The effects of dual carriageway development on nearby house prices: Evidence from the Netherlands.

Master's Thesis
Real Estate Studies

June 2022

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COLOFON

Title	The effects of dual carriageway development on nearby house prices: Evidence from the Netherlands.
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Version	Final
Date	June 2022

ABSTRACT

Over the past two decades a number of dual carriageway projects have taken place in the Netherlands. Existing literature has widely researched the effects of highway infrastructure on residential properties and although researchers agree upon the presence of positive and negative externalities near roads, different research outcomes exist among authors. This paper analyzes to what extent dual carriageway development affects surrounding house prices by analyzing eight dual carriageway projects from the Netherlands. The analysis considers residential transaction data from 2004 to 2021 and consists of two hedonic price models separating the effects from dual carriageway access points and from dual carriageways itself. Using difference-in-difference model specifications, property prices in the target and control area are compared with each other before, during, and after the construction period of the roads. Findings indicate positive effects of dual carriageway onramps on house prices during and after construction. A negative effect on house prices during and after construction is observed for the dual carriageway itself. These effects do not fade away linearly with distance. Results differ between newly constructed and redeveloped roads. Dual carriageway onramps of newly constructed roads generate higher positive external effects on house prices than of redeveloped roads and only an effect on house prices during the construction period is found for newly constructed onramps, which is positive. Only newly constructed dual carriageways itself generate effects on house prices during and after the construction period, which are negative. Redeveloped dual carriageways itself do not seem to impact house prices.

Keywords: difference-in-difference, external effects, residential real estate, house price, dual carriageway, construction, road infrastructure, infrastructural development, the Netherlands.

ACKNOWLEDGMENTS

I would like to extend special thanks to my supervisor Prof. Dr. E.F. Nozeman for providing valuable feedback and assistance throughout the whole research process. I would also like to thank Dr. M. van Duijn for providing explanations about the applied empirical model and methodology during the Real Estate Research course.

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Disclaimer: *Master's theses are preliminary materials to stimulate discussion and critical comment. The analysis and conclusions set forth are those of the author and do not indicate concurrence by the supervisor or research staff.*

1. INTRODUCTION

Accessibility is crucial to a substantial proportion of our society, as it provides us with shorter travel times and opportunities which were out of reach before. Moreover, increased accessibility decreases the cost of transportation, grants persons access to vaster labor markets, and ensures the inflow of a larger variety of products into a region (Johansson, 1993).

Between 2011 and 2018 traffic intensity in the Netherlands increased with 9.3%, while the total amount of road vehicles increased from 7.9 to 11.7 mln between 2001 and 2020, indicating an increase of 47.6% (CBS, 2020a; 2020b). Dutch roads have become busier over the years and the increased traffic leads to issues in traffic flow (e.g., traffic jams), which is time costly for travelers and goes at the cost of productiveness. Satellite images of the Netherlands from the past 15 years indicate a variety of changes in regional and national road infrastructure. The total road length in the Netherlands increased from 130.446 km in 2001 to 141.361 km in 2020, an increase of 8.4% (CBS, 2020c). The construction and widening of roads in the Netherlands aim at reducing traffic jams & congestion, improving road conditions, fostering positive economic effects, and improving accessibility (Rijksoverheid, 2021; Levkovich et al., 2016). Such road infrastructure developments are capitalized in house prices due to the evaluation of homeowners and residents, leading to either a price appreciation or depreciation, depending on the presence of positive or negative effects (Levkovich et al., 2016).

This research focuses on dual carriageway developments in the Netherlands from the past two decades and their effect on surrounding house prices. The projects included in the analysis are dual carriageways which differ from each other in multiple ways. The most fundamental differences are found in the construction period, type of development, and location. With the use of different time periods in this research, an effort is made to account for different stages of the infrastructural development. Understanding the effects of dual carriageway development on house prices benefits, among all, investors, planners, and policy makers and stimulates improvements in housing and road infrastructure policy.

A variety of studies on the effect of accessibility on house prices is available in various settings. Theisen & Emblem (2020) find evidence that a new highway in Norway on average increased house prices by 5%. Chernobai et al. (2011) and Boarnet & Chalermpong (2021) find evidence for an accessibility premium in California by examining the effects of a newly completed highway and toll road construction, respectively, on house prices. Levkovich et al. (2016) find evidence for a positive effect of highway development projects on house prices in the middle of the Netherlands, but that increased traffic density and noise disturbance have negative effects on house prices. This indicates that road infrastructure development has implications for residents living close by roads, as living close to large road structures exposes them with positive and negative externalities. Negative externalities can be summarized into noise and air pollution, increased traffic intensity, fragmented communities, and the destruction of nature (Levkovich et al., 2016; Tillema et al., 2012). While negative externalities seem to negatively impact nearby house prices, accessibility has a positive correlation with house prices, implying that increased accessibility increases house prices (Levkovich et al., 2016; Huang et al., 2017). Improvements in road infrastructure can thus bring opportunities for homeowners and investors due to house price appreciation from increased accessibility, although this depends on the trade-off between positive and negative externalities.

Existing research has focused extensively on factors influencing house prices. However, Tillema et al. (2012) argue that accessibility has not generated the same level of interest across all fields of study, and that the exact influence of accessibility on household location behavior is still relatively unclear. They argue that existing literature widely focuses on negative externalities caused by the road and its users, and therefore, often fails to consider positive externalities caused by roads in the research. Levkovich et al. (2016) argue that researchers agree upon the fact that roads carry positive and negative externalities with them, but that researchers sometimes reach opposite conclusions. Paliska & Drobne (2020) argue that the effect of increased accessibility on property prices is not always clear. Existing studies reveal mixed results in respect of type of property, type of transport infrastructure, study area, and level of country development. However, these studies do acknowledge the importance of improved accessibility in impacting the real estate market. Paliska & Drobne (2020) suggest it would be useful to investigate the impact of motorways[1] on the value of other residential and commercial real estate, as they focus only on houses sold in rural areas without land. Theisen & Emblem (2020) argue that literature on how a new road impacts house prices is limited. Lastly, Martinez & Viegas (2009) argue that the varied approaches used by researchers make it difficult to compare the results of one study with another. Levkovich et al. (2016) also mention that some of the contradictory results are caused by the use of different methods in the analysis, variable data quality, and regional differences.

Existing literature indicates that there is a trade-off in place between the positive and negative externalities, influencing the average effect of road infrastructure development on house prices. Research has been performed in different countries using varying research approaches, making it unsure whether those findings apply to the Netherlands. Therefore, a deeper understanding needs to be created of the impact of road infrastructure development on house

[1] *Motorways* and *Highways* are considered to have the same definition throughout this paper. The analysis and results in section four will consider regional roads, which are referred to as *Dual carriageways*.

prices. This paper aims to fill in the abovementioned gap and to contribute to the existing literature by analyzing eight road infrastructure developments in the Netherlands from the last two decades, while using up-to-date housing transaction data up to 2021. This research further distinguishes itself by including dual carriageways, opposed to previous studies, which focus primarily on highways. To further fill the gap in the existing literature, an attempt is made to focus on both positive and negative externalities from dual carriageway developments within this research by using two separate distance models and additionally by focusing on the difference between newly constructed and redeveloped dual carriageways.

The research aim of this study is to investigate the relationship between large dual carriageway developments and nearby house prices in the Netherlands, with a specific focus on completely new and redeveloped regional roads, which provide regional and national accessibility. Another aim of this research is to check whether the results correspond with the existing literature and specifically with which authors, as various outcomes in the literature exist. The main research question that this paper aims to answer is: *To what extent does dual carriageway development affect surrounding house prices in the Netherlands?*

In the aim to answer the main research question, three sub-questions have been formulated:
1. What effects of road infrastructure development on house prices are revealed in existing literature?
2. To what extent are house prices influenced by dual carriageways and their onramps?
3. What is the impact of newly constructed and redeveloped dual carriageways on nearby house prices?

To answer these research questions, housing transaction data from the Netherlands will be analyzed. A hedonic regression model with a difference-in-difference (DID) specification will be operationalized to analyze the effects of dual carriageway development on surrounding house prices. A sensitivity analysis will be introduced to analyze the robustness of the findings.

Section two continues with discussing existing literature, where accessibility and factors affecting house prices will be discussed more in-depth. Section three discusses the data, methodology, and dual carriageway projects considered in this research. In section four the results of the data analysis are presented. Section five discusses the sensitivity and robustness analysis. Section six proceeds with the discussion and reflection. Finally, in section seven the conclusions and suggestions for future research are given.

2. THEORY

An extensive amount of research exists on the factors influencing house prices. To identify how road infrastructure development influences property values, it is necessary to create an understanding of the factors determining real estate values. This section presents existing theories and previous studies in the field of real estate property values and road infrastructure.

2.1 Property values, location, and accessibility

Von Thünen (1966) developed the classical location theory model considering agricultural land use to analyze the relationships between markets, production, and distance. According to the model, land use is determined based on transportation costs to the market. Von Thünen (1966) predicts that land nearby a market is, therefore, higher in value because of lower transportation costs. Land value thus decreases when distance to the market increases as a result of higher transportation costs. Following this theory, one could argue that accessibility is a fundamental attribute in determining land values, and thus property prices. The worse the accessibility for a property becomes to an urban core, the lower the property value.

Henneberry (1998) argues that the value and the location of a property are strongly interrelated, with accessibility being a key aspect of location. Physical accessibility is determined by time and cost of travel to other locations, and depends on the presence, effectiveness, and efficiency of transport modes. Urban economic theory predicts that urban growth patterns are influenced by highway improvements through land prices, as land values, all other things being equal, and house prices, will be higher at locations that are more accessible to employment and other desirable destinations. If accessibility is improved by highways, a so-called accessibility premium will be reflected in higher land prices, and thus higher house prices (Boarnet & Chalermpong, 2001). Home buyers value accessibility, as empirical evidence suggests that persons are willing to pay a price premium for properties located in close proximity to public transportation hubs (Agostini & Palmucci, 2008; Debrezion et al., 2011). Furthermore, an accessibility premium is identified for properties located in close proximity to highway ramps and tunnel entries (Boarnet & Chalermpong, 2001; Mikelbank, 2004; Bao et al., 2020).

The urban land rent theory proposed by Alonso (1964) and further developed by Muth (1969) and Mills (1972) predicts that the choice of residential location comes from the trade-off between travel costs to the central business district and the costs of space. In their theory, all jobs are assumed to be located in the central business district and transportation costs offset profits. Based on these theories new transportation infrastructure produces benefits, such as improved accessibility and reduced transportation costs, leading to an increase in land prices

(Paliska & Drobne, 2020). Paliska & Drobne (2020) further argue that when analyzing property prices, one should consider that an individual property also consists of a bundle of physical, location, and neighborhood characteristics. House prices are influenced by many different factors, some of which are difficult to measure. Therefore, the impact of transport infrastructure on house prices cannot be identified without properly controlling for other factors influencing house prices (Paliska & Drobne, 2020).

Real estate values are influenced by a wide variety of internal characteristics that define a property and external factors shared by multiple properties in the same area. Research on the drivers of house prices often include internal characteristics such as square meters of the property and the lot, the age of the building, the number of bedrooms and bathrooms, and whether certain amenities (e.g., swimming pool, air conditioning) are installed in a property (Sirmans et al., 2006). External characteristics influencing property values include, among others, transport accessibility, distance to amenities, quality of schools, and crime rates (Tse, 2002; Gibbons & Machin, 2008). While it is difficult for homeowners to alter the spatial environment, nearby real estate absorbs such changes as alterations to the urban environment are reflected by changes in property values (Ki & Jayantha, 2010; Atkinson, 2015; Cervero et al., 2009). Kohlhase (1991) argues that external characteristics can be a source of property value appreciation, and at the same time also reduce the value of a property, depending on the effect it has on a property. The real estate market imposes a price discount or premium into properties that are located in close proximity to distress or benefits. Hughes Jr. & Sirmans (1992) investigate the price effects on housing of traffic within a neighborhood in a medium-sized city in the US. In their analysis they apply a standard hedonic pricing model on single-family home transaction data from between 1985 and 1989. Findings indicate that a significant price discount is found for properties located in neighborhoods with high traffic intensities. Conversely, a price premium is identified for properties located closely to public transport hubs, properties located in the central business district, and properties with a nice view (Simons & Saginor, 2006; Agostini & Palmucci, 2008; Debrezion et al., 2011; Evans, 2004).

Tillema et al. (2012) find comparable results in their article exploring the need and possibilities for broadening the scope of highway planning by considering the residential context and to create a deeper understanding of the influence of accessibility characteristics and negative externalities on the residential context of households. They do this by investigating existing literature in a review-based manner. The authors argue that households living near highway infrastructure are impacted by both positive externalities (accessibility) and negative externalities (e.g., noise and air pollution). Changes in these factors may trigger relocation or preferences. This implies that the attractiveness of locations will be reflected by house prices.

Results indicate that households prefer to live close to highways to benefit from high regional accessibility, but that they do not want to face the negative externalities that come with it. Based on their findings, Tillema et al. (2012) present a model including four locations opposed to a highway in order to indicate the most attractive location in theory (see figure 1).

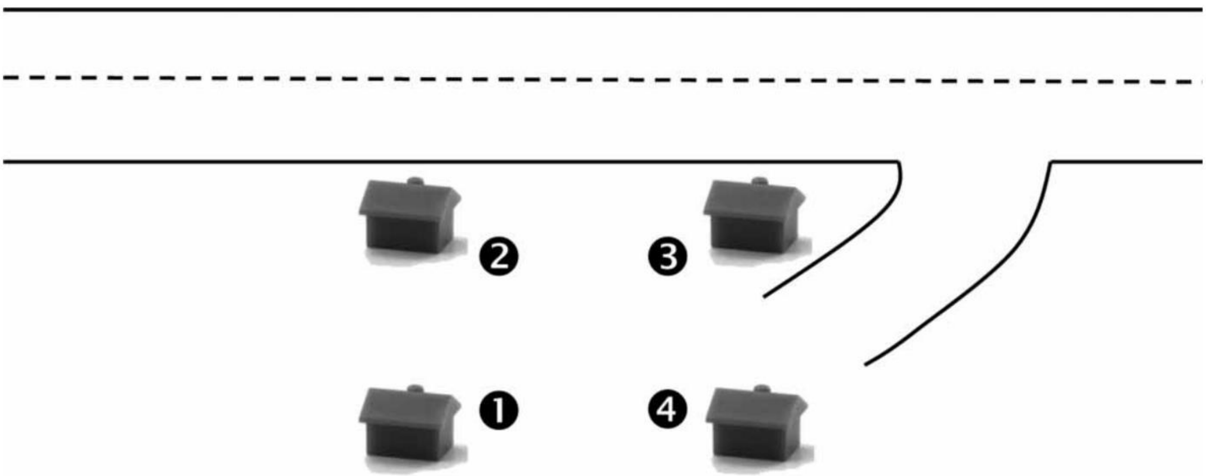

Figure 1. Relationship between road proximity and the positive and negative effects associated with road infrastructure (Tillema et al., 2012).

