2013). In the studies examined by these literature reviews various modes of transport and types of investments into public transport were investigated. There were, however, also papers within these reviews that focused their research solely on the impact of new light rail stations on housing value.

In a paper on the effects of a new light rail system in Hudson, New Jersey, for instance, it was found that proximity significantly increased housing prices (Kim & Lahr, 2014). Herein the focus was on the walking distance to the nearest station and the decrease compared to the distance before the new station was opened. They found that the larger increases were mostly in areas that were within 400 meters from the new stations. In addition, they found that the largest marginal benefits were around the stations that were farthest from the newly revitalized central business district. The last finding supports the monocentric city model discussed earlier, as travel time saving are largest for those that live there, meaning that the transportation cost decrease is largest for them, which results in the largest land value increase.

The research that has gone into the relation between the quality of transport infrastructure and the land value is limited, but Ryan (1999) did find that land values were only significantly improved by infrastructure investments when those investments had a significant impact on travel times. Meaning it is important for the impact of the line that it connects to employment areas, such as in New Jersey, or provides faster access to the rest of the network so time savings can be realised.

In conclusion, based on the papers discussed above, it is likely that through the benefits that public transport provides to residents in inner cities, such as increased connectivity and decreased transportation costs, it is likely that property values will increase as investments are made into light rail.

2.5 Employment effects

It is likely that the improvement in accessibility by the addition of access to public transport in a neighbourhood also improves the employment opportunities for its residents. This effect is mostly present for those that are less educated, as they are less likely to own a car (Favas, 2019). In Amsterdam, for example, 9 out of 10 higher educated people have ownership of a car, while the less educated people only own a car 40 percent of the time. In addition, less educated non-western immigrants travel by bike a lot less often than residents that were born in the Netherlands, meaning their mobility is even lower. This lower mobility can have a large impact on the employment opportunities for the poorer people, as there is a limit to how much time people are willing to spend commuting, as the average constant travel time is 75 minutes (Hupkes, 1982). According to Hupkes, decisions around commuting are not based on distance, but on the amount of time travelled and people are usually unwilling to increase this past 75 minutes. Therefore, those who have more mobility and access to faster transportation methods have access to a larger labour market and increase their job opportunities. Those who do not own a car or bike are therefore very dependent on public transportation to increase the area they can reach within these 75 minutes, to provide them with sufficient job opportunities.

This effect is clearly visible in previous research, it was found, for example, that in Flanders those that live in poverty travel less, slower and less far compared to the average individual (Van den Broeck & Van Os, 2015). The negative consequences of this lowered mobility are illustrated by the difference in odds that having a driving license has on an individual finding a job in Flanders. Those that do not possess a driving license have access to 72% less job opportunities, compared to those that do own one (Fransen, 2017). By gaining access to a tram or metro, the mobility of these individuals is increased, which improves the job opportunities available to them by increasing the area that is within their reach within the 75 minutes mentioned before. Thereby decreasing the disadvantages in terms of mobility those without access to a car face on the job market.

The increased mobility one gets from new public transit lines not only affects the job opportunities available, it can, namely, also influence the choices that are made with regards to education. According to a study on university enrolment decisions in Sweden the accessibility of university education plays a significant role in the decision-making process (Eliasson, 2006). Eliasson finds that the magnitude of the impact is dependent on the background of the potential new student. Meaning that persons who have a less privileged background are more likely to be deterred from enrolling in case of bad university accessibility, compared to those with a more privileged background. In addition, the influence of this accessibility is lowered significantly by parental education, parental earnings and individual ability. Just as with the influence of accessibility on job opportunities, these findings show that the impact of increased mobility has a bigger impact on those who are less educated and have a lower income.

Overall, it is clear that better public transportation in a neighbourhood has the potential to improve the job opportunities and educational choices available to its residents, particularly those who are lower educated or have lower incomes. The increased mobility that comes with better access to public transportation can expand the area that is within reach within a reasonable travel time, thereby increasing the number of job opportunities available. Furthermore, it can influence decisions regarding university enrolment, particularly for those who come from less privileged backgrounds.

2.6 Defining the gentrifier

Since 1964, a lot of research has gone into this topic, and many new theories discussing the causes and consequences thereof have been conducted. The role of the gentrifier, for example, has been researched in more detail since then. More specifically, it has been researched who exactly the people are who move into gentrified neighbourhoods. It has been found that the most significant characteristics of the gentrifier are, their high income and their education level (McKinnish et al, 2010). The average household income of migrants moving into gentrifying neighbourhoods was $36,000 compared to $25,000 for those moving into non-gentrifying neighbourhoods. In addition, 19.7% of gentrifiers were college educated compared to 12.2% for non-gentrifiers. Other than that, they also found that the average gentrifier is younger, more often childless and less often an immigrant compared to people who move into non-gentrifying neighbourhoods.

These findings support an earlier explanation of the cause of gentrification, which was the rise of the new middle class and the changing labour market brought about by the post-industrial economy (Ley, 1999). According to Ley the changes this brought to the city centre and the new job opportunities this opened up there, meant the city centre became more attractive for the new middle class which motivated them to migrate towards these neighbourhoods. These movements towards the city centres were then the cause of gentrification. Which is why the gentrifiers are, according to Ley, characterised as; small and usually childless middle-class households, often unmarried, primarily under 35 years of age, employed mainly in the advanced services (professional, administrative, technical, and managerial occupations), and highly educated.

This is also why educational attainment, income and type of occupation are most often used as socioeconomic variables to measure whether gentrification has occurred in an area (Bardaka, Delgado & Florax, 2018). Hereby, educational attainment is defined in most studies as the percentage of inhabitants over 25 years old that have obtained at least a bachelor's degree. Occupation was defined as the percentage of workers aged over 16 years old that hold a job in a managerial or professional position. As this allowed for the researchers to measure whether the change in occupation that is associated with gentrification has occurred. Income is then usually defined as average or median household income (Bardaka et al., 2018). In a paper by Atkinson (2000), several other demographic variables were also included to measure whether gentrification and displacement happened in the Greater London Area. They also added the variables, working class, rate of renting, elderly, unskilled, minority, lone parent and unemployment. Atkinson measured what happened to the percentage of people that fit in these categories in gentrified neighbourhoods and how that relates to the increase in professionals in these same areas. The conclusion drawn in this paper was that, except for the rates for lone parents and unemployment, these variables were negatively correlated with the proportion of professionals in an area.

Aside from these socioeconomic variables, researchers also include several housing variables, to measure whether there is also an ascent of the neighbourhood concurrently with the gentrification of it (Owens, 2012), in addition this allows for real changes to neighbourhoods to be measured beyond changes to socioeconomic statuses of its residents. In order to measure this, Owens added the housing value and average rent as variables in their analysis.

2.7 Gentrification and light rail development

As mentioned before, gentrification can be caused by neighbourhood upgrading, as the presence of public transport is considered as an amenity. Both by poorer individuals who tend to use it more and richer inhabitants who are less dependent on it.

According to academic literature, there is evidence that investments in public transport can have an influence on the gentrification of involved areas (Baker & Lee, 2019; Fernando, Heinen & Johnson, 2021). Many of these studies have used different areas and methods to examine this relation between the two though, which has also resulted in large variation in the found results. As an example, in a study on the effects of the construction of the Manchester's Metrolink it was found that the demographics characteristics of the neighbourhoods before construction play a large role in the effects on gentrification (Fernando et al, 2021). Where neighbourhoods which have higher shares of residents who are lower educated, poor or minorities are more likely to gentrify. In addition, this study found that the time of the exposure had a large influence on the results, with neighbourhoods that already access for a decade still seeing changes due to the exposure to public transit.

In another study that made distinctions between park and ride and walk and ride stations, it was found that these characteristics have a large influence on the benefits the stations provide (Kahn, 2007). While an increase in the percentage of college graduates in treated areas was found, which was used as an indicator for gentrification, there was a large difference between the various cities and types of stations. Walk and ride stations usually increased housing prices in their surrounding areas, whereas park and ride did this to a much smaller extend or even reduced it. According to Kahn the reason why the effect of park and ride stations on price is a lot smaller or even negative is due to the disadvantages they provide to the residents compared to walk and ride stations. Walk and ride stations promote a lifestyle with more foot traffic, where cars are used less. This could result in higher living standards in areas, which might attract a richer populace. Park and ride stations, on the other hand, have negative externalities for the residents as they increase congestion, due to cars travelling towards stations. Therefore, residents could see increased travel times and more noise and air pollution (Kahn, 2007). According to Kahn these negative effects combined with the fact that richer people use public transport less often can deter them from moving to these neighbourhoods, which could be the reason why housing prices drop in some neighbourhoods which gain access to a park and ride rail station. An important note hereby is though that this research was performed in the United States, where due to the lesser quality of the public transport infrastructure wealthy individuals are less likely to use public transport compared to those in the Netherlands. A similar experiment conducted in the Netherlands could therefore yield different results.

Similar results as described above were found in another study on US cities (Baker & Lee, 2019). Although they did not differentiate between walk & ride and park & ride stations, they did also not find a consistent relation between the presence of public transport and gentrification. Their results vary wildly across different cities, in some cities there is strong evidence that access does indeed cause gentrification, whereas in other cities the opposite relation is found and public transport access seems to cause counter gentrification (Baker & Lee, 2019). They did add, however that efforts by planners in focusing on more inclusive development could help with realizing maximum benefits of TOD.

2.8 Network effects

As previously mentioned, the benefits provided by new light rail infrastructure are caused by the increase mobility it provides to residents along the route. It can therefore be drawn from this that the magnitude of this benefit depends on how much coverage the line, and by extension the network, provides. In other words, the increase in accessibility a network offers to neighbourhoods or regions. This is in line with economic theories that suggests the size of the network increases the value it provides to its users (Liebowitz & Margolis, 1994).

A line from one residential area to another that does not connect to the rest of the network is unlikely to increase the mobility of most individuals, as there will be a lack of important services and places of employment along the route. The biggest benefit is therefore likely to be found when the line passes through large employment hubs and connects to the rest of the infrastructure network, so as to increase the accessibility for the residents as much as possible. In this same way the addition of a line could also have effects elsewhere in the network, extensions to current lines increase the accessibility of the earlier existing stations, as they are now also connected to the areas around the new stations. In addition, due to possible new transit stations in the line, coverage area and travel times can be improved even further. Due to transit stations connecting the line to the rest of the network in the city, the accessibility is improved for everyone living along lines connecting to the new line. The extent of this increase is obviously depended on the size and importance of the newly connected area and the distance between the new public transport infrastructure and the previously connected stops.

This conclusion also means that it is likely that other residents in the city, who do not live along the new line, benefit from it in terms of mobility, provided they do live next to an existing line that connects to the new infrastructure. This is caused by the fact that the construction of the new line means that the total coverage area of the network of the city or region increases, meaning their ability to reach services and employment improves. In addition, the new infrastructure will for a part of the travellers result in lower travel times, as new travel options arrive due to the increased coverage, meaning the accessibility of the residents is bettered across the region. As mentioned before, the gentrification that might occur when new lines are constructed is caused by increased connectivity. This means that it is likely that the increased accessibility in other parts of the network, which occurs because of the construction of the new line, also leads to gentrification in neighbourhoods around lines that connect to the new line.

Compared to the number of studies that have been conducted on the impact of construction of new light rail infrastructure on surrounding neighbourhoods, the effects of these investments along existing lines elsewhere in the network are not studied as often. A recent study, however, did investigate the impact of a new railway line on existing stations elsewhere in the network. The researchers found that opening a new line in Singapore, increased prices around stations in existing lines (Zhu & Diao, 2022). They conclude that the increase in housing prices along these existing lines was approximately half of the local effect of opening a new station, with prices increasing by 30.3% more in neighbourhoods around the new stops compared to the control group. Prices in areas around existing stations increased by 15.0% more compared to prices in areas in the control group. The researchers attribute the increase around existing stops to the increasing network size, meaning that the attractiveness of these areas is increased as well.

Even though this paper studies railway infrastructure as opposed to trams it could still be relevant in this case, as Singapore is very small in size for a country and the new line is built in a ring around the city centre, meaning that in total length and distance between stops it would be more comparable to a Dutch metro than train. With it being only 35 kilometres total in length and having a maximum speed of 80 km/h.

3. Methodology

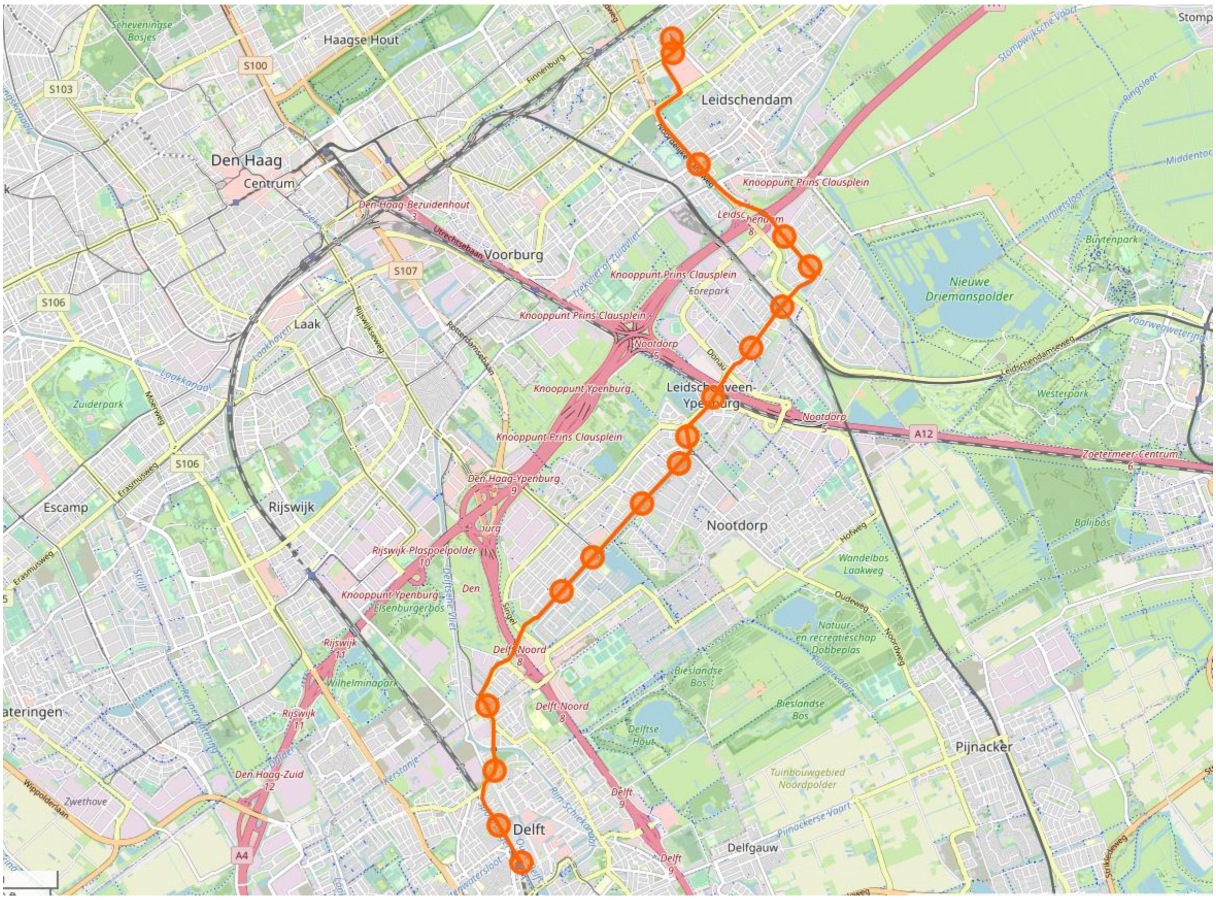
In this section the methodology of this paper will be described. This will be done by first describing the research design, accompanied by an explanation for the choices made.

As mentioned before, the goal of this thesis is to find out whether constructing a new tram line has an effect on gentrification, either in the neighbourhoods adjacent to the new line or in neighbourhoods surrounding connecting lines. To test this effect, it is essential to analyse a line with sufficient data available on the surrounding areas in the periods before and after the construction of the line to measure the changes that happened afterwards. Additionally, it is crucial to eliminate other possible causes of gentrification or changes in demographics as much as possible. As an example, a line through a newly constructed neighbourhood might not be representative of this research, as due to the new houses it is expected that there would be large changes in the neighbourhood regardless of the construction of the new line.

Therefore, the choice was made to focus this paper's research and analysis on tram line 19 from Leidschendam to Delft, as this line meets the criteria mentioned above. The line was opened in July 2010, meaning there is plenty of data available on both the period before treatment and after treatment. Line 19 differs from the other lines in the network of HTM, the public transport operator in the "The Hague" region, by being the only line that does not connect to the centre of the Hague. Instead, the line mainly connects the eastern parts of the region with each other, with stops in Leidschendam, Leidschenveen, Nootdorp and Ypenburg before ending its route in Delft. Originally the plan was for the line to extend to the campus of the university in Delft. However, due to technical issues, this part of the line is as off 2022 still not in operation, even though the stops and rail have already been constructed.

The fact that line 19 connects the outskirts of the tram network in the region makes it a suitable choice for the analysis because those areas previously had limited tram connections and generally had fewer public transport options available to residents. Therefore, the construction of the new line should have a more significant impact on the accessibility of the neighbourhoods surrounding it than a new line that connects parts in the inner city. Due to the existing alternatives available for the residents, the marginal impact on connectivity is likely to be lower in these areas.

Figure 3.1: Map of the The Hague region with line 19 From Leidschendam to Delft highlighted.



In addition, the fact that the line 19 connects a lot of new areas makes it appropriate for this research as it offers an opportunity to explore whether the construction of a new line also has an influence on gentrification in neighbourhoods in other parts of the city, along other lines of the tram network. The way this effect could be affecting the gentrification in other neighbourhoods is due to improvements in their connectivity. As mentioned, the reason why gentrification is likely to occur in places where access to new public infrastructure is gained, is because of the improvements the residents get in accessibility. Which in turn makes the neighbourhood more attractive for people looking to move, increasing prices and forcing out the original population. By improvements in the coverage of the tram network and in travel times by the construction of new lines, neighbourhoods along the whole network gain improvements to their connectivity, meaning all of these become more attractive. While this improvement is likely smaller than in the neighbourhoods where the new line is built it could still cause gentrification in these neighbourhoods.

Tram 19 is a suitable line for testing this, because due to connecting to a lot of new areas the improvements in total network coverage are relatively large. Therefore, the effects on the rest of the network are expected to be larger for line 19 compared to other lines. This will make it easier to measure whether there is an effect on improvements to the network by construction of new lines on gentrification in neighbourhoods along lines in other parts of the network.

Around the stops of tram 19 there are relatively more businesses though, which means that those that depend on public transport for their travels, might see an increase in job opportunities, which could have a larger impact on the characteristics in newly connected neighbourhoods. Both around line 19 and elsewhere in the network, around lines that connect to the new line.

This could be the case in Delft, as this city was only connected to the rest of the network through a single line, meaning the construction of line 19 made them more intertwined with the rest of the network in the Haaglanden region. As can be seen on the picture below, line 1 was the only line that connected to Delft before 2010, which has the disadvantage of being relatively isolated from the rest of the network until the Holland Spoor stop, which is a large hub as it is a major train station. Since it takes quite long though to get there for residents of Delft via Tram and the train also travels along the same route, this meant taking the tram was often not a viable alternative. The construction of the line 19 increases the use case of the old line 1 however, as it provides travellers with many new options for reaching their destination. Therefore, the construction of line 19, could potentially increase the accessibility in neighbourhoods along line 1 by a substantial amount, which could result in gentrification in these areas.

3.1 Identification of gentrification

As the research question states, the goal of this paper is to measure whether the construction of the new line results in gentrification. In order to establish whether this phenomenon is indeed present it is important to define how this will be measured in the analysis. As shown in the theoretical framework, the difference between gentrification and neighbourhood upscaling is visible in the demographic changes that occur when there is gentrification. This means that for the distinction to be made, the changes that are usually associated with gentrification need to be present. As mentioned in the theoretical framework, it was found in previous research that in neighbourhoods that experience gentrification there is usually an influx of singles and smaller households (Ley, 1999; Mckinnish et al, 2010) which is why the choice was made to include the variable average household size in the regression. As a decrease in number of people per household in the treatment group compared to the untreated could point to gentrification.

As the gentrifiers are less likely to be non-western immigrants (Atkinson, 2000; Mckinnish et al, 2010), the percentage of non-western immigrants in neighbourhoods is also included in the regressions, as this number is expected to decrease over the years, compared to untreated neighbourhoods if gentrification is indeed present. The choice to only look at non-western immigrants was made, because non-western immigrants have a larger proportion of richer expats, who themselves are more often among the gentrifiers. Atkinson also found in their research that there was a decline in the percentage of elderly in a region that gained access to public transit. For this reason, this variable is also included in the analyses, where elderly is defined as 65 and older.

If statistically significant differences in the variables above are measured in the treated regions the conclusion can be drawn that there is gentrification caused by the construction of the new line. This does, however, not automatically mean that this is also because of forced displacement. Therefore, the choice was made to also research whether the neighbourhoods experienced socioeconomic upscaling, as if this is the case and, for instance, the prices for houses has risen dramatically since the construction it is more likely that the gentrification is also caused by forced displacement.

To draw conclusion on whether the investments into the new line, also caused an upscaling of the neighbourhood, Owens (2012) proposed using variables to measure how the residents of the neighbourhood are doing financially. In their research these include house value, income, educational and high-status job attainment. Since there is not enough data to include the last two variables in the analysis, these are not included in the regression analyses. Instead of high-status job attainment, however, two other variables are included in the regression as a proxy that should be able to measure the same effect. Namely, percentage of people with high income in a neighbourhood and the share of people in a neighbourhood who receive social benefits. The reasoning for including these variables as substitutes is that there is a high correlation between high earning jobs and high-status jobs. Share of residents receiving benefits was included for a similar reason, as these measure the share of people who are either unemployed or otherwise have incomes low enough that they are entitled to benefits. Meaning that by including this variable the inverse effect of high-status job attainment could be measured, as a high share of the population of a neighbourhood on benefits indicates that the average inhabitant is employed in low-status jobs.

Aside from these two variables, the housing value is included to measure socioeconomic ascension of the neighbourhoods. The variable used to measure the housing value per neighbourhood per year is the WOZ (Waardering Onroerde Zaken). This is the value the government deems houses to be worth and using it comes with the benefit of all properties being valued by the same criteria and ensures that there is a value for every neighbourhood for every year in the dataset. The disadvantage of this method is that the value lags behind the current time by one year, as the current WOZ is the value the government deems properties to be worth on the 1^{st} of January of the previous year.

3.2 Estimation method

To measure the impact of investments into new tram lines, difference in difference (DiD) regression analyses will be performed. The reason the difference in difference method will be used to measure the impact, because there is a clear before and after period in the data, which makes it suitable for this type of analysis. The DiD regression allows for the effects of the increased accessibility in neighbourhoods through rail investments to be measured. This regression method is a popular method for researching effects of an intervention, as it allows for analyses in studies where experiments are not feasible, for example due to costs associated with it. That is also why it is suitable for this particular study, as a controlled experiment on the required scale is not realistic. This means that most regression analyses apart from the DID method are not suitable for this experiment, as with those analyses there is an assumption of a random sample.