House number 1 lies far away from the highway itself and from the access lane, providing low accessibility and low negative externality effects. House number 2 lies far away from the access lane but close to the highway itself, providing low accessibility and high negative externality effects. House number 3 lies close to the access lane but also close to the highway itself, providing high accessibility but also high negative externality effects. House number 4 is located on the most optimal location. It lies close to the highway access lane but further away from the highway itself, providing it with high accessibility benefits and low negative externality effects. House number 4 is thus expected to generate the highest house price, while house number 2 is expected to generate the lowest house price. They conclude that households prefer to live further away from large roads in order to reduce the nuisances created by it. This implies that road infrastructure development may have a negative effect on nearby house prices. However, especially those living near a highway benefit from increased accessibility, as long as there is a ramp nearby. House prices may appreciate due to improved accessibility, indicating that house prices seem to be negatively correlated with the distance to the nearest highway access lane (Tillema et al., 2012). Other authors (e.g., Levkovich et al. (2016); Huang et al. (2017); Boarnet & Chalermpong (2001)) also argue that increased accessibility leads to higher house prices, implying that road infrastructure development can have a positive effect on house prices.

2.2 Empirical evidence of the impact of road infrastructure on real estate values

In the United States, studies on the impact of highways on land and house prices start to appear in the late fifties during the start of the Interstate Highway Program (Boarnet & Chalermpong, 2001). Huang (1994) examines the literature on hedonic price studies of the impact highway access has on house prices and concludes that the early studies, from the fifties and sixties, usually indicate large land price increases near major highway projects. Later studies, from the seventies and eighties, however, indicate a smaller and often statistically insignificant land price effect from highway development projects. Giuliano (1989) comes to similar conclusions when examining literature on the effect of transportation infrastructure on urban development, as the later studies indicate smaller impacts of highway access on house prices. Reasons for these results in later studies according to Huang (1994) are due to generally good accessibility throughout the road network in most U.S. cities, while noise and other negative externalities due to living close to a highway reduce the value of residential properties. In a study on homes near the Washington D.C. Beltway, Langley (1976) concludes that house prices increase with increasing distance from the highway up to 1,125 feet (343 m) and decrease with increasing distance from the highway beyond 1,125 feet. He argues that below 1,125 feet the negative externalities dominate the value of accessibility.

In the spatial analysis of the relationship between housing values and investment in transportation infrastructure Mikelbank (2004) identifies two different results in Columbus, Ohio, depending on the spatial dimensions considered. A hedonic price function is operationalized via regression analysis using data from two spatial databases which consider single-family detached residential properties sold during 1990, and investment information on all regionally significant projects. Mikelbank (2004) examines the impacts along three time-dimensions: 1. preconstruction – the announcement period, when the house is sold after the project was made official, but before construction began; 2. during construction – the house was sold during construction; 3. after completion – the house was sold after the project was completed. The investments were investigated along two spatial dimensions: 1. close to the transacted house. 2. located between the house and other regional accessibility points. Investments made within a radius of 1 mile of a house indicate negative and significant announcement effects on house prices, reflecting the potential inconvenience of the construction in vicinity of the property caused by expectations. This causes a temporary and significant loss-of-value for these properties. During construction also negative and significant effects on house prices are found, supporting the inconvenience due to infrastructure investment when occurring in the immediate proximity of the transacted property. Proximity effects have a depressive force on a local housing market from the announcement date until the completion of a project. For houses within 0.25 miles of a completed investment (after construction) the average effect on house prices is positive. For investments made between a house and the CBD or nearest retail center the effect on house prices is positive and significant. According to Mikelbank (2004), at this scale households anticipate and value the potential accessibility increases after completion of construction. This anticipation effect of accessibility in the future is then reflected in the house transaction prices. This indicates that households value well invested-in routes to regional accessibility points (Mikelbank, 2004). Finally, Mikelbank (2004) finds that up to approximately 6.7 miles to a highway interchange, house prices decrease with increased distance from a highway exit. This further support that households value nearness to well-developed highway networks. After the turning point of 6.7 miles, however, house prices increase with distance from the highway, as a so-called remoteness premium comes into place. Houses located within 0.25 miles from a highway, but without a ramp, see a discount in the house price of 7% as the effect of the highway on house prices is negative and significant within this distance range. Somewhat different results are found by Paliska & Drobne (2020), who examine how new motorway sections affected the house prices in the mostly rural Northeastern part of Slovenia. There the results indicate that proximity to a motorway does not significantly affect house prices for properties within 300 m range of a motorway. However, the effect of the proximity to a motorway ramp on house prices is positive and is stronger at closer ranges, and becomes insignificant for properties within 500 m of an exit and at distances greater than 6 km.

In a perfectly efficient market, information about the future is absorbed by the market and reflected by price changes (Poterba, 1984; McMillen & McDonald, 2004). Real estate prices can as well be influenced by information, which leads to expectations about the future, which are reflected in house prices. Besides Mikelbank (2004), a variety of authors identifies an anticipation effect as the overall effect of infrastructural development on house prices is often already noticeable before the opening of the road due to public anticipation (Levkovich et al., 2016). Theisen & Emblem (2020) examine the impact of a new highway parallel to an existing road on house prices in Norway. The new highway constructed in 2009 connects the coastal towns in the South of Norway and is of significantly higher standard than the existing roads, while providing two more lanes, a higher speed limit, better safety, and reduced risk of delays caused by congestion and accidents. With a difference-in-difference regression, Theisen & Emblem (2020) examine how this change in infrastructure affected house prices in the region using transaction data containing 37.126 observations from between 2003 and 2013. Results indicate house price increases of 13% 30km from the core town and 9% 50km from the core town. 70km from the core town no increase in house prices were experienced, despite the reduction in travelling time. Theisen & Emblem (2020) argue that this could be due to the town at 70km distance having a better balance between population and workplaces than the other towns limiting the need of commuting to the core town, or the distance to the large core being too large to be acceptable as daily commute, as 50 minutes is close to the maximum time that people in Scandinavia are willing to spend on a one-way commute (Sandow & Westin, 2010). These results are in line with Osland et al. (2007), who found that house prices are least affected in the areas with the longest commute. Theisen & Emblem (2020) also argue that investments in infrastructure will be capitalized into house prices, as house prices in the treatment towns started to increase slightly after construction began. The full treatment effect materialized after the moment the highway was opened. Two explanations are given to why new infrastructure is not always discounted into house prices at the time of the decision, but later on. First, information about the decision to build a new highway might not always reach the public. Second, even if the public knows about the decision to build a new highway, there might still be doubt to whether the project is actually going to be built, and whether there will be no delays. Only when construction begins, those doubts will be swept away.

Chernobai et al. (2020) studies the effect of a newly completed highway extension in California on surrounding house prices using 24.724 single-family home sales for the period between 1995 and 2006. The timeframe consists of 7 years before to 4 years after completion of the highway extension. The sample was disaggregated by 0.4-mile distance intervals, as larger increments failed to capture short-distance non-linearities in the distance effects, and shorter increments weakened the statistical results due to decreasing observations within each interval. Results indicate that after completion of the highway extension houses in the closest and more distant areas to the highway extension appreciated less rapidly than houses in the intermediate distance intervals. The maximum house price appreciation caused by the new highway occurs at moderate distances from the highway after completion. Lower price increases are observed for houses sold closer to highways and much further away. Boarnet & Chalermpong (2001) also based their study in California, where they examine the link between highways and urban development by employing hedonic analysis and multiple sales techniques to study the impacts of the construction of toll roads on house prices. Their dataset contains 367.841 observations on every home sale in Orange County from 1988 until early 2000. Results indicate that the construction of the toll-road network generated an accessibility premium reflected in the house prices, corresponding with findings from Levkovich et al. (2016), Tillema et al. (2012), and Huang et al. (2017). Evidence suggests that homebuyers are willing to pay for increased access to newly constructed roads.

Levkovich et al. (2016) study the effects of highway development on house prices by studying the Dutch A30 and A50 highways, both completed in 2004. They perform a repeat sales analysis based on housing transaction data consisting of approximately 438.000 transactions between 1995 and 2011. They define three phases of the project: 1. 1995-1999: the control period, which is the period before the development; 2. 2000-June 2004: the construction period; 3. July 2004-2011: the treatment period, which is the period after the opening of the highway. Results indicate that changes in accessibility cause for a significant positive effect on house prices in municipalities surrounding the projects. Increased traffic intensity and noise disturbance, on the other hand, cause house price decreases. The overall total effect of highway construction on house prices is positive and noticeable before opening due to public anticipation. Martínez & Viegas (2009) find somewhat comparable results when examining the relationship between the availability of transportation infrastructure and services on residential property values in Lisbon. Their results indicate that proximity to urban ring roads and radial networks have a positive impact on property prices due to accessibility, while proximity to urban distribution networks and motorways have a negative impact on property prices. They argue that these results can be caused by congestion and noise externalities experienced near motorways and distribution networks, reducing attractiveness of properties in these areas, and dominating the positive externalities (such as accessibility). In Hong Kong, similar to Levkovich et al. (2016), Bao et al. (2020) examine the impacts of a transportation development project on residential property prices. The analyzed tunnel provides a direct route between a residential district in the urban periphery to the airport and the Hong Kong-Zhuhai-Macao bridge. A hedonic pricing model in a difference-in-difference model framework and repeat-sales indices are used to analyze residential property transaction data within 20 km from the tunnel from between April 2005 and October 2008. Bao et al. (2020) define three stages as well: 1. The proposal (June 2009-October 2011). 2. The announcement (October 2011-June 2013). 3. Construction period (June 2013 to present, 2018). Results indicate that the residential property market capitalizes the expected accessibility benefits of the tunnel well before its actual opening. The accessibility premium is the largest during the proposal period. Higher price appreciation in the areas is found closer located to the tunnel due to increased preferences for residential properties on those locations, corresponding with findings from Tillema et al. (2012), Paliska & Drobne (2020), Boarnet & Chalermpong (2004), Mikelbank (2004), but contrasting with findings from Langley (1976), Chernobai et al. (2020), and Levkovich et al. (2016).

2.3 Hypotheses

The exact effects of dual carriageways, or regional roads, on house prices has not been researched as widely as highways, making it unsure how they impact house prices. However, dual carriageways from the Netherlands carry similar characteristics to highways in Europe. Therefore, the hypotheses are based on literature on highway infrastructure development. The review of existing literature indicates that not all authors come to the same conclusion.

Urban and economic theories predict that accessibility is a fundamental attribute in determining land values, and thus property prices. Researchers often agree upon the fact that accessibility is positively valued by homebuyers, as house prices seem to appreciate nearby access points to road networks. However, researchers argue that negative externalities such as noise and air pollution from road infrastructure also play a role in determining property prices. Drawing from the available literature, the hypotheses considered in this paper are defined as follows:

1. Dual carriageway access points have a positive effect on surrounding house prices during and after the construction period.
Evidence is for this is found by authors such as Huang (1994), Boarnet & Chalermpong (2001), Mikelbank (2004), and Chernobai et al. (2020) in the United States, by Levkovich et al. (2016) in the Netherlands, by Theisen & Emblem (2020) in Norway, and by Bao et al. (2020) in Hong Kong.

2. Dual carriageways itself have a negative effect on surrounding house prices during and after the construction period.
Evidence for this is found by authors such as Langley (1976) and Mikelbank (2004) in the United States, by Levkovich et al. (2016) in the Netherlands, by Martínez & Viegas (2009) in Lisbon, and by Tillema et al. (2012).

3. The optimal location for residential properties is as close to a road access point as possible for accessibility benefits, but as far away from the road itself to avoid negative externalities.
This is based on the theory described thoroughly by Tillema et al. (2012) on the optimal residential real estate location opposed to highway infrastructure. Kohlhase (1991), Boarnet & Chalermpong (2001), Huang et al. (2017), and Bao et al. (2020) find corresponding evidence by finding an accessibility premium close to onramps. Mikelbank (2004) and Levkovich et al. (2016) find corresponding evidence by finding a price discount close to a road. Therefore, by analyzing whether there exists an accessibility premium close to onramps and a price discount close to dual carriageways itself, we check whether this hypothesis is rejected for dual carriageways using the two models introduced in section 3.

4. The effect of newly constructed roads and redeveloped existing roads on surrounding house prices is similar. To the best of my knowledge, this has not been researched before and, therefore, the analysis will bring insight into if this hypothesis is rejected for dual carriageways.

3. DATA & METHODOLOGY

This section discusses a variety of topics in preparation of the analysis. It starts with discussing the conceptual framework, followed by the empirical model. Then the target and control area are discussed, followed by the study area. Finally, the data and variables used in the analysis are discussed, followed by the descriptive statistics.

3.1 Conceptual framework

The statistical analysis is based on the conceptual framework presented in figure 2, which has been developed based on existing literature and the dataset. The conceptual framework indicates variables that impact house prices. On the one hand house prices are influenced by property, transaction, and locational characteristics. On the other hand, house prices are influenced by road infrastructure development through the positive and negative externalities that result from such development. Negative externalities such as air and noise levels can be measured but are not included in the analysis due to the lack of precise data for each individual property. Instead, distance dummies will be introduced to account for negative externalities, as one could argue that the effect on house prices becomes negative if the negative externalities are more dominant than the positive externalities within a distance ring from the road, and the other way around, as externalities are capitalized into the real estate market (Levkovich et al., 2016). In this analysis, transaction prices of the properties are used as indicator for house prices, as this comes as close to the willingness to pay for each individual property as possible.

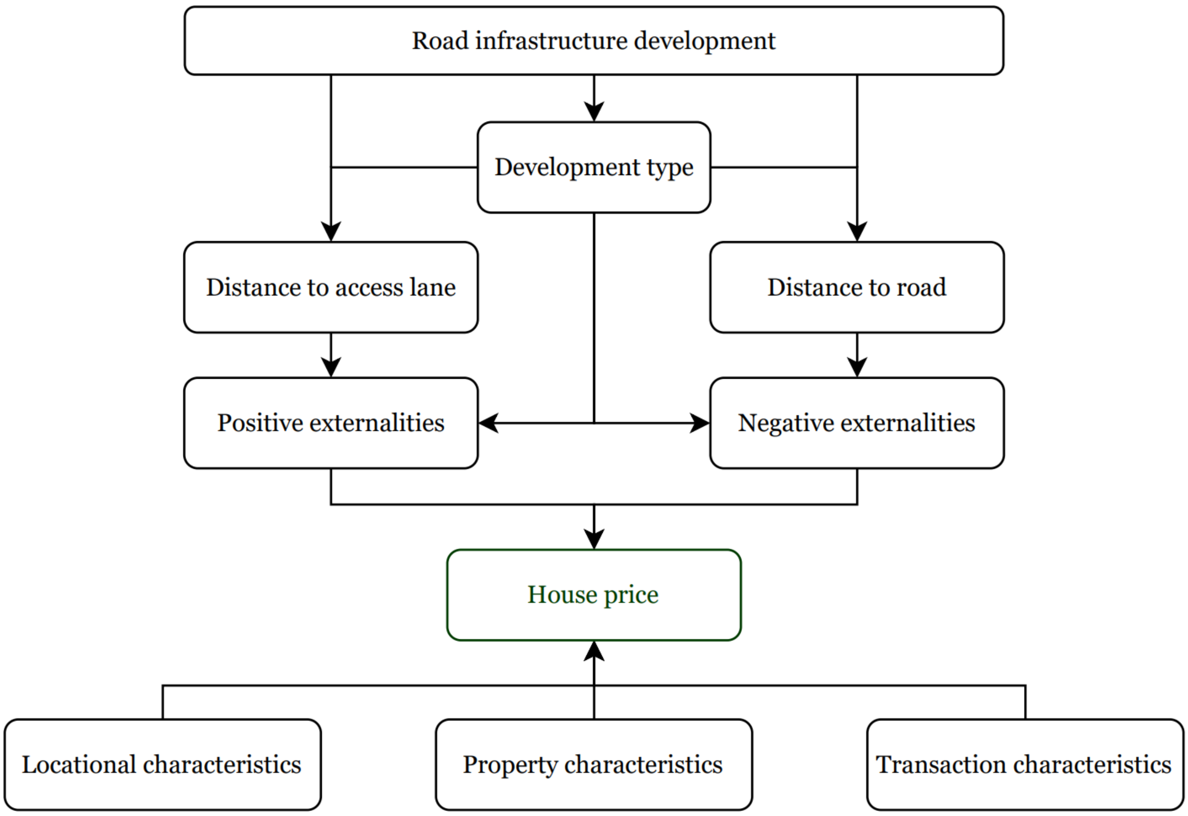

Figure 2. Conceptual framework.

Across the globe, a wide variety of road classifications are known, such as carriageway, single carriageway, dual carriageway, expressway, state highway, and district road; and they are often very similar. In the Netherlands, all highways are labeled with an A followed by a number, whereas all non-highway regional roads (carriageways) are labeled with an N followed by a number. This research includes eight so-called N-roads from the Netherlands. Six of these roads are four-lane dual carriageways, the two other projects consist of a mix between sections single carriageway and sections dual carriageway. However, in the Netherlands all of them are known as *N-wegen*. Therefore, for the ease of interpretation and understanding of the results we will refer to all roads included in the sample as dual carriageways.

3.2 Empirical model

A common methodology to determine the effect variables have on property prices is to operate a hedonic price model (Rosen, 1974). To measure the effect dual carriageway development has on house prices, a difference-in-difference hedonic price model is estimated to capture the price change during and after the developments in predefined target and control areas (Zhang et al., 2019). A difference-in-difference framework is preferred as it is able to measure the effect on house prices during different periods of time, while including more properties than, for example, in a repeat sales analysis. Based on the work of Zhang et al. (2019) and Levkovich et al. (2016), the following equation is estimated:

$$
\begin{aligned}
\ln\left(Price_{ijt}\right) = \; & \beta_0 + \beta_1\, Target_i + \beta_2\, Target_i \times Trend_t + \beta_3\, Target_i \times Distance_i \\
& + \beta_4\, Target_i \times Trend_t \times Distance_i + \beta_5\, Target_i \times Construction_t \\
& + \beta_6\, Target_i \times Construction_t \times Distance_i + \beta_7\, Target_i \times After_t \\
& + \beta_8\, Target_i \times After_t \times Trend_t + \beta_9\, Target_i \times After_t \times Distance_i \\
& + \beta_{10}\, Characteristics_{kit} + \beta_{11}\, Year_t + \beta_{12}\, Postcode_j + \varepsilon_{ijt}
\end{aligned}
$$

where $\ln(Price_{ijt})$ is the log of the transaction price of property i in a geographical area j and in sale year t; $Target_i$ is a dummy variable indicating whether property i is located within the target area or not. $Target_i$ is equal to one if property i is located in the target area, and zero if otherwise; $Trend_t$ is the difference between the year of sale of property i and either the year of start of construction or the year of completion of the nearest dual carriageway; $Distance_i$ is the distance between property i and either its nearest dual carriageway or its nearest onramp; $Construction_t$ is a dummy variable indicating whether property i is sold during the construction period of the nearest dual carriageway or not. $Construction_t$ is equal to one if property i is sold during the construction period, and zero if otherwise; $After_t$ is a dummy variable indicating whether property i is sold after the opening (i.e., after construction) of all sections of the nearest dual carriageway or not. $After_t$ is equal to one if property i is sold after the opening of the dual carriageway, and zero if otherwise; $Characteristics_{kit}$ represents characteristics k of property i in sale year t (e.g. type of property, days on market, building period, number of rooms, size); Year_t controls for time fixed effects with transaction year of property i; Postcode_j controls for spatially fixed effects; ε_{ijt} is an error term. The coefficients to be estimated are β_0 - β_{12}.

The difference-in-difference approach includes a variety of variables of interest. These variables are used to investigate the effects dual carriageway development has on surrounding house prices. Target_i captures the difference in house prices between the target and control area before the development of the dual carriageways. The main variable of interest is $\text{Target}_i \times \text{After}_t$. $\text{Target}_i \times \text{After}_t$ equals one if property i is located in the target area and is sold after the opening of the dual carriageway, and zero if otherwise. The coefficient measures the external effects of dual carriageways on house prices in the target area. Furthermore, $\text{Target}_i \times \text{Construction}_t$ equals one if property i is located in the target area and is sold during the construction period of the dual carriageway, and zero if otherwise. This coefficient will give an indication of the effect dual carriageway development has on house prices during the construction period. Target_i and $\text{Target}_i \times \text{After}_t$ are interacted with Trend_t. $\text{Target}_i \times \text{Trend}_t$ identifies the temporal heterogeneity of property price difference between target and control area before dual carriageway development. $\text{Target}_i \times \text{Trend}_t$ equals property i's transaction year minus the year of the start of the construction, given that property i is sold before the start of construction of the dual carriageway and located within the target area. This coefficient can be interpreted as how the price difference between the target and control area before dual carriageway development changed over time. $\text{Target}_i \times \text{After}_t \times \text{Trend}_t$ equals property i's transaction year minus the year of opening if property i is located in the target area and sold after opening of the dual carriageway and suggests how the external effects of dual carriageways development on house prices vary over time.

Four variables are interacted with Distance_i, which allows the observation of how these effects vary with distance. Distance_i is measured by the Euclidean distance between property i and the nearest dual carriageway and is done in two ways. The first method is the distance between property i and the nearest dual carriageway access point, as this takes into consideration the benefits of regional and national accessibility, which we expect to have a positive effect on house prices. The geographical locations of these road access points are 'the point of no return', where there is no way back and a vehicle has to proceed onto the onramp. The second method is the distance between property i and the nearest location of the actual dual carriageway, implying that there is not always an onramp in the vicinity. This takes into consideration the possible negative externalities (e.g., noise and air pollution) from the dual carriageways, which we expect to have a negative effect on house prices. The Euclidean distance calculation is justified based on the notion that the few hundred additional meters an individual has to drive from their property in reality to reach an onramp is generally neglectable compared to the total length of a trip when travelling by dual carriageways (Wilhelmsson, 2000). Furthermore, Euclidean distance calculation is the most suitable method for measuring the distance between the property and the road itself as negative externalities travel in a straight line. The distances are calculated using Geographic Information System (GIS) techniques.

3.3 Target and control area

Tillema et al. (2012) argue that the most optimal location for a property is as far away from a road as possible to avoid negative externalities such as noise and air pollution, but at the same time as close as possible to a road access point to enjoy accessibility benefits (see figure 1). Therefore, this research will make use of two models to separately measure the effect dual carriageways itself and their onramps have on surrounding house prices. The first model will be considered the 'accessibility model'. The second model will be considered the 'road distance model'. The major difference between these models is how Distance_i is calculated. In the accessibility model, the distance is measured between property i and the nearest dual carriageway access point. In the road distance model, the distance is measured between property i and the nearest coordinate where the nearest dual carriageway is located. Other differences will be discussed in the remainder of this section. The most significant differences are found in the size of the target and control area, leading to a difference in sample size between the two models. The use of two models aims to make an effort to separately measure different effects from dual carriageway development on house prices and provide various perspectives. The accessibility model focuses on positive externalities, the road distance model focuses on negative externalities.

Accessibility model

A target area consisting of properties within 6 km of the nearest dual carriageway access point is proposed for the accessibility model based on the work of Paliska & Drobne (2020). A control area which considers all properties located between 6 and 10 km of the nearest dual carriageway access point is proposed based on the work of Mikelbank (2004) and Levkovich et al. (2016). According to Levkovich et al. (2016) this control area is supported by the assumption that postal code areas within 10 km range share common spatial and housing market characteristics with the treatment area, while not each property is affected by the development.

Road distance model

For the road distance model, a target area which considers all properties located within 2.5 km of the nearest dual carriageway section is proposed. The proposed control area consists of properties located between 2.5 and 4 km, which approximately matches the ratio between target and control area distance of the accessibility model. While literature suggests that negative externalities fade away at approximately distances between 100 m and 640 m, noise from tires is able to travel further depending on circumstances. With the dual carriageways considered in this research traveling through less densely populated areas in a relatively flat country, such as the Netherlands, one can assume that in some regions tire noise travels multiple kilometers depending on wind directions. The flat surface also plays a role in the landscape, as new dual carriageways can cause visual pollution, especially in areas where no road existed before. Also during construction, one is able to see, and possibly hear, road construction works, depending on the circumstances (e.g., weather conditions and vegetation). Therefore, it becomes interesting to create a broader view instead of only measuring the effects closely located around the road. To take into account the effect onramps have on house prices and prevent some of the interference from accessibility benefits, all properties within 500 m of a dual carriageway access point are removed from the sample of the road distance model.

3.4 Air pollution, noise disturbance and traffic intensity

Tillema et al. (2012) argue that road-related factors impact their surroundings at different spatial scales. The effect of air and noise pollution from roads are generally limited to the first 100 m from a road. Studies on noise valuation indicating that noise effects fade away at a distance between 300 and 600 m from a road, depending on the methodology applied (Eliasson, 2005). Wilhelmsson (2000) finds evidence that for distance less than 300 m from a road in suburban areas in Sweden the marginal contribution of traffic noise to the surrounding noise disturbance is substantial. Levkovich et al. (2016) implement a noise level dummy which considers properties within 300 m from a highway to be impacted by noise pollution from the highway. Langley (1975) finds comparable results in the United States as house prices increase with distance from the highway up to 1.125 ft, after which they begin to decline. This implies that negative externalities dominate below approximately 340 m, while these fade away above this point where possibly accessibility benefits dominate the negative externalities. Mikelbank (2004) finds comparable results, as houses located within approximately 400 m (0.25 miles) from a highway, without an onramp nearby, see a discount of 7% as the effect of the highway on house prices is negative and significant within this distance range. Chernobai et al. (2011), furthermore, find evidence that in the first three years of construction house prices increase as the distance from the highway increases from zero to 0.4 miles, also indicating the existence of negative externalities near a road. Therefore, the implementation of dummy variables to take into account some of the negative externalities is proposed. The first dummy is based on Tillema et al. (2012) and controls for noise and air pollution in close proximity of a road and considers properties located within 100 m of a dual carriageway. The second and third dummy variables follow the work of Levkovich et al. (2016). The second dummy is also a noise and air pollution dummy and considers properties located within 300 m of a dual carriageway. These two dummy variables will be applied to both models and exclude properties within 500 m of an onramp in both models to prevent interference from accessibility benefits to some degree. As redeveloped roads produced negative externalities before construction as well, both noise dummies consider the period before, during, and after construction for redeveloped dual carriageways and the period during and after construction for newly constructed dual carriageways. The third dummy considers properties located within 1,000 m from the nearest dual carriageway onramp and sold after construction of the dual carriageway. It aims to control for traffic intensity, but can also suggest that an accessibility premium exists, depending on the coefficient. This dummy is applied in both models, but in the road distance model results apply to properties within 500 m and 1,000 m of an onramp as properties within 500 m of an access point are not considered in this model to prevent interference from accessibility externalities.

3.5 Housing data

This research uses residential real estate transaction data from the Dutch Association of Real Estate Brokers and Real Estate Experts (NVM). The NVM is the largest association of real estate agents and appraisers in the Netherlands, accounting for almost 75% of all Dutch houses sold (NVM, 2021). The data of the NVM reaches from January 2004 to April 2021 and consists, among all, of a wide variety of variables: address, transaction price, transaction date, and property characteristics (i.e., size, number of rooms, type & construction year). The total dataset includes 841.171 properties. The infrastructural projects considered in this research are based on data from planning approval decision reports from the Ministry of Infrastructure and Water Management and historic and current satellite images of the Netherlands. Eight projects, which do not interfere with each other, and 106 road access points on a total of 66 junctions are included; see table 1, figure 3, and Appendix A for project information.