Since an actual experiment is not possible in this case and the decision to build new infrastructure is not random, the assumptions would be violated. As the treated sample in this case is neighbourhoods that received investments, there is a chance that the neighbourhoods have certain characteristics that are more prevalent in the sample. For example, it is possible that the municipality wants to invest in new rail infrastructure in places where fewer people have cars, as they stand to gain more in accessibility by having better access to public transit. Factors like these mean that the sample can have errors e that are common among the treatment group and differ from the untreated group, which can result in wrong estimations of standard errors. Due to the assumption that the error terms are random and independent of each other.

This could lead to biased estimates, meaning it is better to use the DiD design in the regression in this case, as it uses a quasi-experimental design. This means it allows for evaluation of the intervention of building new tram infrastructure, without randomization. This makes it suitable for this study as the decision to build stations is not random, which could lead to biases in the results when using other methods of analysis. Stations are, for example, usually build in neighbourhoods with high growth potential, as local governments believe building new connections in these locations will result in the most benefits. By using the difference in difference method, this bias can be prevented, allowing for a fair analysis of the effect of the new stations. This is done by estimating pre-treatment and post-treatment means and drawing a comparison between them, to conclude whether there is a statistically significant difference between them, which would show an effect of the tram connection. One of the prerequisites of the DiD regression is though that the that the trends in the treatment group pre-treatment should be same in the treatment and control group. If this requirement is not fulfilled there is a risk that the difference in the post treatment period is not caused by the treatment, but to unrelated circumstances which could lead biased estimates. For that reason, the control group in the regression analyses must be similar to the treatment group.

As the neighbourhoods in the treatment group consist of neighbourhoods that have their centre in close proximity to stops of line 19, the choice was made to let the control group consist of neighbourhoods that are also close to the newly constructed line but are further away from the actual stops. This choice was made so the neighbourhoods in the control group and treatment group resemble each other as much as possible. An example of how this helps to ensure that they are similar over the analysed period, is that this way the neighbourhoods in both the treatment and control group experience the negative externalities of the construction of the new line. These factors include noise pollution and road congestion due to construction activities. For the control group a catchment area of three kilometres of line 19 was used, meaning that the neighbourhoods which have their centre within a three-kilometre radius of the new line, but are in not in the catchment areas of the stations have been added to the control group.

In this experiment the pre-treatment period will be until 2010 and post-treatment after that, as line 19 which will be researched was opened in July 2010. In the experiments a dummy variable will be created for the treatment, called posttreatment, which will take on a value of 1 for treated neighbourhoods from 2010 and 0 otherwise.

In order to perform the analysis, a choice has to be made on which estimator to use in the regression. The simplest form of the method can be done by using a linear regression, with a treatment indicator and an indicator thereof. While this method can measure whether there are differences due to treatments, its simplicity also has its problems. An example of this is the selection bias that often occurs in panel data models. Not accounting for the presence of unmeasured time-invariant confounders can result in violation of the parallel trends assumption. Therefore, researchers often include fixed effects in their analyses to account for these unobserved confounders (Mummulo & Peterson, 2018). Fixed effects namely ignore all between-unit variation and instead only consider within-unit variation. Including this to the regression therefore eliminates the issue of time-invariant confounders thereby reducing selection bias. Making the choice to include fixed effects and therefore not using between-unit variation also comes with its disadvantages though, as through this means the possibility of measuring dynamic causal relationships is lost (Imai & Kim, 2019). These researchers propose considering whether the benefits of eliminating unobserved time-invariant confounders outweighs the benefits of losing the possibility to measure dynamic causal relationships. In another study examining the effects of including fixed effects, the impacts on regression models with both unit and time fixed effects, like two-way linear fixed effects models do not suffer from the same trade-off (Imai, Kim & Wang, 2021). Since the DiD is largely similar to two-way linear fixed effects models in this regard, this leads to the conclusion that for the regressions used in this paper, unit fixed effects can be included without concerns as long as time fixed effects are included as well.

As can be seen in figure 3.1 below, there are also other means of confounding that could lead to biases. Including unit-level fixed effects helps adjust for time-invariant covariates X, where the effects of X on the outcome do vary.

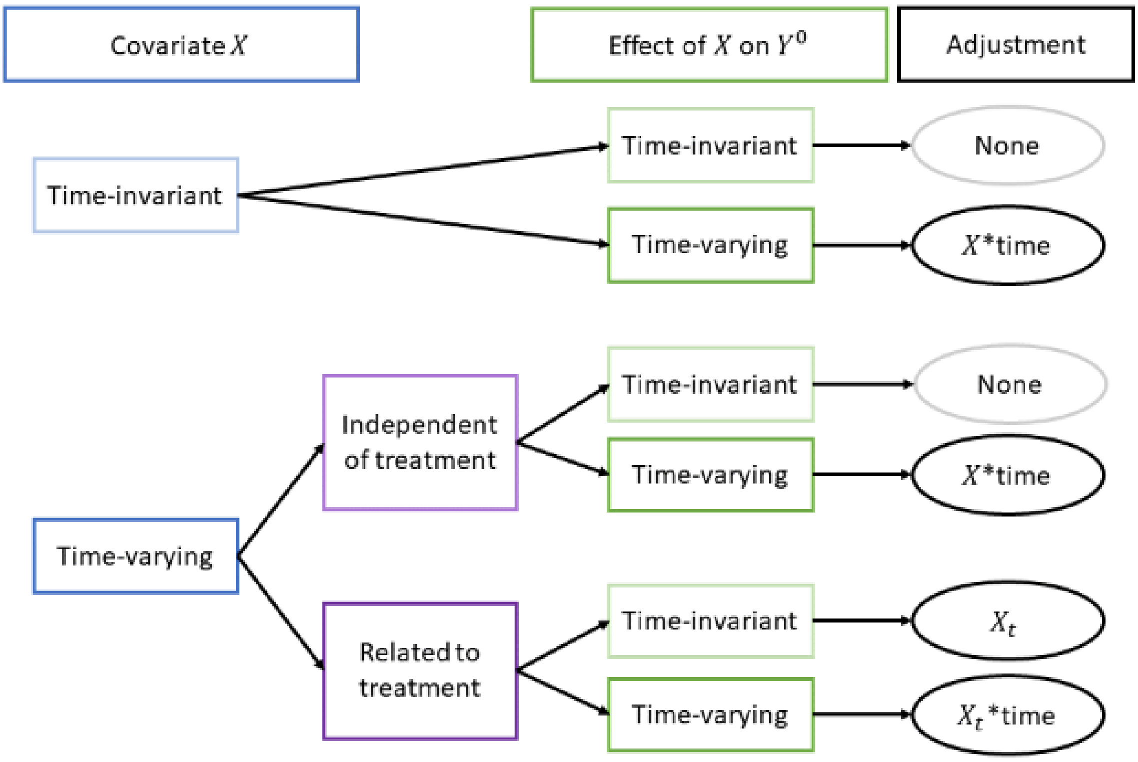


Figure 3.2: Confouding in linear settings From: *Difference in differences* by Zeldow, B., Hatfield, L.A. (2019)

3.3 Hypotheses

Two hypotheses have been formulated to answer the research question of what the impact of investments into new public transport infrastructure is on the neighbourhoods in which they are located.

For the first hypothesis, the direct effect of a new tram line on the surrounding neighbourhoods will be measured. It is expected that the construction of a new line will provide the local residents with gain improved access to facilities and employment opportunities. This is caused by the improved connectivity, which will lead to increased attractiveness and potential gentrification of the area. This could in turn lead to more people wanting to move here which increases housing prices and results in gentrification of the neighbourhoods. Therefore, the first hypothesis is formulated as follows:

Hypothesis 1a: Construction of light rail infrastructure will cause neighbourhood upgrading in neighbourhoods alongside it.

Hypothesis 1b: Construction of light rail infrastructure will cause gentrification in neighbourhoods alongside it.

These hypotheses will be tested using difference-in-difference regression analyses, wherein the variable determining whether a neighbourhood is counted among the treatment group or not is the distance of its centre to the nearest station of the new line. The neighbourhoods studied are those in the municipalities through which the line travels, where if the distance is less than 800 metres, the neighbourhood is placed in the treatment group. The effect of the treatment on property value, the share of residents with a high income, and the share of residents who receive benefits will determine whether a neighbourhood has upgraded as a result of new public transport infrastructure. In addition, the effect of the treatment will be determined by analysing the changes in several demographic variables, the share of elderly residents, the share of non-western immigrants and the average size of households in the neighbourhood. Together these will indicate whether gentrification has also occurred.

This distance was chosen based on research showing that this is the average distance pedestrians walk to a stop of a HOV line (van der Blij, Veger & Slebos, 2010), where a HOV line indicates that it is a line of high quality. In the paper in question busses are researched where HOV bus lines are ones that have separate lanes and travel faster on average. Since tram 19 has a dedicated lane on most of its trajectory, the conclusion was made that it is most comparable to this kind of line, which is why the choice was made to use these distances as indicators for how far residents would be willing to travel to a stop. Therefore, for the first hypothesis, neighbourhoods that have their centre located within 800 metres of a stop of line 19 are considered treated and are added to the treatment group. The neighbourhoods that have some point of the line within 3000 metres of their centre are added to the control group in this experiment. The centres of the areas and the distance in between them and the stops and line are calculated using Qgis. As mentioned before, the total dataset contains data from 2004 to 2016 and the treatment period is from 2010 onwards.

The second is:

Hypothesis 2: The magnitude of the effect of new tram lines on gentrification and neighbourhood upgrading will increase as the distance from the nearest stop decreases.

In the first hypothesis connection to a station is modelled as a binary variable, meaning that all stations are assumed to be equally well connected no matter the distance to the station, as long as it falls in the range. It is more likely that the effect varies with the distance to the station, where neighbourhoods closer to stops see larger effects. To test this hypothesis, the catchment area cannot simply be labelled as within or outside the catchment area, as was the case for hypothesis 1.

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, the second for walking and cycling, and finally one intended only for cyclists. Research mentions that residents using their bicycle in their commute are willing to travel further to stops, meaning that in order to capture the full effect of the construction of the new line, the new categories need to have larger catchment areas (van der Blij et al., 2010). As the average cyclist travels 2300 metres to a stop, this will be used as the maximum distance from the centre for neighbourhoods to still be considered treated. For category two an influence distance of 1150 metres will be used as according to van der Blij, the share of cyclists in commuters to public transit is about twenty percent, meaning this is the distance the average commuter is willing to travel.

To summarize, for the second hypothesis three distance zones will be used, zone 1 is for pedestrians, who travel up to 800 metres. Zone 2 captures the average commuter who travels 1150 metres, meaning a catchment area of between 800 and 1150 metres and finally zone 3 which accounts for cyclists, who travel up to 2300 metres, meaning a catchment area between 1150 and 2300 metres.

The third is:

Hypothesis 3: Investments in new tram lines will cause gentrification in neighbourhoods around connecting lines.

Since the expected gentrification that occurs because of new transport infrastructure can likely be attributed to increases in connectivity, these effects are also expected to be found elsewhere in the network along connecting lines. Residents who live nearby already existing rail lines will experience increased accessibility if their line connects to new lines, as they will be able to reach new areas. This will result in them having access to more facilities and job opportunities, which could increase the value of their neighbourhood and could therefore result in gentrification of their neighbourhoods due to increased attractivity.

For the third hypothesis, a difference-in-difference regression will be performed with two distinct groups. The aim of the hypothesis is to find the difference in effects of the new light rail line on neighbourhoods that have existing infrastructure connecting to the new line compared to those that do not. This way, it will be possible to conclude whether residents benefit from improved connectivity due to improvements elsewhere in the network. The treatment group will consist of the neighbourhoods that benefit from the new line in terms of mobility. This will be neighbourhoods along line 1 in Delft, as they will see significant reductions in their travel times towards Leidschendam and the stops in between Delft and Leidschendam, as line 1 was the only tram line in Delft before the expansion to the network. For instance, travelling from the main train station in Delft, where both trams 1 and 19 stop, to amenities such as the large mall in Leidschendam, for example, takes about 20 minutes less now. The total travel time using public transit was approximately 55 minutes before the construction of the new line, whereas it takes only 35 minutes now, eliminating transfers and increasing the comfort of the trip. In addition, tram 19 connects to a lot of other tram lines and other forms of transport, such as train and metro, providing many new options in terms of public transport travel for the residents in Delft that live along line 1.

4. Data

In the following section the data collection will be described, then the data on Line 19 will be described, which will include tests on the parallel trends and coefficients plots. In addition, manipulations to the data will be discussed. This will be followed by a similar overview for the data on Line 1.

The data used in this paper has been obtained from the CBS database “Kerncijfers wijken en buurten” this dataset contains data on many neighbourhood statistics and has been released yearly since 2003, meaning the way the data is measured is generally the same over the entire time period of the time period used in this study. Exceptions hereon are variables that have only recently been added to the database or ones that are not reported anymore. The number of students and working people, for example, has not been reported since 2009, meaning it could not be included in the regression. To find the distances from the stops of the line 19 and line 1 to the neighbourhoods, QGIS has been used. All neighbourhoods have been assigned a centre, neighbourhoods that have their centre within 3000 metres of the lines were added to the dataset. Neighbourhoods that had their centre within 2300 metres of the nearest stop were added to zone 3, 1100 metres to zone 2 and 800 metres to zone 1.

4.1 Line 19

4.1.1 Descriptive statistics

Table 4.1: Frequency table of treatment in post treatment period for hypothesis 1

Group	Frequency	Percentage
Control	101	74.26
Treatment	35	25.74
Total	136	100

As can be seen in table 4.1, slightly over 25% of the neighbourhoods in the dataset in hypothesis 1 belong to the treatment group. In this hypothesis these are the neighbourhoods which have their centroid within 800 metres of the nearest stop of line 19.

Since the regression that will be performed will use panel data, each neighbourhood will have multiple observations in the dataset. As the dataset runs from 2004 to 2016, there are thirteen observations per neighbourhood, meaning the total amount of observations is 1768, of which 952 are after the treatment has occurred.

Table 4.2: Frequency table of treatment per municipality in post treatment period for hypothesis 1

Municipality	Control group	Treatment group	Total
The Hague	7	10	17
Delft	48	14	62
Leidschendam-Voorburg	17	6	23
Pijnacker-Nootdorp	6	2	8
Midden-Delfland	1	0	1
Wassenaar	6	0	6
Rijswijk	16	3	19
Total	101	35	136

From table 4.2 it can clearly be seen that line 19 has it stops in the outskirts of the service area of HTM's network, as only 17 neighbourhoods within the Hague are within three kilometres of the line. Most of the neighbourhoods in the experiment are in Delft, Rijswijk and Leidschendam-Voorburg which are all positioned further away from the centre of the Hague, where most lines go through and in general is the busiest area of the HTM's network.

Table 4.3: Frequency table of zones in post treatment period for hypothesis 2

Group	Frequency	Percentage
Control	56	58.25
Zone 1	35	18.56
Zone 2	15	7.73
Zone 3	30	15.46
Total	136	100

Table 4.4: Frequency table of zones per municipality in post treatment period for hypothesis 2

Municipality	Control group	Zone 1	Zone 2	Zone 3	Total
The Hague	6	4	3	4	17
Delft	16	20	9	17	62
Leidschendam-Voorburg	9	8	2	4	23
Pijnacker-Nootdorp	6	1	0	1	8
Midden-delfland	1	0	0	0	1
Wassenaar	6	0	0	0	6
Rijswijk	12	2	1	4	19
Total	56	35	15	30	136

For the second hypothesis, neighbourhoods that have their centre between 800 and 1150 or between 1150 and 2300 are also included in the treatment group. As can be seen from the tables this results in the treated and untreated groups having a more similar number of observations. Due to the fact that the range of distance for category two is only 350 metres, namely between 800 and 1150 metres, the sample size of this group is only half of the size of that of category one and three, which will make it harder to find significant result for this group.

In addition is it clear from the division in zones per municipality that this line mainly connects large parts of Delft and Leidschendam-Voorburg where a vast majority of the neighbourhoods are in the treatment group. In the Hague the share of treated neighbourhoods is also slightly higher with this influence area, although the overwhelming majority of neighbourhoods is still considered unconnected to line 19 with the larger coverage area.

Table 4.5: Correlation table between the treatment indicator and the control variables for line 19

Variable	Treatment	Address density	Population	Neighbourhood upgrading	Gentrification
Treatment	1.00				
Address density	0.057	1.00			
Population	-0.032	0.44	1.00		
Neighbourhood upgrading	0.026	0.038	-0.37	1.00	
Gentrification	-0.058	-0.12	-0.24	0.53	1.00

As can be seen from table 4.5 above, there is no high correlations between the regressor, the treatment variable, and the control variables. Treatment in this table indicates whether a neighbourhood is in the treatment group or not and does not differentiate between the before and after treatment periods, meaning that those in it always have a value of 1, while those in the control group always have a value of 0. The correlation between the two control variables population and the address density in neighbourhoods is 0.44. This indicates that there is some correlation between the variables, but this is quite moderate and not to a degree where it is problematic. The positive correlation between neighbourhood upgrading and gentrification indicates that, just like the theory suggested, wealthier neighbourhoods tend to be more gentrified. This could mean that if improved accessibility increases the attractiveness of neighbourhoods, this will also lead to gentrification within these neighbourhoods.

Table 4.6: Descriptive statistics for the dataset on line 19

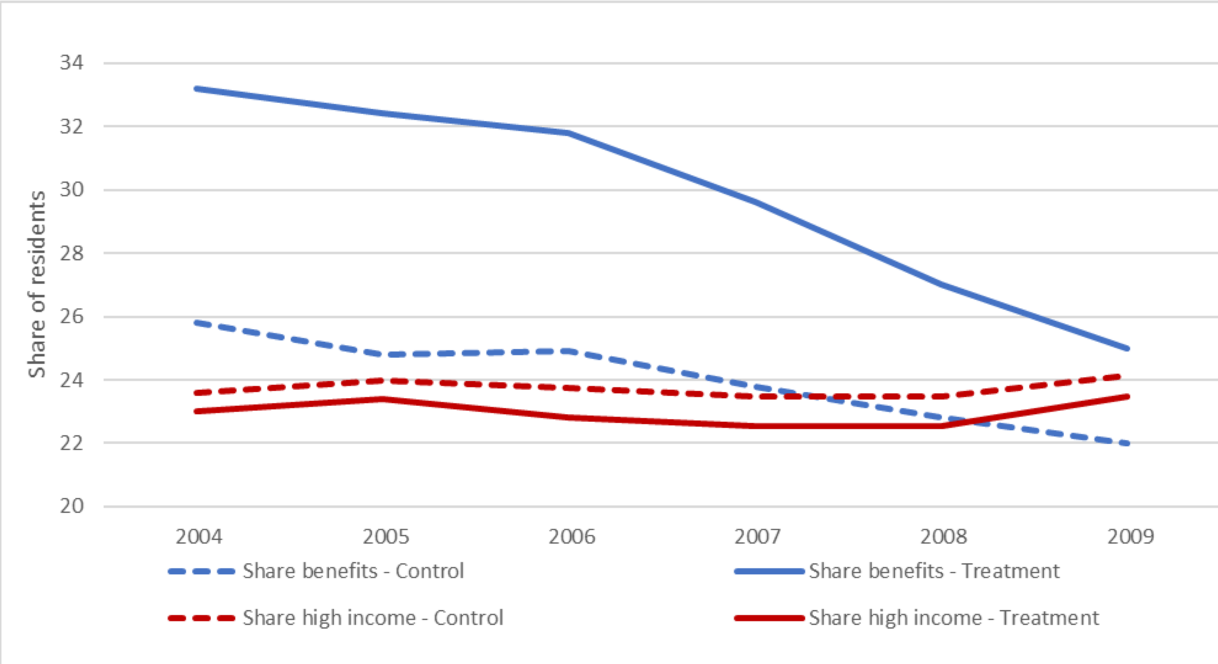
Variable	Mean	Standard Deviation	Minimum	Maximum
Density	3619.9	1693.8	579	8717
Population	3360	2782	215	15220
Property value	212.8	115.6	38	743
Household size	1.98	0.38	1.1	3.3
Share of High Income	23.5	13.8	1	67
Share of Elderly	17.2	11.1	0	72
Non-western Immigrants	21.5	19.5	0	91
Benefits	30.2	31.1	0	191
Neighbourhood upgrading	0.022	1.0	-1.8	3.7
Gentrification	$-6.5*10^{-10}$	1.0	-4.5	1.2
Observations	1768			

As can be seen from the descriptive statistics in the table above, there are large differences between the different neighbourhoods in the data sample, both in terms of demographics and in terms of wealth. With the share of residents receiving benefits, for instance, ranging from 0 to 191 per thousand inhabitants. Similar differences can be found in the share of immigrants, elderly and high earners.

4.1.2 Parallel Trends

Since the DiD regression design requires similar trends before the intervention in order to be able to produce reliable results, the trends of the regressors have been plotted in the following section, so an informed decision can be made if the assumption is not violated.

Figure 4.1: Parallel trends plot of share of residents receiving benefits and earning a high income before treatment.



As the graph above shows, the trendlines of the share of residents who earn a high income before the treatment is parallel and the absolute values are also close between the control and treatment group. Therefore we can conclude, for this variable, that the assumption is not violated and we can include high income earners in the regression on whether neighbourhoods are upgraded due to access to light rail. The share of residents receiving benefits also has a very similar pattern between the two different groups, in contrast to high income however, the absolute values already start out quite far apart. In 2004 about 26 out of 1000 residents in the control group recevied benefits while about 33 out of a 1000 residents received these in the treatment group. Since both groups do experience a decrease in these values between 2004 and 2009, the trends are parallel but it does point out a difference in characteristics between the groups.

Figure 4.2: Parallel trends plot of average property value before treatment.

For the average housing value, the absolute values are quite close over the entire period between the different groups, however, there are some slight differences in trends between the two. The control group has a slightly lower average value up until 2007, but experiences a slightly faster increase in prices in 2008, resulting in the average value being slightly higher in these years. As these trends appear to differ quite a bit, an extra trend hereon has been performed at the of this section, to provide statistical evidence of whether the trends are parallel.

Figure 4.3: Parallel trends plot of share of non-western immigrants and elderly residents before treatment.