Based on the data, three time periods are identified: target, construction, and after. The target period for each individual infrastructural project is three years before the start of construction. The second period is a so-called anticipation period, or construction period, which considers the period between the month construction began up to the month the road officially opened. The third period is the treatment period, which is referred to as after and considers two and a half years after the opening of the whole project. The use of months in which construction began and the road opened is preferred as for some projects information on exact dates lacks. Moreover, with the assumption of the public anticipation effect, it is expected that the residential property market capitalizes the expected accessibility benefits before the actual opening of the road, and the possible construction nuisances some time before the day construction starts (Mikelbank, 2004; Levkovich et al., 2016; Bao et al., 2020). Furthermore, with some projects opening in sections, it has been decided upon to use the opening month of the last section because even if a section opened earlier, construction was continuing on other sections, meaning that the full potential of the infrastructural development could not be used. This also implies that until the last section opens, accessibility benefits might not reach all areas yet, while traffic intensity during construction might be lower than after opening due to road obstructions.

The fundamental reason for the three years before and two and a half years after the construction period is data availability. For the oldest project there are no data available more than three years before the start of construction, and for the newest project there are no data available more than two and a half years after completion. However, as existing literature hints at an anticipation effect in infrastructural developments, where prices in the target area start rising before the completion of the project as a result of public anticipation, two and a half years after completion should suffice to measure the external effects infrastructural developments have on surrounding house prices. One could choose to drop the two most recent projects and extend the treatment period from two and a half years to four and a half years, partly compensating for the loss of observations in such case. However, this would mean that the second and third largest projects in terms of road length would be dropped (see table 1), not only significantly reducing the number of observations, but also the extent to which the result would apply to a larger part of the country. It is expected that two and a half years after completion is sufficient to measure the effect of dual carriageway development has on surrounding house prices.

3.6 Study area

Figure 3 presents the study area considered in this research. It consists of eight dual carriageways, which have undergone construction work between 2007 and 2018. As many projects as possible have been added to the analysis to expand the sample size, to consider various regions of the Netherlands and to generate more general results, which are not case-specific. However, due to data limitations and target area overlap, about half of the initial projects were dropped. Table 1 gives an overview of the projects included. The road sections included in this research are located across eight of the twelve Dutch provinces and, including the control areas, properties from nine provinces are included in the analysis. In total, roughly 180 km of road infrastructure is analyzed. Please note that project #3 consists of two projects merged into one, which is possible due to major construction period overlap and due to both projects being part of a larger overarching project. This has been done to prevent overlap in the target areas. Figures including the target and control areas can be found in Appendix A.

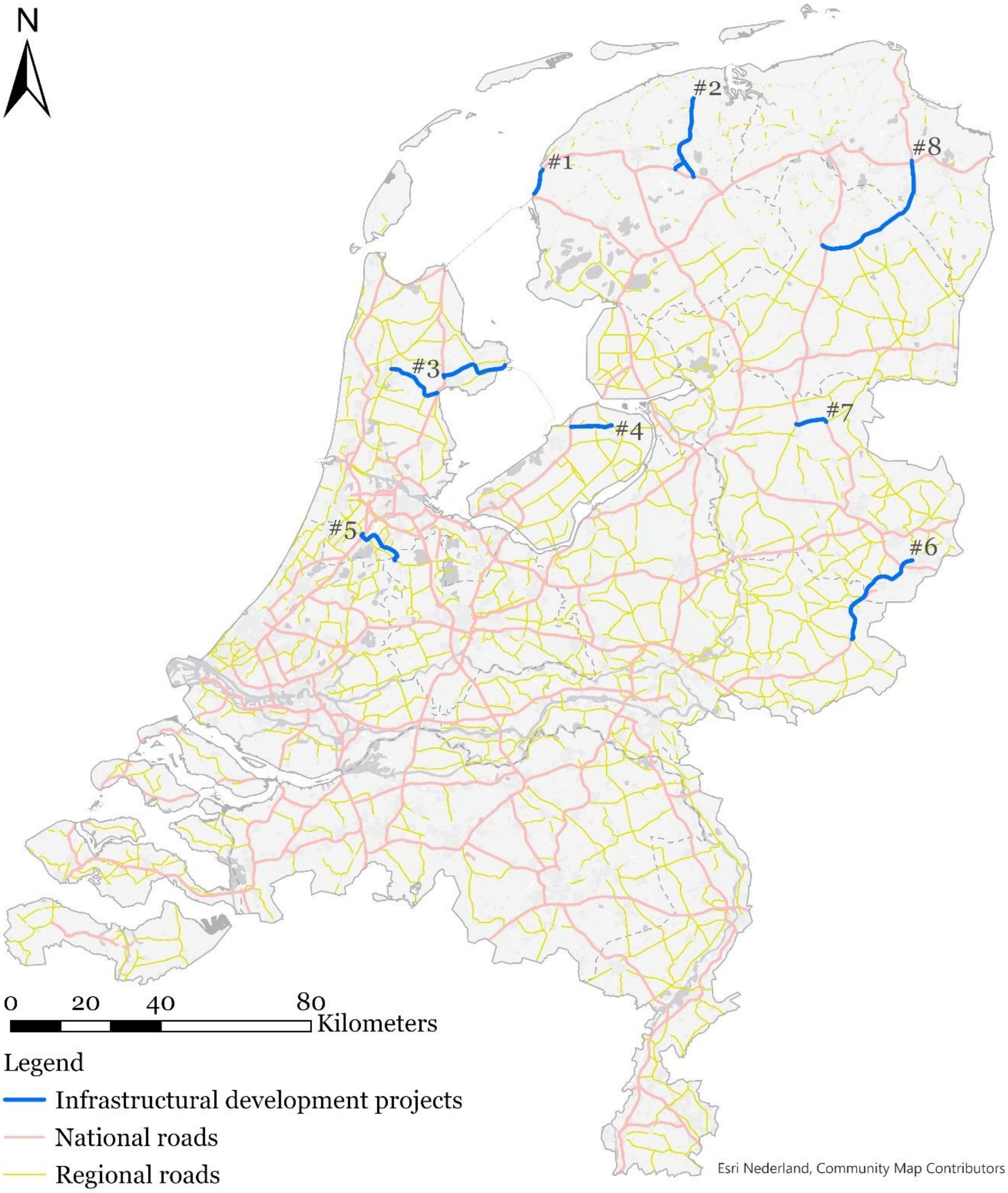

Figure 3. The eight infrastructural projects considered in the analysis.

Table 1. Dual carriageway projects

#	Road	Section	Start	Open	Type	Junctions	Lanes	Length
1	N31	Zurich – Harlingen-Zuid	2007 Jul	2008 Dec	Redeveloped	Elevated	4	6.96 km
2	N356	De Centrale As	2012 Sep	2016 Oct	New	Elevated	4	27.12 km
3	N23	Enkhuizen - Heerhugowaard	2014 Nov	2018 Nov	Redeveloped	Level & Elevated	2 & 4	35.78 km
4	N23	Lelystad - Dronten	2009 Dec	2012 May	New	Elevated	2	10.93 km
5	N201+	Schiphol – Mijdrecht	2007 Jan	2014 May	New	Level & Elevated	2 & 4	15.43 km
6	N18	Groenlo – Enschede	2016 Oct	2018 May	New	Elevated	2 & 4	32.02 km
7	N36	Omleiding Ommen	2009 Feb	2010 Jun	New	Level	2	8.54 km
8	N33	Assen - Zuidbroek	2013 Mar	2014 Sep	Redeveloped	Elevated	4	43.49 km
							Sum	180.28 km

3.7 Variables and data selection

The dataset of the NVM consists of 841,171 properties. In preparation of geoprocessing and distance calculations, properties have been geocoded in ArcGIS Pro, which is the process of transforming addresses into geographic coordinates so that they can be projected onto locations on a map. After projecting the properties onto a base map, all superfluous observations have been removed by using buffers around the projects. 590,827 observations were dropped in the process of removing all addresses outside of the buffer area consisting of 10 km around the infrastructural projects and 10 km around the access points combined, resulting in a dataset of 250,344 observations. For those 250,344 observations the distance to the nearest road and access point has been calculated, after which the dataset has been imported into Stata as the basis for both the accessibility and the road distance model. The data have been prepared in Stata before separately analyzing the two models. Observations containing missing values have been dropped. Observations containing values labeled as being unrealistic have also been dropped, such as properties with a transaction price of €1, or a living area of either 0 m^2 or 9,999 m^2. PC6 with less than six and more than six characters have been dropped, as for PC6 to be correct it needs to contain four numbers followed by two letters. PC4 0000 and 9999 have been dropped as 0000 does not exist and 9999 is not located within the target nor control area. Observations containing properties sold outside of the time frame considered in the analysis (target, construction, and after) have been dropped.

A handful of observations have been adjusted by hand to prevent dropping these observations. Using online databases (e.g., Kadaster), the most unrealistic construction years for properties were adjusted to the correct ones (previously below 1450 and above 2030), after which construction years before 1450 and after 2023 have been dropped. Also a handful of remarkably high transaction prices were adjusted as sometimes there were simply too many zeros behind the value, indicating a typo. This has been repeated until most properties matched the current price estimation in terms of number of digits. One should note here that the price itself has not been adjusted. Only the number of digits has been adjusted if it was clearly human error, e.g., a current price estimation of €650,000 for a given property indicates that a historic transaction price of €4,500,000 contains a typo, as the correct price should be €450,000. Transaction prices below €75,000 and above €1,500,000 have been dropped to prevent the outliers influencing the regression results. Finally, for the accessibility model all observations with a distance more than 10 km to the nearest dual carriageway access point have been dropped. For the road distance model, all observations with a distance less than 500 m to a dual carriageway access point and a distance more than 4 km to a dual carriageway itself have been dropped. This has resulted in 121,036 observations in the accessibility model, and 51,189 observations in the road distance model. Besides data cleaning, a number of variables have been transformed. The market days variable (number of days on the market until sold) has been transformed into a logarithm as the original variable was highly skewed. Also the living area and number of rooms variables have been transformed into a logarithm as the original variables had a large right-sided tail. All variables considered in the analysis and the creation of these variables can be found in the STATA Syntax in Appendix D & E. The variable descriptions of the variables used in the analysis can be found in table 3.

Table 4 and 5 present the descriptive statistics for the accessibility model and the road distance model. The target and control area are quite similar in both models. Most noticeable is the difference in the transaction price between the target and control areas. The average transaction price is €247,875.10 in the target area and €272,210.90 in the control area of the accessibility model. The average transaction price is €245,316.30 in the target area and €252,779.90 in the control area of the road distance model. In appendix B the transaction prices and transaction prices per m^2 of the target and control areas are compared. It can be concluded that the trend in both target and control areas follow similar patterns in both models. From table 3 and 4 it becomes clear that in both models over 84% of the properties sold are houses and that in the target area more properties are constructed after 2010 compared to the control area. In both the accessibility model and road distance model 110 and 534 properties lie within 100 m and within 300 m of a dual carriageway, respectively. In the accessibility model, 2.535 properties lie within 1,000 m of an onramp. In the road distance model, 1.959 properties lie within 500 m and 1,000 m of an onramp, as properties below 500 m distance of access points are not included.

According to Brooks & Tsolacos (2010) there are five assumptions to be tested when operating a linear regression model to make sure that the coefficient estimates and associated standard errors are valid. These assumptions are summarized in table C1 of Appendix C. If these assumptions hold, the estimator is known as a Best Linear Unbiased Estimator (BLUE), which indicates that the estimation technique has a number of desirable properties and that hypothesis tests regarding the coefficient estimates could be conducted validly (Brooks & Tsolacos, 2010). The results of the OLS assumption testing can be found in Appendix C. Unfortunately, variables for various road characteristics are not considered in the empirical model due to high multicollinearity with other variables. An example of such variable is a dummy variable indicating whether a project considers a newly constructed road or a redevelopment of an existing road. Since hypothesis 4 makes a statement about newly constructed and redeveloped road, this will be dealt with by splitting the data into two groups and performing separate regressions. Also dummy variables for the type of junctions and number of lanes are taken out of the model due to high multicollinearity with other variables.

Table 2. Variables used in the DID regression

Variables	Variable Type	Description
Dependent variable		
LnTransaction	Continuous	Natural logarithm of transaction prices.
Independent variables		
Target	Dummy	Target area (1): all properties located within 6 km of the nearest dual carriageway access point (accessibility model) – all properties located within 2.5 km of the nearest dual carriageway (road distance model).
Construction	Dummy	Construction period (1): all properties sold within the time period between the start and the end of construction.
After	Dummy	Period after opening (1): all properties sold within two and a half years after the opening of the dual carriageway.
Noise 100 m	Dummy	Properties located within 100 m of a dual carriageway (1) during and after construction or before, during, and after construction.
Noise 300 m	Dummy	Properties located within 300 m of a dual carriageway (1) during and after construction or before, during, and after construction.
Traffic intensity 1 km	Dummy	Properties within 1 km of a dual carriageway onramp (1) after opening.
Distance road	Continuous	Distance in meters between a property and the nearest dual carriageway.
Distance access	Continuous	Distance in meters between a property and the nearest dual carriageway access point.
Interaction variables		
Target*Trend	Dummy * Continuous	The trend of house prices in the target area before construction.
Target*Distance	Dummy * Continuous	Measures the difference in house prices between the target and control area with increasing distance
Target*Trend*Distance	Dummy * Continuous * Continuous	The trend of house prices in the target area before construction with increasing distance to the road.
Target*Construction	Dummy * Dummy	Measures the difference in house prices between the target and control area during the construction period.
Target*Construction*Distance	Dummy * Dummy * Continuous	Measures the difference in house prices between the target and control area during the construction period with increasing distance.
Target*After	Dummy * Dummy	Target area after the opening of the road. The coefficient measures the external effects of dual carriageway development on house prices.
Target*After*Trend	Dummy * Dummy * Continuous	Suggests how the external effects of dual carriageway development on house prices vary over time.
Target*After*Distance	Dummy * Dummy * Continuous	Measures the external effects of dual carriageway development on house prices with increasing distance.
Control variables		
House	Dummy	Dummy indicating whether a property is a house (1) or apartment (0).
Living area	Continuous	Natural logarithm of the living area of a property.
Rooms	Continuous	Natural logarithm of the number of rooms property.
Market days	Continuous	Natural logarithm of the number of days on the market before being sold.
Building category	Categorical	Indicates the type of building the property is located in.
Building period	Categorical	Indicates the construction period in which the property was built.
Fixed effects		
Transaction year	Dummy	Property transaction year dummy controlling for time fixed effects.
PC6	Dummy	Postcode dummy controlling for spatial fixed effects.