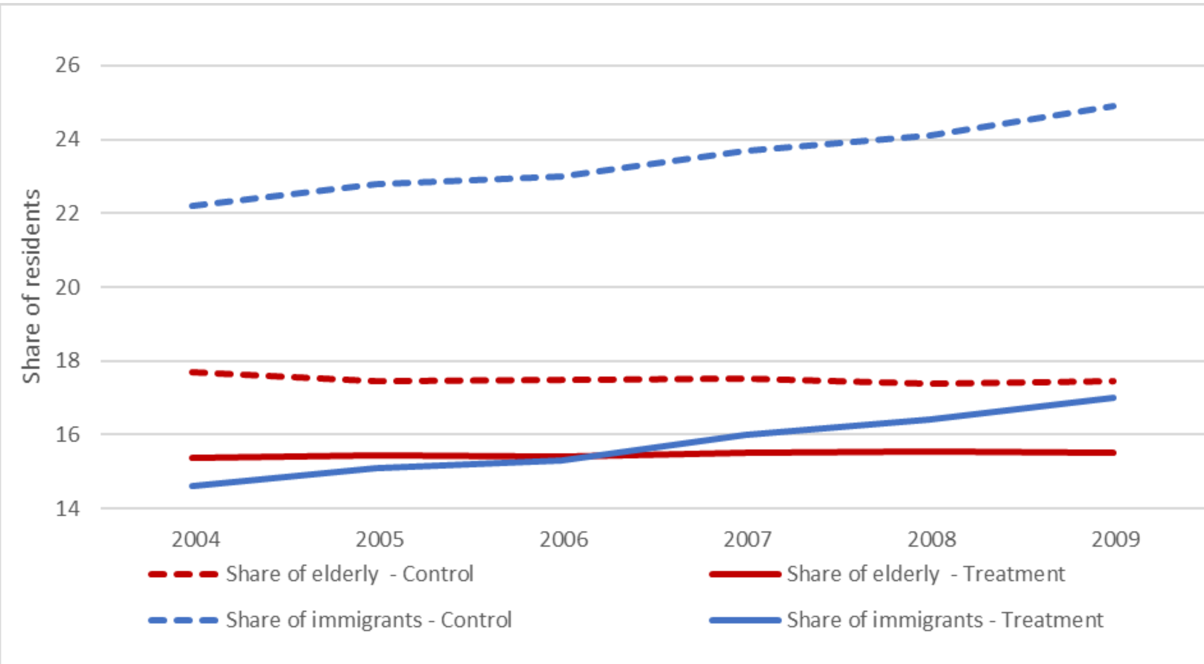
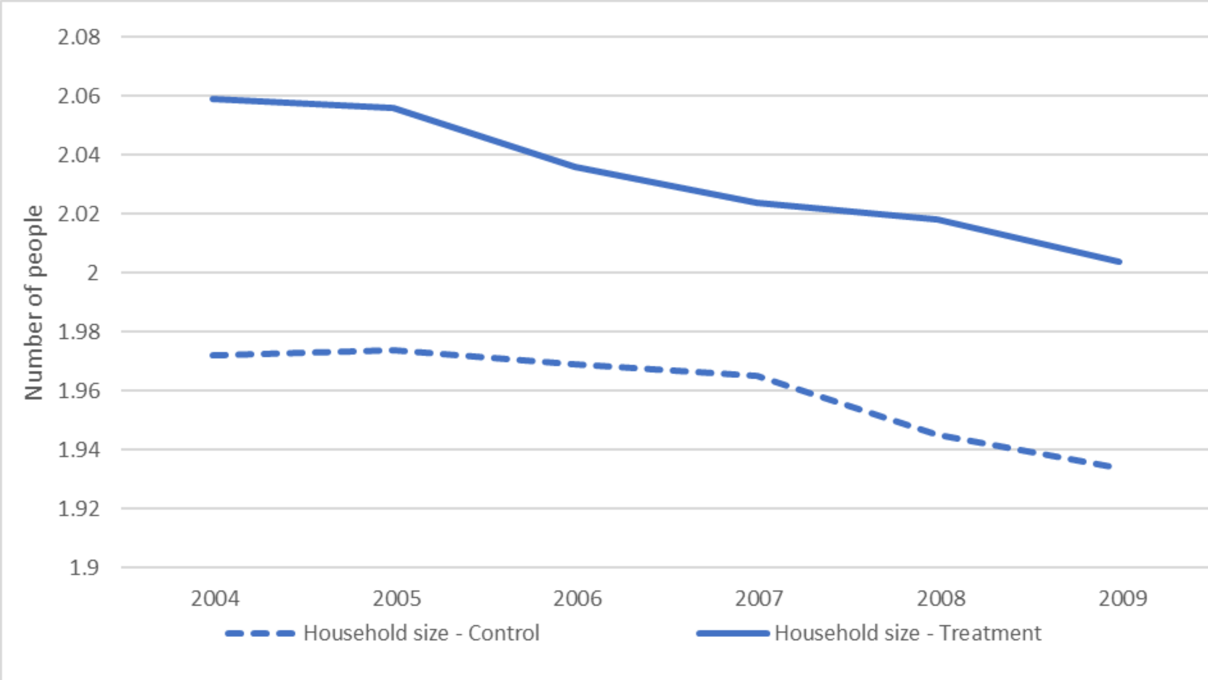


Figure 4.4: Parallel trends plot of number of residents per household.



As can be seen in the figures above, both the trends in the share of elderly residents and the share of non-western immigrants are similar between the treatment group and the control group. The groups do have a sizeable difference in the share of immigrants; however, this value is almost unchanged, in absolute terms, between 2004 and 2009. The share of elderly residents differs less between the two different groups and the overall trends are similar here too. In the treatment group the share is almost completely stable and while it does fluctuate slightly in the control group, the trend is also stable in this group. Meaning that the equal trends assumption is fulfilled for both these variables.

Figure 4.4 shows that, while the overall trend follows the same pattern, there are some differences between the control group and the treatment group for the average household size. In the treatment group, the average size decreases almost continuously from 2004 to 2009, whereas in the control group it is more stable until 2007, after which it experiences a faster decrease. The total decrease in household size is also larger in the treatment group. Therefore, the choice has been made to also conduct an extra test to conclude whether the parallel trends assumption is violated, the results of which can be found in table 4.8 below.

Table 4.7 Parallel trends test pre-treatment period

Variable	F-statistic	P-value
Average property value	2.92	0.089
Average household size	0.88	0.35

As can be seen the p-value of the test is 0.35 for average household size, meaning that the hypothesis of parallel trends cannot be rejected at the 10% level. In conclusion, there is no evidence for a significant difference between the trends and the variable can be used in the regression analysis.

In the case of the property value, the model returns a p-value of 0.089 meaning that the assumption of parallel trends is rejected at the 10% level. Since the assumption is not rejected at the 5% level, which is the conventionally accepted value for statistical significance, the variable will be included in the regression.

To summarize, all discussed regressors satisfy the parallel trends assumption and will be included in the final analyses, whereby the property value, share of high earners and share of residents receiving benefits, will be used to conclude whether a neighbourhood has upgraded. The average household size, the share of residents over 65 years old and the share of non-western immigrants will be used to determine whether gentrification has occurred.

4.1.3 Principal components

Since the three variables per category together determine whether gentrification or neighbourhood upgrading has occurred, the choice has been made to use principal components to indicate whether a change in one of these has occurred. Meaning that variables, property value, benefits and high income have been bundled into one component indicating neighbourhood upgrading. Whereas household size, elders and non-western immigrants have been grouped into another variable indicating gentrification. By bundling the variables into one principal component that retains the most important information, the regression will make it clearer whether the combined effect of the three indicators is significant.

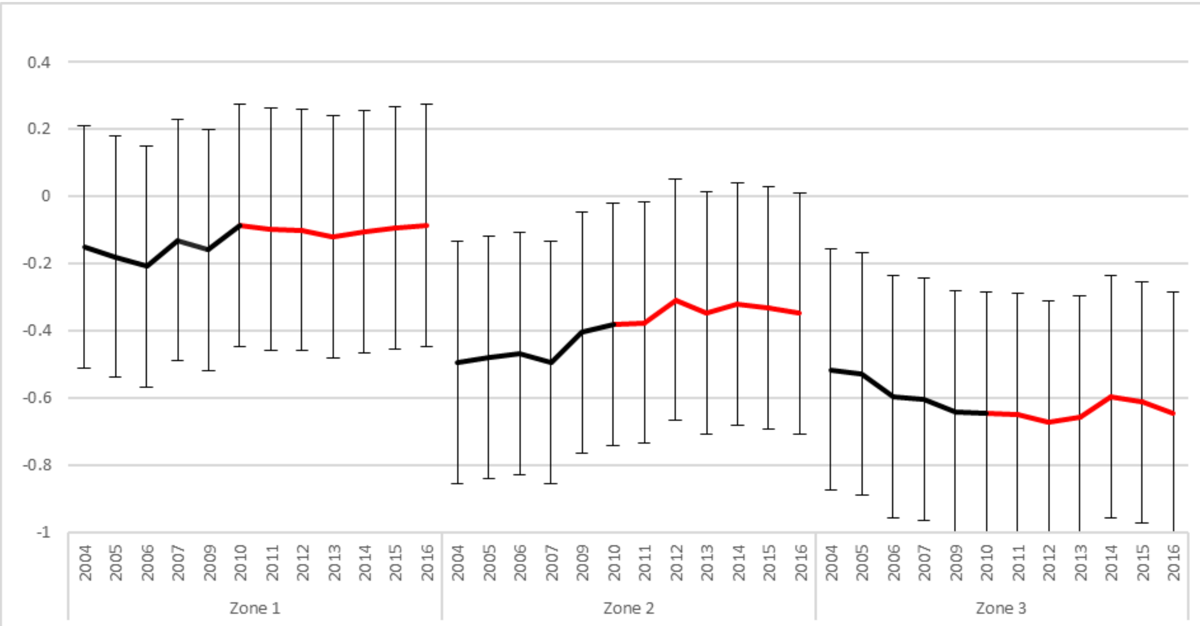
These new variables will respectively be called neighbourhood upgrading and gentrification. In order to ensure that the interpretation of the new variables remains intuitive, a few data manipulations have been performed. For gentrification for instance, the indicating variables are share of elderly, share of immigrants and household size. For all three variables an increase in value, is associated with less gentrification, therefore the found values for the principal component gentrification have been multiplied by -1. As a result, an increase in the value of gentrification, corresponds to a decrease in value of these indicating variables.

For the neighbourhood upgrading variable the issues with interpreting the values were slightly more complicated, as the variables it consists of are property value, share residents earning a high income and share of residents receiving benefits. In this case an increase in property value and high earners, indicates neighbourhood upgrading, whereas the opposite is true for the share of residents on welfare. Therefore, the values of the benefits variable were multiplied by -1 before calculating the principal components, to ensure that neighbourhood upgrading resulted in the same sign for all variables. Because of this modification, an increase in the value of one of the indicating variables, also results in an increase in the value of neighbourhood upgrading.

4.1.4 Coefficient plot

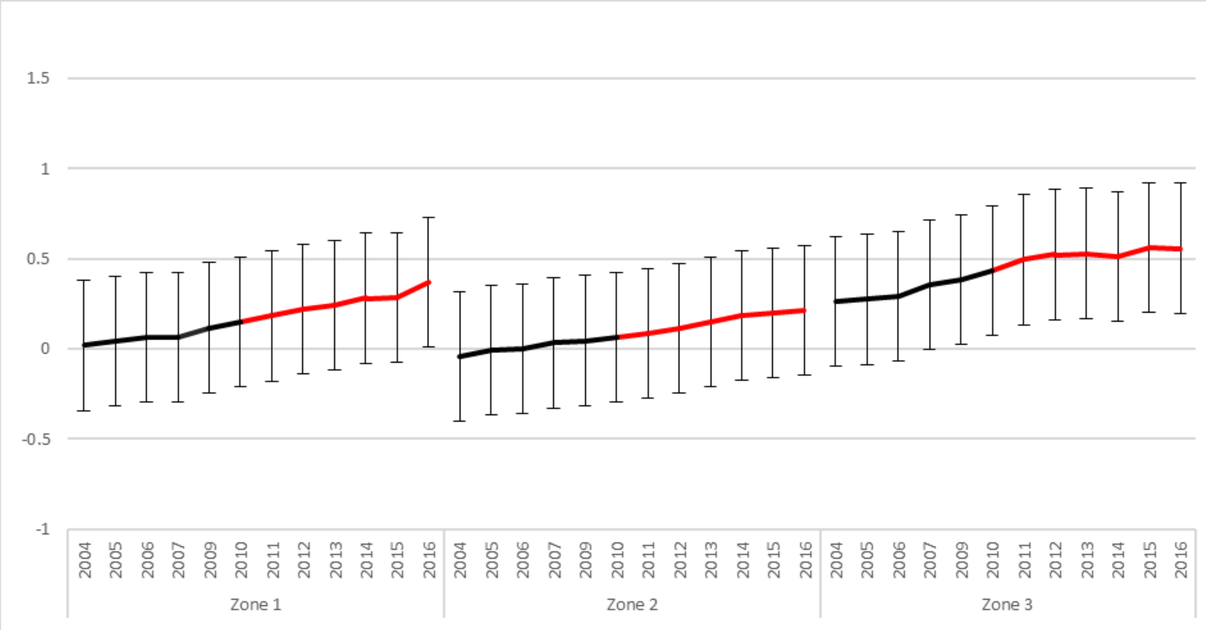
As the outcome of interest for this research is whether proximity to a light rail stop has an effect on neighbourhood upgrading or gentrification, the choice was made to make a coefficient plot based on the results of a linear regression on the principal components, with interaction of the year and zone variables as the regressors. This way it will be visible what the effect over time of being in these zones is, which will show if there is a change in the trend after the treatment in 2010. These coefficient plots based on the regressions are shown in the graphs below.