Table 3. Descriptive statistics accessibility model

	Total				Target				Control			
Variable	**Mean**	**Std.Dev.**	**Min**	**Max**	**Mean**	**Std.Dev.**	**Min**	**Max**	**Mean**	**Std.Dev.**	**Min**	**Max**
Transaction:												
Transaction price	257,410.5	144711.7	75,000	1,500,000	247,875.1	126,623.9	75,000	1,500,000	272,210.9	167,927.3	75000	1,500,000
LnTransaction	12.341	0.465	11.225	14.221	12.320	0.434	11.225	14.221	12.374	0.509	11.225	14.221
Transaction year	2013.817	4.425	2004	2021	2014.091	4.382	2004	2021	2013.392	4.458	2004	2021
Year built (property)	1974.561	32.450	1450	2021	1975.788	32.564	1450	2021	1972.656	32.182	1550	2021
Days on market	186.342	292.625	1	4,334	179.669	285.206	1	3,957	196.700	303.493	1	4,334
Number of rooms	4.707	1.412	1	32	4.652	1.392	1	24	4.793	1.438	1	32
Living area (m^2)	124.022	45.896	10	990	122.324	45.071	10	990	126.658	47.026	10	950
Target area	0.608	0.488	0	1	1	0	1	1	0	0	0	0
Road:												
Distance road (m)	4836.492	2,803.453	3.014	10351.59	2,930.999	1,644.237	3.014	7,034.001	7,794.115	1,216.006	1,815.839	10,351.59
Distance access (m)	4951.053	2756.904	52.063	9999.954	3,063.84	1,586.116	52.063	5,999.941	7,880.303	1,176.503	6,000.035	9,999.954
Noise < 100 m (1=yes)	0.001	0.030	0	1	0.001	0.039	0	1	0	0	0	0
Noise <300 m (1=yes)	0.004	0.066	0	1	0.007	0.085	0	1	0	0	0	0
Traffic intensity <1 km (1=yes)	0.021	0.143	0	1	0.344	0.182	0	1	0	0	0	0
House/Apartment:												
House (1=yes)	0.846	0.361	0	1	0.839	0.368	0	1	0.859	0.348	0	1
Building Category (1=yes):				1				1				1
Semi-detached	0.218	0.413	0	1	0.216	0.412	0	1	0.220	0.414	0	1
Corner house	0.130	0.337	0	1	0.130	0.336	0	1	0.131	0.338	0	1
Terraced house	0.044	0.206	0	1	0.042	0.201	0	1	0.048	0.213	0	1
Townhouse	0.277	0.448	0	1	0.282	0.450	0	1	0.270	0.444	0	1
Detached	0.214	0.410	0	1	0.207	0.405	0	1	0.225	0.418	0	1
Downstairs apartment	0.018	0.132	0	1	0.018	0.135	0	1	0.017	0.128	0	1
Upstairs apartment	0.026	0.159	0	1	0.028	0.165	0	1	0.023	0.151	0	1
Flat/Apartment Building	0.016	0.125	0	1	0.017	0.131	0	1	0.013	0.114	0	1
Penthouse	0.051	0.220	0	1	0.054	0.225	0	1	0.047	0.212	0	1
Portico flat/story	0.005	0.069	0	1	0.005	0.069	0	1	0.005	0.067	0	1
Building period of property (1=yes):												
<1901	0.020	0.141	0	1	0.020	0.141	0	1	0.020	0.141	0	1
1901-1910	0.020	0.142	0	1	0.021	0.142	0	1	0.021	0.143	0	1
1911-1920	0.016	0.127	0	1	0.0154	0.123	0	1	0.018	0.132	0	1
1921-1930	0.049	0.215	0	1	0.040	0.196	0	1	0.062	0.242	0	1
1931-1940	0.039	0.195	0	1	0.034	0.181	0	1	0.048	0.214	0	1
1941-1950	0.017	0.131	0	1	0.015	0.122	0	1	0.021	0.144	0	1
1951-1960	0.068	0.251	0	1	0.060	0.238	0	1	0.079	0.270	0	1
1961-1970	0.116	0.321	0	1	0.113	0.317	0	1	0.122	0.327	0	1
1971-1980	0.187	0.390	0	1	0.195	0.396	0	1	0.175	0.390	0	1
1981-1990	0.135	0.342	0	1	0.149	0.356	0	1	0.114	0.318	0	1
1991-2000	0.138	0.345	0	1	0.143	0.350	0	1	0.131	0.338	0	1
2001-2010	0.128	0.334	0	1	0.125	0.331	0	1	0.132	0.339	0	1
2010<	0.063	0.243	0	1	0.069	0.253	0	1	0.055	0.228	0	1
Number of observations:	**121,036**				**73,611**				**47,425**			

Table 4. Descriptive statistics road distance model

	Total				Target				Control			
Variable	**Mean**	**Std.Dev.**	**Min**	**Max**	**Mean**	**Std.Dev.**	**Min**	**Max**	**Mean**	**Std.Dev.**	**Min**	**Max**
Transaction:												
Transaction price	247,934.1	123173.6	75,000	1,460,000	245,316.3	120,339.3	75,000	1,460,000	252,779.9	128,117.4	75,000	1,425,000
LnTransaction	12.323	0.431	11.225	14.194	12.314	0.426	11.225	14.194	12.339	0.440	11.225	14.170
Transaction year	2014.635	4.198	2004	2021	2014.917	4.050	2004	2021	2014.114	4.4106	2004	2021
Year built (property)	1975.761	34.214	1450	2021	1975.439	34.335	1450	2021	1976.356	33.981	1575	2021
Days on market	179.459	288.837	1	3,957	183.309	294.311	1	3930	172.332	278.287	1	3957
Number of rooms	4.643	1.383	1	21	4.666	1.386	1	17	4.600	1.377	1	21
Living area (m^2)	122.004	44.644	10	990	121.909	44.722	10	990	122.178	44.500	10	894
Target area	0.649	0.477	0	1	1	0	1	1	0	0	0	0
Road:												
Distance road (m)	2,122.283	984.265	28.995	3,999.623	1,521.249	601.659	28.995	2,499.758	3,234.870	430.617	2500.035	3,999.623
Distance access (m)	2,309.199	989.695	500.052	8,255.763	1,752.687	689.412	500.051	6,864.552	3,339.369	527.524	1594.597	8,255.763
Noise < 100 m (1=yes)	0.002	0.046	0	1	0.003	0.057	0	1	0	0	0	0
Noise <300 m (1=yes)	0.009	0.095	0	1	0.016	0.126	0	1	0	0	0	0
Traffic intensity <1 km (1=yes)	0.038	0.192	0	1	0.059	0.236	0	1	0	0	0	0
House/Apartment:												
House (1=yes)	0.841	0.366	0	1	0.849	0.358	0	1	0.824	0.381	0	1
Building Category (1=yes):												
Semi-detached	0.218	0.413	0	1	0.221	0.415	0	1	0.212	0.409	0	1
Corner house	0.131	0.337	0	1	0.130	0.336	0	1	0.134	0.341	0	1
Terraced house	0.044	0.206	0	1	0.049	0.216	0	1	0.036	0.187	0	1
Townhouse	0.276	0.447	0	1	0.262	0.440	0	1	0.301	0.459	0	1
Detached	0.206	0.405	0	1	0.221	0.415	0	1	0.179	0.383	0	1
Downstairs apartment	0.018	0.135	0	1	0.020	0.140	0	1	0.016	0.124	0	1
Upstairs apartment	0.028	0.165	0	1	0.031	0.175	0	1	0.022	0.147	0	1
Flat/Apartment Building	0.016	0.127	0	1	0.015	0.121	0	1	0.019	0.137	0	1
Penthouse	0.056	0.229	0	1	0.044	0.206	0	1	0.077	0.266	0	1
Portico flat/story	0.006	0.077	0	1	0.007	0.081	0	1	0.005	0.069	0	1
Building period of property (1=yes):												
<1901	0.022	0.148	0	1	0.022	0.148	0	1	0.022	0.148	0	1
1901-1910	0.023	0.149	0	1	0.024	0.154	0	1	0.020	0.140	0	1
1911-1920	0.017	0.128	0	1	0.018	0.134	0	1	0.014	0.116	0	1
1921-1930	0.043	0.203	0	1	0.046	0.209	0	1	0.038	0.190	0	1
1931-1940	0.035	0.184	0	1	0.034	0.182	0	1	0.036	0.187	0	1
1941-1950	0.016	0.124	0	1	0.016	0.126	0	1	0.014	0.119	0	1
1951-1960	0.049	0.216	0	1	0.049	0.216	0	1	0.049	0.216	0	1
1961-1970	0.111	0.315	0	1	0.113	0.317	0	1	0.108	0.310	0	1
1971-1980	0.195	0.396	0	1	0.205	0.404	0	1	0.176	0.381	0	1
1981-1990	0.131	0.338	0	1	0.126	0.332	0	1	0.141	0.348	0	1
1991-2000	0.155	0.361	0	1	0.133	0.340	0	1	0.194	0.396	0	1
2001-2010	0.120	0.325	0	1	0.116	0.320	0	1	0.129	0.334	0	1
2010<	0.083	0.276	0	1	0.096	0.295	0	1	0.058	0.234	0	1
Number of observations:	**51,189**				**33,235**				**17,594**			

4. RESULTS

This section discusses the results of the difference-in-difference hedonic price model to investigate the effects of dual carriageway developments on nearby house prices. Please note that the main goal of using the two models is not to compare them, nor to argue which one is more appropriate, but rather to observe how the results can differ using different perspectives, as road infrastructure development is a highly complex process.

4.1 Main results accessibility model

Table 5 reports the results of the baseline model in four columns, including the coefficients and corresponding standard errors. Column (1) considers the most basic model which consists of the key variables and transaction year dummies. The R-squared[2] is 0.0834. Column (2) proceeds by adding housing characteristics to the model, increasing the R-squared to 0.6184. In column (3) the noise and traffic intensity dummies are added, increasing the R-squared to 0.6187. Finally, column (4) presents the complete and preferred regression specification, in which PC6 is added. The R-squared is 0.9302, which indicates that approximately 93% of the variance in the dependent variable LnTransaction can be explained by the model.

Column (4) shows that the coefficient of Target_i is negative and significant, indicating that properties located within 6 km of a dual carriageway access point and sold before the development sell for 7.7% (= (exp$^{(-0.0801)}$ – 1) x 100)[3] less on average than properties in the control area. The coefficient for $\text{Target}_i \times \text{Trend}_t$ is negative and significant, indicating that the price difference between target and control area becomes greater with approximately 1.3% a year until construction starts. The coefficients of $\text{Target}_i \times \text{Distance}_i$ and $\text{Target}_i \times \text{Trend}_t \times \text{Distance}_i$ are positive, yet not statistically significant.

The coefficient for $\text{Target}_i \times \text{Construction}_t$ is positive and significant, indicating that the construction period generates on average a 1.4% increase in property price in the target area, relative to the control area. This suggests an anticipation effect during the construction period. The coefficient for $\text{Target}_i \times \text{Construction}_t \times \text{Distance}_i$ is negative and just outside of the 90% significance level (P>|t| = 0.119). It suggests that properties closer to the dual carriageway access point during the construction period experience a larger positive effect on house prices as the price difference between target and control area becomes larger for properties located further away from the onramps. The positive effect on house prices during the construction period fades away at approximately 5.4 km from a dual carriageway onramp (see figure 4).

[2] With the use of robust standard errors, Stata does not produce an adjusted R-squared.
[3] Please note that all results containing percentages are calculated using (= (exp$^{(\text{coefficient})}$ - 1) x 100), unless stated otherwise.

Table 5. Difference-in-difference regression results for the accessibility model

	(1)	(2)	(3)	(4)
Sample	**<10,000 m**	**<10,000 m**	**<10,000 m**	**<10,000 m**
Target Area	**0-6,000 m**	**0-6,000 m**	**0-6,000 m**	**0-6,000 m**
Control Area	**6,000-10,000 m**	**6,000-10,000 m**	**6,000-10,000 m**	**6,000-10,000 m**
Target	-0.135***	-0.0951***	-0.0938***	-0.0801*
	(0.0122)	(0.00698)	(0.00699)	(0.0458)
Target x Trend	0.0156**	0.0177***	0.0178***	-0.0133***
	(0.00701)	(0.00407)	(0.00407)	(0.00315)
Target x Distance[4]	-0.00866**	-0.0114***	-0.0118***	0.00943
	(0.00355)	(0.00112)	(0.00201)	(0.00772)
Target x Trend x Distance	-0.00189	-0.00123	-0.00127	0.00106
	(0.00194)	(0.00112)	(0.00112)	(0.000861)
Target x Construction	0.108***	0.126***	0.126***	0.0139**
	(0.0131)	(0.00751)	(0.00751)	(0.00579)
Target x Construction x Distance	0.0144***	0.0134***	0.0134***	-0.00259
	(0.00388)	(0.00751)	(0.00223)	(0.00166)
Target x After	0.119***	0.143***	0.142***	0.0446***
	(0.0142)	(0.00751)	(0.00872)	(0.00664)
Target x After x Trend	-0.00599	-0.0220***	-0.0215***	-0.0112***
	(0.00395)	(0.00751)	(0.00256)	(0.00170)
Target x After x Distance	0.00878**	0.00804***	0.00822***	-0.00350**
	(0.00393)	(0.00228)	(0.00237)	(0.00177)
Noise 100 m			-0.104***	-0.0135
			(0.0203)	(0.0436)
Noise 300 m			-0.0884***	-0.00616
			(0.0131)	(0.0232)
Traffic intensity 1 km			0.0117**	0.00647
			(0.00572)	(0.00501)
Year fixed effects	Yes	Yes	Yes	Yes
Building period property	No	Yes	Yes	Yes
Property characteristics	No	Yes	Yes	Yes
Noise externality dummies	No	No	Yes	Yes
PC6 fixed effects	No	No	No	Yes
Observations	121,036	121,036	121,036	121,036
R^2	0.0834	0.6184	0.6187	0.9302

Note: Dependent variable is the natural logarithm of transaction price.
Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

The coefficient for $\text{Target}_i \times \text{After}_t$ captures the external effects of dual carriageway development for properties located in the target area and sold after the opening of the dual carriageway. The coefficient is positive and significant, indicating that the development generates on average a 4.6% increase in property prices compared to properties located in the control area. Hypothesis *1. Dual carriageway access points have a positive effect on surrounding house prices during and after the construction period* is not rejected, as results indicate a positive effect during and after the construction period on house prices in the target area. The coefficient for $\text{Target}_i \times \text{After}_t \times \text{Trend}_t$ is negative and significant, indicating that the external effects of infrastructural developments on property prices decrease with 1.1% a year during the 2.5 years after opening (see figure 5). The negative and significant coefficient

[4] Please note that all coefficients for Distance_i are interpreted for distance in kilometers.

for $\text{Target}_i \times \text{After}_t \times \text{Distance}_i$ indicates that the positive external effects of infrastructural developments decrease with distance, as seen in figure 4. Although the coefficient is small, it supports the notion of an accessibility premium, as properties closer to dual carriageway access points experience a higher positive effect on house prices. On average, the external effects fade away at approximately 12.8 km from a dual carriageway onramp.

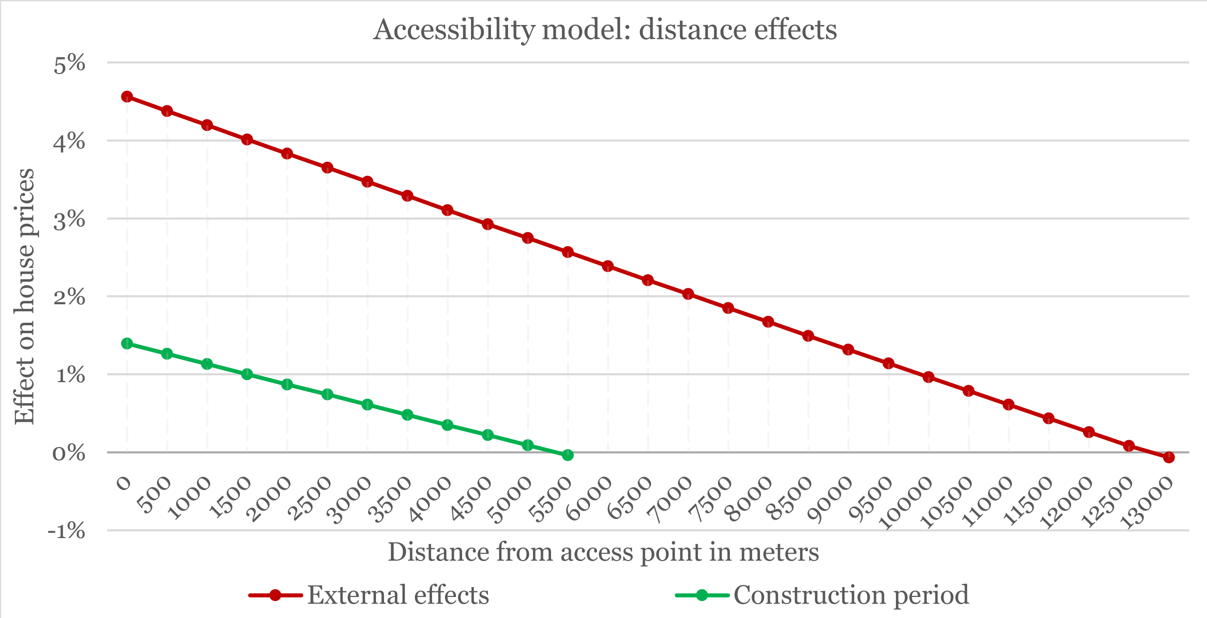

Figure 4. Distance effects of the accessibility model[5].

In column (3), all externality dummies are significant. The results indicate that, compared to other properties, properties located within 100 m and 300 m of a dual carriageway experience a negative effect on house prices of 9.9% and 8.5%, respectively. Being located within 1 km of an onramp, however, has a positive effect on house prices of on average 12.4%, supporting the notion that people tend to value accessibility. In column (4), where PC6 is included, all externality dummy variables are positive but statistically insignificant, indicating that these dummies might not impact house prices for properties located in vicinity of dual carriageways. As it is argued that PC6 can be too small scaled (Abbott & Klaiber, 2011), the same regression (for both models) has been repeated with PC4, resulting in similar outcomes for the externality dummies. The insignificant result for the noise 100 m dummy could result out of a lack of observations, as there are 110 properties located within this area. Another explanation could be that for the 110 properties within 100 m and 534 properties within 300 m of a dual carriageway sufficient measures are in place to prevent negative externalities (e.g., sound barriers). The housing characteristics variables act as expected. Houses generate higher house prices on average compared to apartments. Compared to properties constructed in 1900 and

[5] Please note that $\text{Target}_i \times \text{Construction}_t \times \text{Distance}_i$ has a P-value of 0.119.

before, properties from the last few decades are the most expensive. Interestingly, a steep trend is visible in the effect transaction year has on the transaction price, with ever increasing prices over the past eight years. Compared to 2004, a property sold in 2021 generated a 65% higher transaction price.

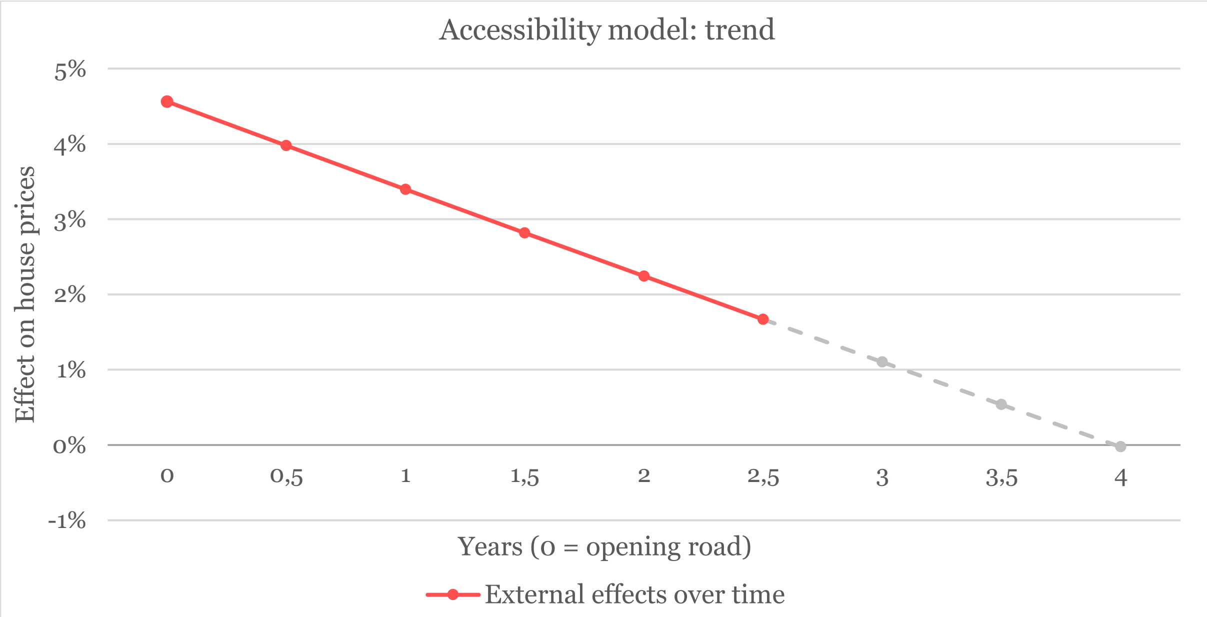

Figure 5. Trend of the external effects in the accessibility model.

4.2 Main results road distance model

Table 6 reports the results of the baseline model in four columns. Column (1) considers the most basic model which consists of the key variables and transaction year dummies. The R-squared is 0.1061. Column (2) proceeds by adding housing characteristics to the model, increasing the R-squared to 0.6820. In column (3) the noise and traffic intensity dummies are added, increasing the R-squared to 0.6832. Finally, column (4) presents the complete and preferred regression specification, in which PC6 is added. The R-squared is 0.9236, which indicates that approximately 92.4% of the variance in the dependent variable LnTransaction can be explained by the model.

Column (4) shows that the coefficient of Target_i is negative and significant, indicating that properties located within 2.5 km of a dual carriageway section and sold before the development on average sell for 22.9% less than properties in the control area. The coefficient for $\text{Target}_i \times \text{Distance}_i$ is positive and significant, indicating that the price difference between target and control area becomes smaller for properties located further away from dual carriageway access points. The coefficients for $\text{Target}_i \times \text{Trend}_t$ and $\text{Target}_i \times \text{Trend}_t \times \text{Distance}_i$ are negative but not statistically significant.

Table 6. Difference-in-difference regression results for the road distance model

	(1)	(2)	(3)	(4)
Sample	**<4,000 m**	**<4,000 m**	**<4,000 m**	**<4,000 m**
Target Area	**0-2,500 m**	**0-2,500 m**	**0-2,500 m**	**0-2,500 m**
Control Area	**2,500-4,000 m**	**2,500-4,000 m**	**2,500-4,000 m**	**2,500-4,000 m**
Target	-0.132***	-0.0926***	-0.0884***	-0.206***
	(0.0218)	(0.0124)	(0.0124)	(0.0701)
Target x Trend	0.0111	0.0247***	0.0253***	-0.00374
	(0.0131)	(0.00771)	(0.00770)	(0.00611)
Target x Distance	0.0169	-0.00843	-0.0110	0.0748***
	(0.0131)	(0.00731)	(0.00730)	(0.0288)
Target x Trend x Distance	-0.00601	-0.0120***	-0.0123***	-0.00444
	(0.00791)	(0.00455)	(0.00454)	(0.00357)
Target x Construction	0.0747***	0.0742***	0.0753***	-0.0228**
	(0.0236)	(0.0134)	(0.0133)	(0.0110)
Target x Construction x Distance	0.0206	0.0276***	0.0267***	0.0115*
	(0.0143)	(0.00802)	(0.00799)	(0.00650)
Target x After	0.109***	0.0727***	0.0172	-0.0336***
	(0.0249)	(0.0142)	(0.0153)	(0.0125)
Target x After x Trend	-0.0134**	-0.0309***	-0.0291***	-0.0156***
	(0.00545)	(0.00339)	(0.00338)	(0.00249)
Target x After x Distance	0.0102	0.0352***	0.0628***	0.0285***
	(0.0144)	(0.00806)	(0.00855)	(0.00695)
Noise 100 m			-0.0790***	-0.0708
			(0.0197)	(0.0711)
Noise 300 m			-0.0631***	-0.00227
			(0.0129)	(0.0250)
Traffic intensity 1 km			0.0905***	0.0281***
			(0.00736)	(0.00672)
Year fixed effects	Yes	Yes	Yes	Yes
Building period property	No	Yes	Yes	Yes
Property characteristics	No	Yes	Yes	Yes
Noise externality dummies	No	No	Yes	Yes
PC6 fixed effects	No	No	No	Yes
Observations	51,189	51,189	51,189	51,189
R^2	0.1061	0.6820	0.6832	0.9236

Note: Dependent variable is the natural logarithm of transaction price.
Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

The coefficient for $\text{Target}_i \times \text{Construction}_t$ is negative and significant, indicating that the construction generates on average 2.3% decrease in house prices in the target area, compared to the control area. This suggests a negative anticipation effect during the construction period if a property is located in proximity of a dual carriageway section. The coefficient for $\text{Target}_i \times \text{Construction}_t \times \text{Distance}_i$ is positive and significant, meaning that the negative effect on house prices during the construction period fades away with distance from the dual carriageway. This negative effect fades away at approximately 2 km, as shown in figure 6. The coefficient for $\text{Target}_i \times \text{After}_t$ captures the external effects of dual carriageway development for properties located in the target area and sold after the opening of the dual carriageway. The coefficient is negative and significant, indicating that dual carriageway development generates on average a 3.3% decrease in property prices compared to properties located in the control area. Based on these results, hypothesis *2. Dual carriageways itself have a negative effect on surrounding house prices during and after the construction period* is not rejected, as findings indicate negative effects on house prices during and after the construction period of a dual carriageway. The coefficient for $\mathrm{Target}_i \times \mathrm{After}_t \times \mathrm{Trend}_t$ is negative and significant, indicating that the external effects of dual carriageway development on property prices get stronger with 1.5% a year during the 2.5 years after opening. This is visualized in figure 7. The positive and significant coefficient for $\mathrm{Target}_i \times \mathrm{After}_t \times \mathrm{Distance}_i$ indicates that the external effects fade away over distance. The negative external effects fade away at approximately 1.2 km from the dual carriageway (see figure 6). The negative effects on house prices tend to carry over a longer distance during the construction period and fade away faster for the external effects.