Figure 4.5: Coefficient plot of the trends in neighbourhood upgrading per zone.



From figure 4.5 above, it is visible that all three zones have lower values for neighbourhood upgrading than the control group, with this difference being particularly large in zone 3. In zone 1, the value does increase compared to the control group, however that effect does seem to be in large part an anticipation effect, as the largest increases are in 2007 and 2010 and while 2010 is considered part of the after-treatment period, large changes in housing prices and income seem to be soon to be explained by the actual effect of the construction of the new line. In zone 2, there is also an increase in the post-treatment period, however this time the value continues to increase longer after the treatment. It does experience the same increase shortly before the treatment as zone 1, indicating that here there might also be an anticipation effect. From the figure it seems like zone 3 benefits less from the new line, although it started lagging behind the control group more before the treatment, while post treatment the value is relatively stable.

Figure 4.6: Coefficient plot of the trends in gentrification per zone.



As figure 4.6 shows, for the principal component indicating gentrification all three zones, show a similar pattern, especially before treatment. All three zones gradually increase in gentrification before treatment compared to the control group, although there are differences in the speed of the increase. From the figure, it can be seen that rate at which gentrification increases picks up for zone 1 after treatment, the same seems to happen for zone 2 although the rate of growth is lower both before and after treatment. For zone 3 the exact opposite happens, as it had the highest growth in gentrification before treatment, whereas from 2011 onwards the rate of gentrification compared to the control group is practically stable.

4.2 Line 1

4.2.1 Descriptive statistics

For the third hypothesis a different dataset is used, as the neighbourhoods of interest are those that lie around line 1 instead of line 19, as is the case for the hypothesis one and two. In this dataset only neighbourhoods in Delft are considered, as all the stops are in this municipality. This means the sample size is smaller, but it does mean the neighbourhoods differ less as there can be no differences due to changed policy in the municipality. For the third hypothesis the same treatment size is chosen as for hypothesis 1, meaning only neighbourhoods that are closer than 800 metres to a stop of tram 1 are considered treated in the regression. This choice was made, because partly due to the smaller sample size of this dataset. As can be seen in the table below, there are only 22 unique neighbourhoods in the untreated group. If the larger catchment area groups would also have been included, this group would have to be split even further, resulting in groups that are too small to draw conclusions from. By only including walking stations the number of observations per group increases, which makes it more likely that the model will return significant results if these are present.

Table 4.8: Frequency table of treatment in post treatment period for hypothesis 3

Group	Frequency	Percentage
Control	22	40
Treatment	33	60
Total	55	100

As can be seen above, the share of neighbourhoods that are treated is slightly larger than the share of untreated neighbourhoods in this regression, due to the fact that only Delft was considered. Since Line 1 crosses a large part of the municipality this means that a large share of the municipality is in close proximity of the tram line. Even though the total dataset is smaller than that of line 19, the even distribution between stops that did and did not receive treatment, ensures that there should be enough to find effects of the treatment if these are present.

Table 4.9: Correlation table between the treatment indicator and the control variables for line 1

Variable	Treatment	Density	Population	Neighbourhood upgrading	Gentrification
Treatment	1.00				
Density	0.44	1.00			
Population	0.045	0.14	1.00		
Neighbourhood upgrading	0.078	0.15	-0.02	1.00	
Gentrification	0.056	0.18	-0.025	0.18	1.00

Table 4.10: Descriptive statistics for the dataset on line 1

Variable	Mean	Standard Deviation	Minimum	Maximum
Density	3403.8	1003.1	924	4959
Road distance	12.3	5.8	4	24
Rail distance	14.5	5.8	3	24
Hospital distance	23.3	8.4	5	39
Population	1542.3	770.7	295	4030
Property value	182.5	56.5	67	327
Household size	1.87	0.35	1.2	3.1
Share of high income	19.2	10.2	1.1	45
Share of elderly	15.4	9.9	0	65
Non-western Immigrants	17.3	13.9	0	69
Benefits	29.1	29.0	0	191
Neighbourhood upgrading	$-2.0 * 10^{-10}$	1.00	-1.8	2.5
Gentrification	$8.7 * 10^{-10}$	1.00	-1.6	5.0
Observations	715			

From the table above, it is clear that, similar to the dataset in line 19 there are large differences between the neighbourhoods. Although still large, from the standard deviations of the variables it can be seen that the variation within this dataset is slightly smaller than in that of line 19, as the relative size of the standard deviation compared to the mean is lower in this case. This could be, because all the neighbourhoods belong the municipality of Delft, resulting in them being more homogenous.

4.2.2 Parallel trends

Since the dataset for line 1 differs from that of line 19, the parallel trends have been examined separately, as there might be differences in the variables that fulfil the assumptions made by the DiD model. As is visible from figure 4.7 below, both the trends on the share of elderly and the share of non-western immigrants follow the same pattern between the treatment and the control group. The share of elderly is stable across the researched period, whereas for both the treatment and control group the share of non-western immigrants gradually increases between 2004 and 2009.

Figure 4.7: Parallel trends plot of share of non-western immigrants and elderly residents before treatment.

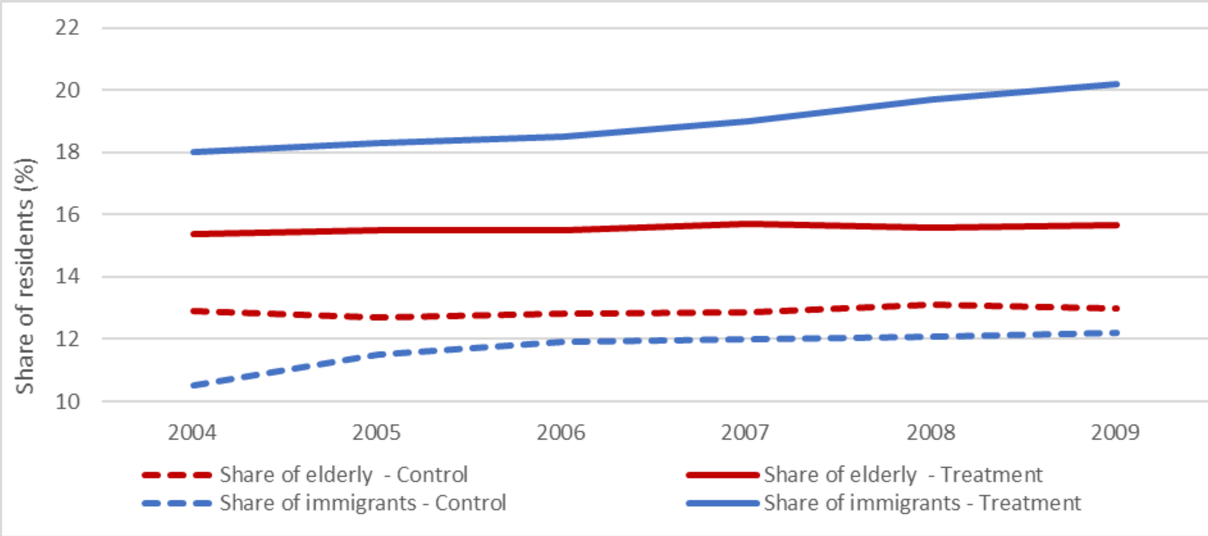


Figure 4.8 shows that there are slightly more differences between the trends for the share of residents who receive benefits. From the figure it is clear that up until 2007 the trends run parallel, but the share of those on benefit decreases by a large amount in 2008 in the control group, while the treatment group keeps the same pattern as before. To determine whether this does not violate the equal trends assumption an extra test will be performed on the assumption at the end of the section. The share of residents is very stable between the two groups, there are some minor fluctuations, but over the whole period the share is consistently slightly higher in the treatment group than the control group.

Figure 4.8: Parallel trends plot of share of residents receiving benefits and earning a high income before treatment.

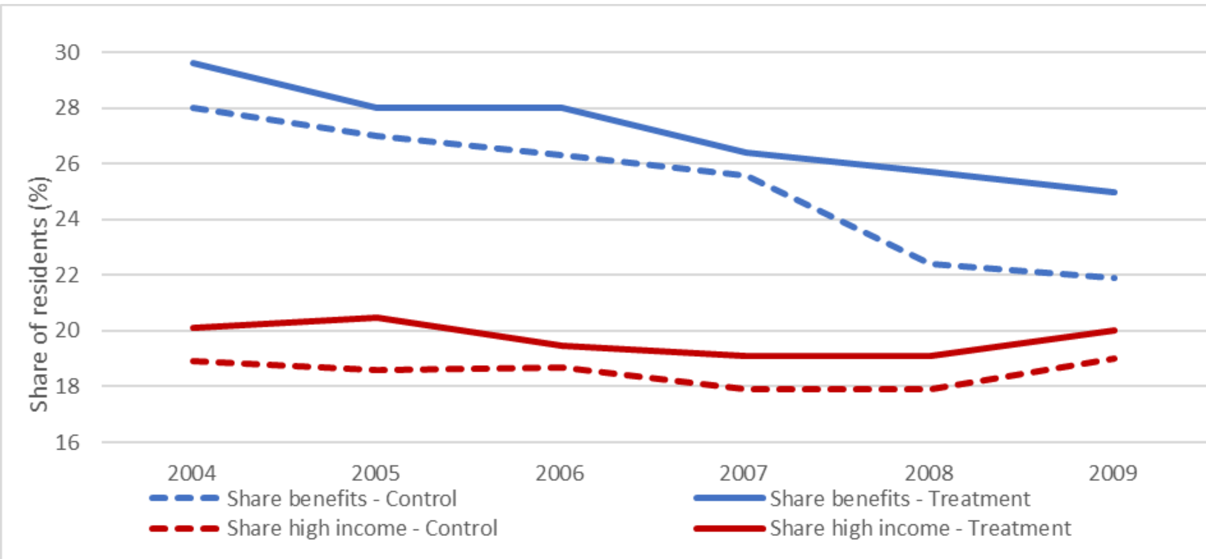


Figure 4.9: Parallel trends plot of share of non-western immigrants and elderly residents before treatment.