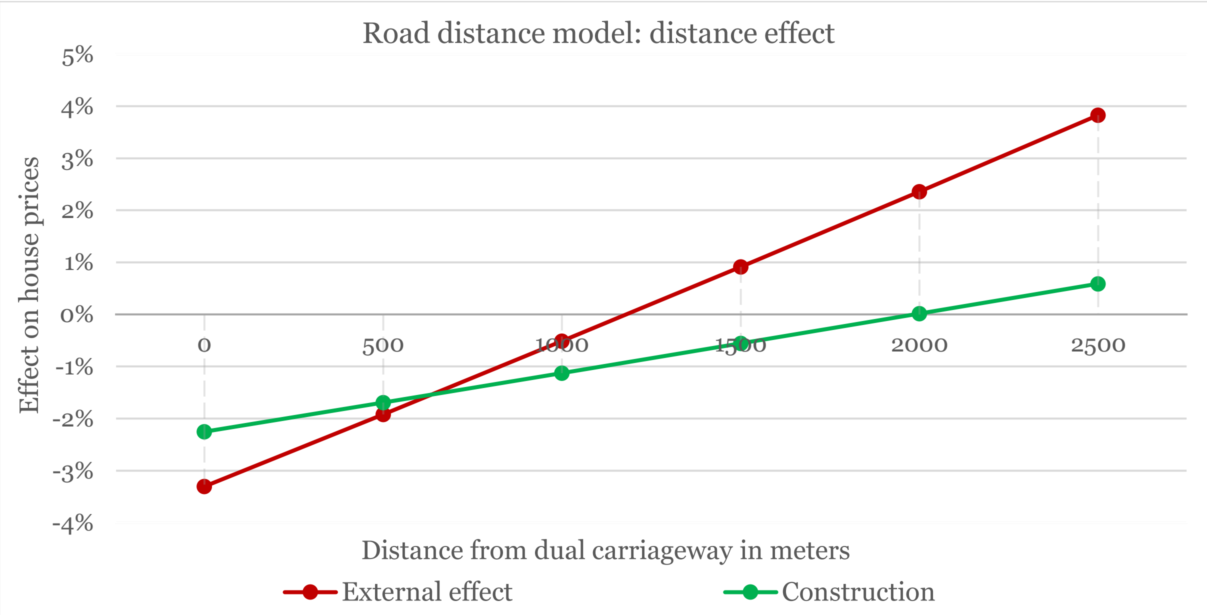

Figure 6. Distance effects of the road distance model.

The negative externality dummies in column (3) behave similarly to the dummies in the accessibility model but have lower coefficients. In column (4), only the traffic intensity dummy is positive and significant, indicating that being located within 500-1,000 m of an onramp has a positive effect of 2.8% on property prices[6]. While this dummy variable is created for interpretation of possible traffic intensity increases, one could also interpret it as the positive effect of being located near an onramp, as the dummy variable is merely a distance dummy. The coefficient thus suggests a positive valuation of accessibility. The insignificant results for the noise 100 m and noise 300 m dummies can be explained by the same arguments given in the accessibility model. The housing characteristics, building period, and transaction year fixed effects act very similar to the accessibility model.

[6] Properties within 500 m of an onramp are excluded in the road distance model.

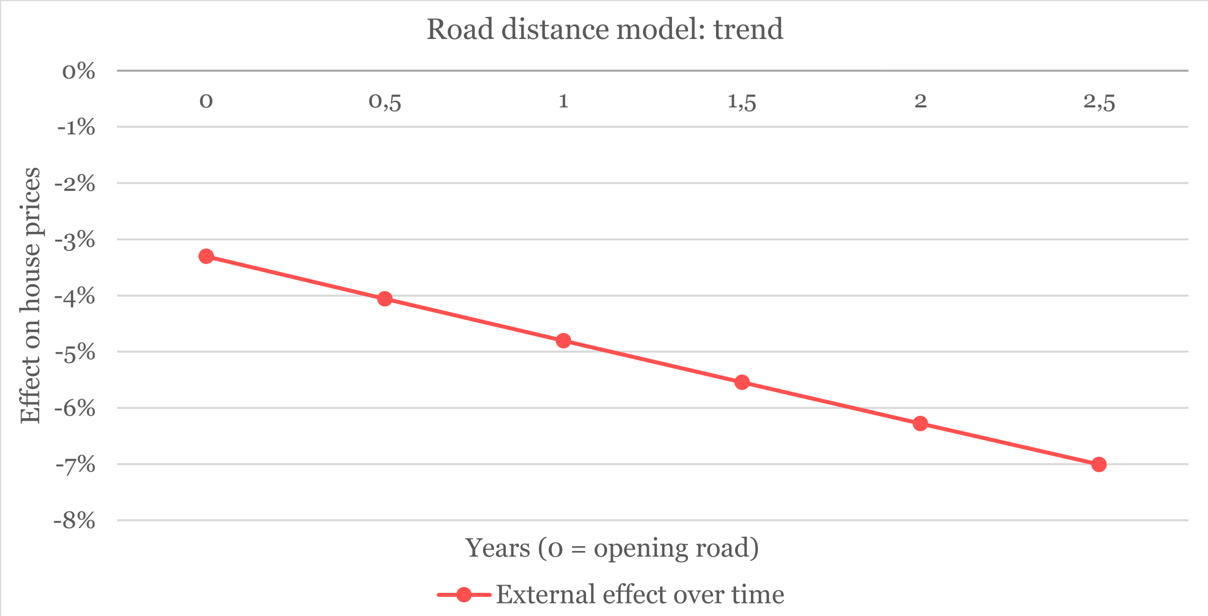

Figure 7. Trend of the external effects in the road distance model.

Now that the results from both the accessibility and road distance models have been discussed, the third hypothesis can be answered. The third hypothesis aims at checking whether the optimal location for residential real estate opposed to highway infrastructure, as described by Tillema et al. (2012), holds for dual carriageways. The first part of the hypothesis is captured by the accessibility model. The second part of the hypothesis is captured by the road distance model. Hypothesis *3. The optimal location for residential properties is as close to a road access point as possible for accessibility benefits, but as far away from the road itself to avoid negative externalities* is not rejected as the accessibility models suggests that the positive effects on house prices fade away with distance from the onramps, hinting at an accessibility premium near dual carriageway access points. The road distance model suggests that the negative effects on house prices fade away with distance from the dual carriageway itself, meaning that a price discount close to the dual carriageway is present. Moreover, being located within 500-1,000 m of an onramp in the road distance model has a positive effect on house prices, also hinting at a positive valuation of accessibility.

4.3 Newly constructed contra redeveloped dual carriageways

This subsection focuses on the comparison between newly constructed and redeveloped dual carriageways in order to answer hypothesis *4. The effect of newly constructed and redeveloped existing dual carriageways on surrounding house prices is similar*. This hypothesis is tested for the accessibility model and road distance model separately. Table 7 reports on the regression results, where the accessibility model results are found in column (1) and (2) and the road distance model results are found in column (3) and (4).

Table 7. Difference-in-difference regression results of newly constructed and redeveloped dual carriageways

Model	**(1) Accessibility**	**(2) Accessibility**	**(3) Road Distance**	**(4) Road Distance**
Group	**New**	**Redeveloped**	**New**	**Redeveloped**
Sample	**<10,000 m**	**<10,000 m**	**<4,000 m**	**<4,000 m**
Target Area	**0-6,000 m**	**0-6,000 m**	**0-2,500 m**	**0-2,500 m**
Control Area	**6,000-10,000 m**	**6,000-10,000 m**	**2,500-4,000 m**	**2,500-4,000 m**
Target	-0.122***	0.113	-0.274***	-0.0466
	(0.0457)	(0.142)	(0.0920)	(0.103)
Target x Trend	-0.0261***	0.0123**	-0.0130	0.0145
	(0.00398)	(0.00612)	(0.00834)	(0.00949)
Target x Distance	0.0144*	-0.0186	0.0908**	0.0160
	(0.00785)	(0.0227)	(0.0378)	(0.0422)
Target x Trend x Distance	0.00283***	-0.00235	-0.00359	-0.00960*
	(0.00102)	(0.00176)	(0.00475)	(0.00551)
Target x Construction	0.0385***	-0.0102	-0.0294*	-0.00208
	(0.00770)	(0.0101)	(0.0162)	(0.0153)
Target x Construction x Distance	-0.00605***	0.00531	0.0232**	0.00203
	(0.00202)	(0.00330)	(0.00925)	(0.00923)
Target x After	0.0553***	0.0350***	-0.0597***	0.0118
	(0.00848)	(0.0119)	(0.0178)	(0.0183)
Target x After x Trend	-0.00517**	-0.0226***	-0.0143***	-0.0185***
	(0.00206)	(0.00312)	(0.00332)	(0.00393)
Target x After x Distance	-0.00353*	0.000930	0.0455***	0.0139
	(0.00213)	(0.00346)	(0.00966)	(0.0101)
Noise 100 m	-0.263***	0.0301	-0.275***	0.0697
	(0.0990)	(0.0363)	(0.0985)	(0.0564)
Noise 300 m	-0.0375	0.0246	0.0119	0.00979
	(0.0390)	(0.0216)	(0.0381)	(0.0255)
Traffic intensity 1 km	0.00802	-0.00295	0.0343***	0.0157
	(0.00760)	(0.00710)	(0.00960)	(0.00958)
Year fixed effects	Yes	Yes	Yes	Yes
Building period property	Yes	Yes	Yes	Yes
Property characteristics	Yes	Yes	Yes	Yes
Noise externality dummies	Yes	Yes	Yes	Yes
PC6 fixed effects	Yes	Yes	Yes	Yes
Observations	83,115	37,921	28,678	22,511
R^2	0.9302	0.9318	0.9225	0.9266

Note: Dependent variable is the natural logarithm of transaction price.
Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

The R-squared of column (1) and (2) are very similar, yet some differences are presented in the variables of interest. The construction period for redeveloped roads shows a negative and insignificant coefficient, while for newly constructed roads the construction period shows a positive and significant coefficient, indicating a house price increase of 3.9%. This positive effect during the construction period fades away over distance for newly constructed roads. $Target_i \times After_t$ is significant for both redeveloped and newly constructed roads. However, the external effects of newly constructed roads on house prices are 5.7% and 3.6% for redeveloped roads. A possible explanation for this difference could be that accessibility on a location where no dual carriageway onramp was located before is valued higher than an improvement of a dual carriageway which already provided accessibility benefits in the past. The external effects fade away over time for both development types, but faster for redeveloped roads. Only for newly constructed dual carriageways a distance effect is measured, indicating that the external effects for newly constructed roads fade away with distance from the dual carriageway onramp.

Interestingly, the noise 100 m dummy is only significant for newly constructed dual carriageways and indicates a negative effect on house prices of on average 23.1%. Possible explanations for this could be that road redevelopment projects pay more attention to improving the livability in surrounding neighborhoods (e.g., sound barriers), while also increasing safety and smooth traffic flows, which reduces the negative externalities. For newly constructed roads the negative and significant effect near the road could naturally come from the negative externalities from the road, such as noise, air, and landscape pollution, which were nonexistent on that location before the new road was constructed.

Based on these results hypothesis *4. The effect of newly constructed and redeveloped existing dual carriageways on surrounding house prices is similar* is rejected for the accessibility model, as the regression results from column (1) and (2) in table 8 indicate differences between the two types of dual carriageway development.

The R-squared for the road distance model in column (3) and (4) are similar as well. $\text{Target}_i \times \text{Trend}_t$ is negative for both dual carriageway development types but lies just outside of the 90% significance level ($P>|t|$ = 0.119) for redeveloped roads. Before development, properties in the target area of newly constructed roads and redeveloped existing roads on average sell for 24.0% and 4.6% less, respectively, than properties in the control area. Results indicate that the construction period and external effects are not significant for redeveloped roads. In fact, the results of the complete and preferred model specification of table 6 seem to be driven largely by newly constructed roads. The construction period of newly roads indicates a negative and significant effect on house prices of 2.9%, relative to the control area. This negative effect is the highest for properties located closer to the dual carriageway, indicated by the positive and significant coefficient of $\text{Target}_i \times \text{Construction}_t \times \text{Distance}_i$. $\text{Target}_i \times \text{After}_t$ is negative and significant for newly constructed roads, indicating that the external effects of new dual carriageway development generate a decrease of 5.8% on house price. This negative effect fades away with distance and gets stronger over time, as indicated by $\text{Target}_i \times \text{After}_t \times \text{Distance}_i$ and $\text{Target}_i \times \text{After}_t \times \text{Trend}_t$. Not observing significant coefficient during and after the construction period of redeveloped dual carriageways itself can be explained as negative externalities were already present near the road before the redevelopment, which means that the negative effects on house prices existent before redeveloping may not have been altered during and after construction for the project considered in this analysis.

The noise 100 m dummy variable is significant for newly constructed dual carriageways and shows a similar coefficient and the same percentage effect on house prices as in the accessibility model. The traffic intensity dummy shows a positive coefficient for both newly constructed and redeveloped dual carriageways, lies just outside of the 90% significance level ($P>|t| = 0.100$). Being located within 500-1,000 m of a dual carriageway access point after the opening of the dual carriageway on average has a positive effect on house prices of 3.5% for newly constructed roads and 1.6% for redeveloped roads. This supports the notion than accessibility is valued positively.

Based on the results hypothesis *4. The effect of newly constructed and redeveloped existing dual carriageways on surrounding house prices is similar* is also rejected for the road distance model. It can be concluded that the effects of newly constructed and redeveloped existing dual carriageways on surrounding house prices is not similar and driven primarily by newly constructed roads in the road distance model.

Some other conclusions can be made as well. The traffic intensity dummy does not seem to influence house prices in the accessibility model but does positively affect house prices in the road distance model. In both models no statistically significant result is observed for $\text{Target}_i \times \text{Construction}_t$ of redeveloped dual carriageways. This could be the explained by the difference in development type as with newly constructed roads, the construction period exposes the surrounding area to negative externalities that were not present before. However, before the construction of redeveloped dual carriageways, there were most likely already negative externalities in place due to the road being in use and producing these externalities. The construction period of redeveloped roads, therefore, might not cause more negative effects than when the road was in use before the redevelopment. A similar argument could be applied to the insignificant coefficient of $\text{Target}_i \times \text{After}_t$ in column (4), as perhaps no improvement in negative externalities and the external effects were created with the redevelopment of the road.

5. ROBUSTNESS & SENSITIVITY ANALYSIS

This section provides additional analyses to check the robustness of the regression results. First, an alternative specification of the complete and preferred model is used to check the presence of distance effects and to see whether the construction and external effects across space are linear. Second, for both the accessibility and road distance model an alternative model specification is presented with adjusted target and control areas. Finally, the heterogeneity of the construction period and external effects of dual carriageway development are tested.