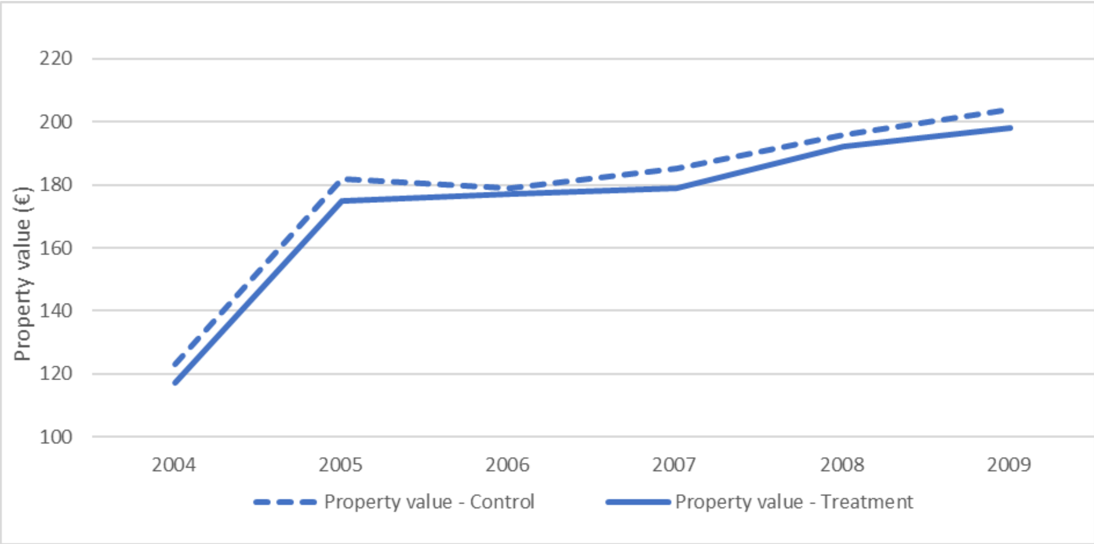
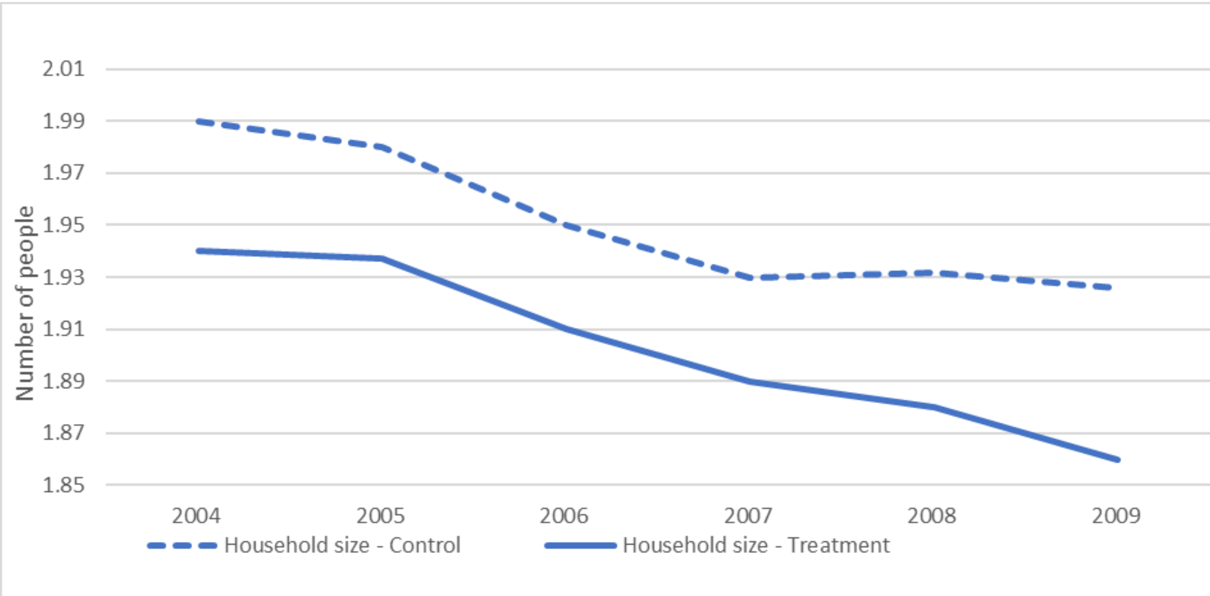


Figure 4.10: Parallel trends plot of number of residents per household.



The plot of the housing value shows that the trends herein were completely parallel between the two groups in the pre-treatment period. The trends between the household sizes does show some differences though, while both the control group and treatment group generally trend downwards, the treatment group has seen a much larger decrease in 2008 and 2009 compared to the control group, which is why a parallel trends test has also been ran on the average household size.

Figure 4.11 Parallel trends test pre-treatment period

Variable	F-statistic	P-value
Share of benefits	2.25	0.15
Average household size	0.57	0.46

In the rightmost column, the results of the test on the share of residents receiving benefits are shown, which show that the parallel trends assumption for share of residents who receive benefits cannot be rejected on the 10% confidence level, meaning it can be included as a regressor. The same goes for the average household size, meaning that all examined variables can be included in the principal components and therefore the final regression.

To summarize, all discussed regressors satisfy the parallel trends assumption and will be included in the final analyses, as a result the principal components will consist of the same variables as the regression on line 19. Therefore, the property value, share of high earners and share of residents receiving benefits, will be used to conclude whether a neighbourhood has upgraded. The average household size, the share of residents over 65 years old and the share of non-western immigrants will be used to determine whether gentrification has occurred.

5. Results

5.1 Hypothesis 1

As mentioned in the previous section, for the first hypothesis the effect of the construction on the neighbourhood upgrading will be measured. This was done by performing a difference in difference regression of the effect of the treatment on the variable indicating neighbourhood upgrading. Next to that, the effects of the construction of the line on gentrification was also tested. The results of these regression can be found in the table below.

Table 5.1: DiD regression analyses on neighbourhood upgrading and gentrification around line 19.

Variable	**Neighbourhood upgrading**	**Variable**	**Gentrification**
Post treatment	-0.022* (0.013)	Post treatment	-0.20*** (0.011)
Treated	0.17*** (0.038)	Treated	0.069*** (0.022)
Population	0.000087*** (0.00024)	Population	0.00011*** (0.000015)
Address density	0.0014*** (0.00032)	Address density	-0.013*** (0.0023)
Constant	-4.11 (0.87)	Constant	3.36 (0.61)
Region effects	Yes	Region effects	Yes
Observation	1632	Observation	1768
Groups	136	Groups	136
R-squared within	0.072	R-squared within	0.35
R-squared between	0.18	R-squared between	0.084
R-squared overall	0.16	R-squared overall	0.077

*p-value <0.1, **p-value <0.05, ***p-value <0.01

The table above presents the results of two regression analyses that examine the effects of a treatment, access to light rail, on two variables, neighbourhood upgrading and gentrification. These are principal components of consisting of several variables that together indicate whether these phenomena have occurred.

The results show that including the control variables population and address density, is important for predicting the outcome in both models. Additionally, the results show that the treatment has a significant effect on both neighbourhood upgrading and gentrification.

In the neighbourhood upgrading model, the treatment group experienced a significant increase in neighbourhood upgrading of 0.17, compared to the control group. This effect is significant at the 1% level. As can be seen in the table in descriptive statistics the average value of this variable is 0.022 and the standard deviation is 1.00, meaning the magnitude of the found effect of treatment is relatively large compared to the values in the dataset, meaning that in addition to showing that access to light rail improves neighbourhoods, this effect is also in fact large enough to be noticeable. The found effect of post treatment is -0.022, this value is significant at the 10% level, meaning that the while the treated neighbourhoods experience neighbourhood upgrading after treatment, those in the control group in contrast experience a decrease in the variables indicating it.

For the gentrification model, the found effect of treatment is an increase in gentrification of 0.069. The effect of treatment, again, is significant at the 1% level, meaning there is a treatment has a significant and positive effect on gentrification in neighbourhoods. Based on how the variable gentrification is defined, this means that the average effect of treatment on the outcome is that after gaining access to light rail, the proportion of elderly and non-western immigrants in neighbourhoods decreases, as well as the number of residents per household in the treated neighbourhoods. Just as in the neighbourhood upgrading model, the effect of post treatment is negative and significant, this time even on the 1% level. However, this time the effect of post treatment is larger than that of treatment, meaning that, using the definition of gentrification used in this analysis the treatment group neighbourhoods also become less gentrified in absolute terms. This can probably be accounted to the fact that the share of elderly residents and immigrants is rising nationwide over time, however according to the results above, access to light rail slows this down.

As can be seen by the R-squared values, the model explains more of the variation in the data in the post-treatment period for neighbourhood upgrading compared to gentrification. However, the overall R-squared values for both variables are relatively low, indicating that there may be other factors not accounted for in the model that are affecting the outcomes. Therefore, it is hard to conclude whether the changes in the outcomes are solely due to the access to new light rail connections.

5.2 Hypothesis 2

For the second hypothesis the same dataset was used to perform the analysis, however in this case multiple categories were introduced to make distinctions based on the distance from the centre of the neighbourhoods to the stations. This will allow for conclusions to be drawn on whether closer proximity to stations will increase the positive or negative effects associated with access to light rail stations. Just as was the case with hypothesis 1, two separate regressions were performed to examine the effect on neighbourhood upgrading and gentrification.

Table 5.2: DiD regression analyses on neighbourhood upgrading and gentrification around line 19 per treatment zone.

Variable	Neighbourhood upgrading	Variable	Gentrification
Post treatment	0.00074 (0.0024)	Post treatment	-0.0028* (0.0017)
Treatment		Treatment	
Zone 1	0.096*** (0.032)	Zone 1	0.042** (0.021)
Zone 2	0.14*** (0.049)	Zone 2	0.053 (0.033)
Zone 3	-0.059 (0.052)	Zone 3	-0.074** (0.034)
Population	0.00097*** (0.00020)	Population	0.00091*** (0.00014)
Address density	0.015*** (0.0032)	Address density	-0.0014*** (0.00022)
Constant	-4.17 (0.87)	Constant	3.34 (0.61)
Region effects	Yes	Region effects	Yes
Observation	1632	Observation	1768
Groups	136	Groups	136
R-squared within	0.046	R-squared within	0.33
R-squared between	0.14	R-squared between	0.093
R-squared overall	0.13	R-squared overall	0.086

*p-value <0.1, **p-value <0.05, ***p-value <0.01

As can be seen from the results table above, the model shows the same significance for neighbourhoods in zone 1 as the model used in the first hypothesis. The magnitude of the effect is slightly lower with 0.096, but the sign is still positive, and the effect is significant at the 1% level. The found effects of the treatment on the neighbourhoods in zone 2 is similar, although the effect is slightly larger with 0.14. This result is again significant at the 1% level. For zone 3, however, a negative effect of light rail access on neighbourhood upgrading was found with a found value of -0.059. This variable, however, is not significant at the 10% level, meaning this result cannot be interpreted. As the first two zones, located closer to the new stations, did receive significant benefits on their neighbourhood, while the neighbourhoods further away did not enjoy this effect, the found results support the formulated hypothesis.

Just like with the neighbourhood upgrading model, the gentrification model also results for zone 1 that are similar to those of the first hypothesis. Treatment is still associated with an increase in gentrification, while the average effect of the post treatment period is still negative. Compared to the model in hypothesis 1, the coefficient is a bit lower though and slightly less significant. With the result found new being an increase in gentrification of 0.042, significant at the 5% level.

The results, again seem to indicate that closer proximity to light rail stations increase the benefits they provide, as while zone 2 has a positive coefficient than that found for zone 1, the significance level of this value is too low to consider it significant at the 10% level, meaning this cannot be attributed to the treatment. The third zone does have a significant result, however it indicates that the effect of the treatment on neighbourhoods in zone 3 reduces gentrification with 0.074, this result is significant at the 5% level.

5.3 Hypothesis 3

As described in the methodology, for the third hypothesis the effect of the construction of line 19, on neighbourhoods around the stops of line 1 was examined. The regression performed here is similar to that of hypothesis 1, as only neighbourhoods in close proximity to the stations were considered meaning the stations were again given a catchment area of 800 metres.

Table 5.3: DiD regression analyses on neighbourhood upgrading and gentrification around line 1.

Variable	**Neighbourhood upgrading**	**Variable**	**Gentrification**
Post treatment	-0.044*** (0.0093)	Post treatment	-0.0041 (0.0064)
Treated	0.15*** (0.058)	Treated	0.033 (0.038)
Population	-0.000099 (0.00011)	Population	-.00056*** (0.000081)
Address density	-0.000031 (0.000081)	Address density	-0.00015*** (0.000058)
Constant	0.33 (0.30)	Constant	1.16 (0.21)
Region effects	Yes	Region effects	Yes
Observation	864	Observation	936
Groups	72	Groups	72
R-squared within	0.078	R-squared within	0.28
R-squared between	0.145	R-squared between	0.064
R-squared overall	0.126	R-squared overall	0.070

*p-value <0.1, **p-value <0.05, ***p-value <0.01

Just as was the case in the models for hypothesis 1, the found effect for the treatment on the neighbourhood upgrading is positive and significant at the 1% level for neighbourhoods around line 1. The value of the coefficient is also quite similar in size to that of the models of line 19. While the effect of post treatment on the neighbourhood upgrading was positive though in the models of line 19, it is negative around the neighbourhoods in line 1, this value is significant at the 1% level. As the coefficient is only -0.044 compared to the 0.15 of the treatment effect, the treated neighbourhoods still experience neighbourhood upgrading in both relative and absolute terms.

As can be seen in the table, the R^2 values of the model are even lower than in models of line 19, meaning that less of the variation can be explained and that even though the found values are significant there are reasons to believe the effects could be attributed to other factors outside of the model.

In the gentrification model, the found effect of treatment is not significant for neighbourhoods around line 1, contrary to earlier models. The found coefficient is positive, but as it is not significant at the 10% level, it is not possible to conclude that this effect is caused by the treatment, meaning it cannot be concluded that treatment results in a positive effect on gentrification for neighbourhoods around the stops of line 1.

5.4 Robustness check

In order to assess whether the estimated treatment effects found in the previous section were due to the actual treatment and not to outside factors, the choice has been made to perform a regression with a placebo treatment as a robustness check.

This was done by performing the same experiment as the one on line 19, with the difference being that the treatment group did not actually receive the treatment, meaning that the neighbourhoods in the treatment group already had access to light rail stops before the treatment period. We can then compare the estimated treatment effect for the actual treatment group with that of the placebo group. If the estimated treatment effect for the placebo group is not statistically significant, it suggests that the estimated treatment effect for the actual treatment group is due to the treatment and not to other factors increasing the validity of the results. Amsterdam has been chosen as the location for the placebo experiment, as there were no significant changes to the network between 2004 and 2016, meaning there is no reason for large changes around the treatment period. The treatment group consists of neighbourhood in the centre that have access to a light rail stop within 800 metres of the centre of the neighbourhood, while the control group consists of neighbourhoods that have their centre within a 2000 metre radius from the line but are outside of the catchment area of the stops.

Table 5.1: DiD regression analyses on neighbourhood upgrading and gentrification around light rail stops in Amsterdam.

Variable	**Neighbourhood upgrading**	**Variable**	**Gentrification**
Post treatment	0.0097 (0.0081)	Post treatment	-0.014*** (0.0033)
Treated	0.089* (0.042)	Treated	0.017 (0.022)
Population	-0.000039** (0.000018)	Population	$-7.8*10^{-6}$ ($7.4*10^{-6}$)
Address density	0.0078*** (0.0012)	Address density	0.0064*** (0.0013)
Constant	-0.11 (0.11)	Constant	-0.025 (0.047)
Region effects	Yes	Region effects	Yes
Observation	1260	Observation	1365
Groups	105	Groups	105
R-squared within	0.27	R-squared within	0.10
R-squared between	0.063	R-squared between	0.088
R-squared overall	0.095	R-squared overall	0.062

*p-value <0.1, **p-value <0.05, ***p-value <0.01

The model on neighbourhood upgrading shows the same sign of the treatment effect as the earlier models. Treated neighbourhoods see an increase in neighbourhood upgrading of 0.089, with this value being narrowly significant at the 10% level. While the significance level for the effect of treatment is lower than that of neighbourhoods around line 19, this does indicate that there might be other confounding factors increasing the values of these neighbourhoods that are not captured by the model that are wrongly attributed to the treatment effect.

The gentrification model on the other hand does not return significant results for the model on Amsterdam. The model does find a small positive coefficient however, the p-value hereof is far above 0.10, meaning that the treatment does not significantly alter gentrification. Therefore, the results of the robustness check do support the validity of the original model for gentrification.

6. Discussion

The final part of this thesis consists of the conclusions that can be drawn from the results of the analysis, as well as recommendations for further research into this topic. This will be done by first answering the hypotheses and the research question that were formulated in previous sections. Afterwards policy recommendations will be made, based on the found answers to these questions. This chapter will be ended by a discussion section, wherein the limitations of this research will be mentioned and the effects of those on the results. Finally, specific suggestions will be given on how to further research can improve and build further on this study.

6.1 Hypotheses

As cities in the Netherlands continue to experience rapid urbanization, the government has invested in public transport as a means to alleviate congestion and improve accessibility. However, access to public transit has also been linked to gentrification and displacement of lower-income residents. By understanding the complex interactions between transit and urban development, policymakers can create more liveable and accessible cities for all residents. Therefore, the research question *"What is the effect of access to light rail on gentrification in urban neighbourhoods?"* has been formulated.

Three hypotheses have been proposed to address the research question, which relates to the impact of proximity on light rail access and what the indirect effect of development of new infrastructure is on other parts of the network. Examining these hypotheses will yield valuable insights into the influence of light rail on gentrification and allow for the research question to be answered.

The first hypothesis is split into two smaller sub-hypotheses and states that by investing in public transport infrastructure by constructing new light rail lines will cause neighbourhood upgrading, which will in turn, also result in gentrification in neighbourhood that are upgraded through the benefits in connectivity they gain from access to these new lines and stations. In order to test these hypotheses, two models have been formulated, one with a dependent variable that models neighbourhood upgrading and the other with a proxy of gentrification as a dependent variable. For both models a difference in difference test has been performed by analysing the effect of a treatment, the construction of a light rail line, using a fixed effects regression model with panel data.

Hypothesis 1a: Construction of light rail infrastructure will cause neighbourhood upgrading in neighbourhoods alongside it.

Hypothesis 1b: Construction of light rail infrastructure will cause gentrification in neighbourhoods alongside it.

Based on the results of the difference in difference regression performed on the dataset on line 19, the conclusion can be drawn that the construction of the new tram line led to both neighbourhood upgrading and gentrification in neighbourhoods located within 800 metres from the nearest tram stop. Therefore, this result supports the hypotheses that improved accessibility through access to light rail improves neighbourhoods and increases their desirability.

To find out what the effect of the proximity to the new tram line stops on gentrification and neighbourhood upgrading in affected neighbourhoods is, multiple treatment groups were specified for the second hypothesis. One for neighbourhoods up to 800 metres away, meaning the same distance as the original treatment group in hypothesis 1, one for neighbourhoods from 800 metres to 1150 metres away and one for those from 1150 metres to 2300 metres away. These were respectively called zone 1, 2 and 3.

Hypothesis 2: The magnitude of the effect of the new tram line on gentrification and neighbourhood upgrading will increase as the distance from the nearest stop decreases.

Since the first zone is the same as the treatment group in the previous regression, it returned similar and significant results. Zone 2 also saw a significant increase in neighbourhood upgrading, although contrary to what was hypothesised the found effect is larger than that of the neighbourhoods closer to the stops in zone 1. Zone 3 does not experience a significant change due to the construction of the new line, meaning the distance did influence results in this case.

The tram line only had a significant positive influence on gentrification in neighbourhoods in zone 1, the coefficient found for zone 2 is not significant and zone 3 saw a significant decrease in gentrification due to the treatment. These results suggest that the positive effect of access to light rail on gentrification is strongest for neighbourhoods closest to the new stations, as evident from the significant increase in upgrading in zone 1. However, since zone 3 experienced a significant decrease in gentrification, despite its proximity to the new stations compared to the control group, it indicates the presence of other unaccounted factors influencing the results of the regression, which could also have had an effect on the results found for zones 1 and 2. This is also reflected in the predictive power of the model, which had an R^2 of 0.086, indicating that there are other variables accounting for variation in the results.

For the third hypothesis, tram line 1 in Delft was researched, to figure out whether the construction of new line 19 also had effects elsewhere in the network, around existing lines. Since finding this relation could point to a much larger total effect on gentrification than just the confined area around new stops.

Hypothesis 3: Investments in new tram lines will cause gentrification in neighbourhoods around connecting lines.

The regression results on line 1, show vastly different conclusions for neighbourhood upgrading and gentrification. Where treated neighbourhoods gain a large increase in neighbourhood upgrading, that is significant at the 1% level, the effect on gentrification is not significant at the 10% level, meaning that no changes herein can be attributed to the treatment. Based on the papers discussed in the literature review, it is possible that the time period of the after-treatment period is not long enough in this case to find significant results on gentrification in these neighbourhoods. As mentioned, research on Manchester's metro network showed that influence of exposure to public transport increases over time (Fernando et al, 2021), with some areas only showing impacts more than decade after lines opened.

The answers from the hypotheses allow for an answer to be given on the research question:

What is the effect of access to light rail on gentrification in urban neighbourhoods?

Based on the findings in this study, access to light rail has a positive impact on gentrification in neighbourhoods that are in close proximity to stations around these lines. Positive effects were found for those that have their centre within 800 metres of the nearest stations, however no significant positive effects were found for neighbourhoods that lie further away. In addition, no evidence was found for gentrification through network effects around pre-existing lines in the network.

6.2 Limitations and recommendations

While this study has provided some valuable insights into the research question, there are also some limitations that should be acknowledged. Identifying the constraints and limitations in this study, will assist in providing an understanding in how these results should be interpreted. These will be discussed in this section, accompanied by recommendations for further research.

As mentioned earlier, many of the regression models had relatively low predictive power, this is in part due to not accounting for some possible predictors of gentrification such as education level and access to job opportunities. These variables were not included, due to a lack of sufficient data on neighbourhood level, however these could explain some of the variation found in the results and add to the robustness of the models.

Another factor which could influence the found results is the time horizon of the study. The treatment period studied in this paper consisted of data from 2010 to 2016. As shown in the paper on Manchester's metro network, it is possible for effects of access to gentrification to continue to grow for over a decade (Fernando et al, 2021), meaning that increasing the examined period after treatment could provide more relevant information. A recommendation for further research is therefore to concentrate on light rail development that was conducted longer ago, so the effects on gentrification can be measured over a longer period of time. An added benefit of increasing the period over which the analysis is performed, is that it will allow for conclusions to be drawn on whether anticipation effects are present. The coefficient plots showed increases in neighbourhood upgrading in the years just before treatment, increasing the time period before treatment will allow for analysis on whether the anticipation effect is statistically significant.

In conclusion, light rail lines have the potential to bring about both positive and negative changes to the communities they serve. While they can increase connectivity and economic development, they can also lead to rising housing costs and displacement, particularly for the elderly residents and migrants. To address this issue, local authorities should implement measures such as affordable housing mandates, rent control policies, and targeted subsidies for low-income households. However, policymakers should not just focus on the direct impact of these new lines on the surrounding neighbourhoods, but also consider the indirect effects on other areas of the city. For example, underserved neighbourhoods that currently lack public transit access should also benefit from improved connectivity. Therefore, it is essential for policymakers to consider measures that will benefit all residents within the area.

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