5.1 Effect of distance

Table 8 presents the results of the alternative model specification of the complete and preferred model from tables 6 and 7, in which the target area is divided in distance rings from the source. One should keep in mind that the accessibility model, presented in column (1), measures the distance between a property and the nearest onramp. The road distance model, presented in column (2), measures the distance between a property and the nearest dual carriageway itself.

Column (1) presents the regression results for the complete and preferred model specification of the accessibility model. The only significant result for $\text{Target}_i \times \text{Construction}_t$ is found within 2,000-3,000 m, indicating a positive effect of 1.7% on house prices. $\text{Target}_i \times \text{After}_t$ shows positive and significant coefficients at all distances, indicating a positive effect from dual carriageway development on house prices. It can be observed that the distance decay effect of the dual carriageway development is not entirely linear. Properties located within 2,000-3,000 m experience the largest house price increase compared to the control area, which is 5.5%. Properties located closest to the onramp, within 500 m, experience a price increase of 3.7% after the opening of the road. A possible explanation for this would be that being close to an onramp also implies being closer to the negative externalities of the dual carriageway. However, the noise dummies are highly insignificant and show positive coefficients, meaning that this notion cannot be supported by the negative externality dummies. The traffic intensity dummy has been omitted due to unacceptable multicollinearity with the interaction variables.

The results do not indicate that the target area chosen is incorrect. However, abovementioned results suggest that the distance decay effect might not be linear. Only when starting at $\text{Target}_i \times \text{After}_t\ (2{,}000 - 3{,}000\ \text{m})$ and moving to more distant areas a distance decay effect can be observed for the external effects, but this does not apply to the distance rings between 0-3,000 m. The distance rings indicate that an accessibility premium is not supported by the data, as the highest house price increases are found within 2,000-3,000 m and 500-1,000 m. Th external effects tend to fade away over time fastest for the 2,000-3,000 m distance ring.

Column (2) shows the regression results of the complete and preferred model specification of the road distance model. The only significant result found for $\text{Target}_i \times \text{Construction}_t$ is within 1,000-1,500 m, which indicates a negative effect of 1.7% on house prices, relative to the control area. The road distance model does not act as expected, as most $\text{Target}_i \times \text{After}_t$ variables are insignificant, suggesting that no effect on house prices is measured within these distance intervals. A positive and significant coefficient is observed for $\text{Target}_i \times \text{After}_t$ (2,000 – 2,500 m), indicating that the external effects generate a house price increase of 4.8% within these distances. This positive effect is similar to, but higher than in figure 6 at this distance interval and, therefore, quite robust. A possible explanation for this positive effect on house prices could be that these properties are located far away enough from the road itself to still experience negative externalities, while accessibility benefits reach these properties as accessibility reaches over a further distance, causing positive external effects; or that accessibility benefits override the negative externalities coming from the road at this distance. The coefficients indicate that the positive external effects within 2,000-2,500 m get stronger over time during the 2.5 years after opening of the dual carriageway.

Table 8. Regression results alternative specification with distance rings.

	(1)		(2)
Model	**Accessibility**	**Model**	**Road distance**
Sample	**<10,000 m**	**Sample**	**<4,000 m**
Target Area	**0-6,000 m**	**Target Area**	**0-2,500 m**
Control Area	**6,000-10,000 m**	**Control Area**	**2,500-4,000 m**
Target (0-500 m)	-0.0360	Target (0-500 m)	-0.0594*
	(0.0295)		(0.0353)
Target (500-1,000 m)	-0.0458*	Target (500-1,000 m)	-0.0455*
	(0.0271)		(0.0246)
Target (1,000-2,000 m)	-0.0278	Target (1,000-1,500 m)	-0.00309
	(0.0237)		(0.0204)
Target (2,000-3,000 m)	-0.0221	Target (1,500-2,000 m)	-0.0251
	(0.0223)		(0.0168)
Target (3,000-4,000 m)	-0.00680	Target (2,000-2,500 m)	-0.0263**
	(0.0210)		(0.0125)
Target (4,000-5,000 m)	-0.0252		
	(0.0178)		
Target (5,000-6,000 m)	-0.0223*		
	(0.0133)		
Target x Trend (0-500 m)	0.000768	Target x Trend (0-500 m)	0.000543
	(0.00850)		(0.0117)
Target x Trend (500-1,000 m)	-0.0146***	Target x Trend (500-1,000 m)	-0.0115**
	(0.00567)		(0.00510)
Target x Trend (1,000-2,000 m)	-0.0120***	Target x Trend (1,000-1,500 m)	-0.00222
	(0.00337)		(0.00520)
Target x Trend (2,000-3,000 m)	-0.0157***	Target x Trend (1,500-2,000 m)	-0.0152***
	(0.00283)		(0.00409)
Target x Trend (3,000-4,000 m)	-0.00326	Target x Trend (2,000-2,500 m)	-0.0139***
	(0.00320)		(0.00412)
Target x Trend (4,000-5,000 m)	-0.0103***		
	(0.00365)		
Target x Trend (5,000-6,000 m)	-0.00726**		
	(0.00324)		

Target x Construction (0-500 m)	0.00438	Target x Construction (0-500 m)	-0.00770
	(0.0140)		(0.0189)
Target x Construction (500-1,000 m)	0.00410	Target x Construction (500-1,000 m)	-0.0101
	(0.0101)		(0.00957)
Target x Construction (1,000-2,000 m)	0.00545	Target x Construction (1,000-1,500 m)	-0.0169**
	(0.00587)		(0.00858)
Target x Construction (2,000-3,000 m)	0.0168***	Target x Construction (1,500-2,000 m)	-0.00313
	(0.00547)		(0.00752)
Target x Construction (3,000-4,000 m)	0.00603	Target x Construction (2,000-2,500 m)	0.00664
	(0.00627)		(0.00767)
Target x Construction (4,000-5,000 m)	0.00718		
	(0.00740)		
Target x Construction (5,000-6,000 m)	-0.00727		
	(0.00660)		
Target x After (0-500 m)	0.0361**	Target x After (0-500 m)	-0.0159
	(0.0178)		(0.0229)
Target x After (500-1,000 m)	0.0503***	Target x After (500-1,000 m)	-0.00757
	(0.0119)		(0.0130)
Target x After (1,000-2,000 m)	0.0260***	Target x After (1,000-1,500 m)	-0.0112
	(0.00726)		(0.0107)
Target x After (2,000-3,000 m)	0.0539***	Target x After (1,500-2,000 m)	0.00356
	(0.00669)		(0.00960)
Target x After (3,000-4,000 m)	0.0323***	Target x After (2,000-2,500 m)	0.0466***
	(0.00754)		(0.00911)
Target x After (4,000-5,000 m)	0.0259***		
	(0.00900)		
Target x After (5,000-6,000 m)	0.0210***		
	(0.00788)		
Target x After x Trend (0-500 m)	-0.00921	Target x After x Trend (0-500 m)	-0.0237**
	(0.00773)		(0.00925)
Target x After x Trend (500-1,000 m)	-0.0147***	Target x After x Trend (500-1,000 m)	-0.0175***
	(0.00487)		(0.00501)
Target x After x Trend (1,000-2,000 m)	-0.00552*	Target x After x Trend (1,000-1,500 m)	-0.0109**
	(0.00333)		(0.00482)
Target x After x Trend (2,000-3,000 m)	-0.0184***	Target x After x Trend (1,500-2,000 m)	-0.00815*
	(0.00308)		(0.00426)
Target x After x Trend (3,000-4,000 m)	-0.00927***	Target x After x Trend (2,000-2,500 m)	-0.0238***
	(0.00323)		(0.00383)
Target x After x Trend (4,000-5,000 m)	-0.00902**		
	(0.00410)		
Target x After x Trend (5,000-6,000 m)	-0.0117***		
	(0.00352)		
Noise 100 m	-0.0124	Noise 100 m	-0.0797
	(0.0443)		(0.0722)
Noise 300 m	-0.00311	Noise 300 m	-0.0178
	(0.0236)		(0.0256)
Traffic intensity 1 km		Traffic intensity 1 km	0.0311***
			(0.00793)
Year fixed effects	Yes		Yes
Building period property	Yes		Yes
Property characteristics	Yes		Yes
Noise externality dummies	Yes		Yes
PC6 fixed effects	Yes		Yes
Observations	121,036		51,189
R^2	0.9302		0.9236

Note: Dependent variable is the natural logarithm of transaction price.
Traffic intensity dummy omitted for accessibility model.
Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

From table 8 it becomes clear that the external effects of dual carriageway development do not fade away linearly with distance from the road. The findings do not suggest that a linear distance decay effect exists during and after the construction period, thus implying that a price discount near dual carriageways is not supported by the data. This is also observed using the noise dummies, as these do not seem to impact house prices in column (2). However, the traffic intensity dummy is positive and significant. Being located within 500-1,000 m of an onramp in column (2) on average has a positive effect of 3.2% on property prices, supporting the notion that accessibility is positively valued.

The abovementioned results from both the accessibility and road distance model imply that hypothesis *3. The optimal location for residential properties is as close to a road access point as possible for accessibility benefits, but as far away from the road itself to avoid negative externalities* has to be re-evaluated, as the results from table 8 do not seem to support an accessibility premium near onramps nor a price discount near roads. Therefore, hypothesis 3 is rejected, as the findings indicate that the most optimal location for residential properties opposed to dual carriageways is not the same as opposed to highway infrastructure. Similarly to section 4.2, but based on the results of table 8, an attempt is made to argue what the most optimal location is for housing opposed to dual carriageways. The accessibility model indicates that during the construction period only a positive effect on house prices is observed within 2,000-3,000 m of a dual carriageway onramp and that the highest external effects are observed within 2,000-3,000 m as well. The second largest effect on house prices after construction is found within 500-1,000 m of an access point in the accessibility model. In the road distance model, a positive effect is found within 500-1,000 m near an access point as well, as indicated by the traffic intensity dummy in column (2). Interestingly, the external effects for the road distance model are insignificant besides distance ring 2,000-2,500 m, which indicates a positive effect on house prices. Therefore, the results seem to suggest that house number 1 in figure 1 is the most optimal location for dual carriageways opposed to dual carriageways, which is located further away from both the dual carriageway and the onramp, as (higher) positive effects on house prices are observed at these distances. Based on the findings from section 4 and 5.1 the target area of the accessibility model is enlarged. The target area of the road distance model is reduced and enlarged in subsection 5.2 to observe how the coefficients differ.

5.2 Adjusted target and control areas

Table 9 presents the regression results of the complete and preferred model as similar to section four, but with adjusted target area size. Based on the results from section 4.1 through 5.1, a target area of 7 km and 8 km is implemented for the accessibility model, as the results and figure 4 indicate that the positive external effects might reach further than 6 km. For the road distance model, a target area of 2 km and 3 km is proposed, based on the results from 4.2 and figure 6, and to check whether the results impact a larger area. The control area outer boundary remains the same for both models. Column (1) and (2) report on the regression results of the accessibility model. Column (3) and (4) report on the regression results of the road distance model.

Table 9. Difference-in-difference regression results with adjusted target and control areas

	(1)	(2)	(3)	(4)
Model	**Accessibility**	**Accessibility**	**Road distance**	**Road distance**
Sample	**<10,000 m**	**<10,000 m**	**<4,000 m**	**<4,000 m**
Target Area	**0-7,000 m**	**0-8,000 m**	**0-2,000 m**	**0-3,000 m**
Control Area	**7,000-10,000 m**	**8,000-10,000 m**	**2,000-4,000 m**	**3,000-4,000 m**
Target	-0.0682	-0.0902	-0.169**	-0.182**
	(0.0505)	(0.0599)	(0.0686)	(0.0743)
Target x Trend	-0.0148***	-0.0146***	-0.00597	-0.00751
	(0.00285)	(0.00270)	(0.00736)	(0.00529)
Target x Distance	0.0127*	0.00775	0.0845**	0.0638**
	(0.00722)	(0.00708)	(0.0357)	(0.0253)
Target x Trend x Distance	0.00147**	0.00123**	-0.00202	-0.00254
	(0.000658)	(0.000551)	(0.00530)	(0.00264)
Target x Construction	0.0155***	0.0120**	-0.0141	-0.0242**
	(0.00523)	(0.00493)	(0.0131)	(0.00967)
Target x Construction x Distance	-0.00353***	-0.00241**	0.00375	0.0112**
	(0.00126)	(0.00105)	(0.00954)	(0.00499)
Target x After	0.0458***	0.0437***	-0.0247	-0.0197*
	(0.00595)	(0.00562)	(0.0151)	(0.0110)
Target x After x Trend	-0.0113***	-0.0115***	-0.0105***	-0.0202***
	(0.00160)	(0.00158)	(0.00280)	(0.00240)
Target x After x Distance	-0.00431***	-0.00400***	0.0155	0.0182***
	(0.00133)	(0.00110)	(0.0104)	(0.00524)
Noise 100 m	-0.0135	-0.0132	-0.0710	-0.0710
	(0.0436)	(0.0436)	(0.0703)	(0.0705)
Noise 300 m	-0.00616	-0.00592	-0.00423	-0.00619
	(0.0232)	(0.0232)	(0.0247)	(0.0253)
Traffic intensity 1 km	0.00650	0.00511	0.0252***	0.0208***
	(0.00483)	(0.00475)	(0.00718)	(0.00643)
Year fixed effects	Yes	Yes	Yes	Yes
Building period property	Yes	Yes	Yes	Yes
Property characteristics	Yes	Yes	Yes	Yes
Noise externality dummies	Yes	Yes	Yes	Yes
PC6 fixed effects	Yes	Yes	Yes	Yes
Observations	121,036	121,036	51,189	51,189
R^2	0.9302	0.9302	0.9235	0.9237

Note: Dependent variable is the natural logarithm of transaction price.
Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Column (1) presents the regression results for the accessibility model using a target area of 7 km. What becomes clear is that the R-squared is identical to column (4) of table 5 and that the results are similar. Target_i is no longer significant, but $\text{Target}_i \times \text{Construction}_t$ has a slightly higher coefficient than in table 5 and $\text{Target}_i \times \text{Construction}_t \times \text{Distance}_i$ is slightly more negative. Also the coefficient for $\text{Target}_i \times \text{After}_t$ has become slightly higher, indicating larger

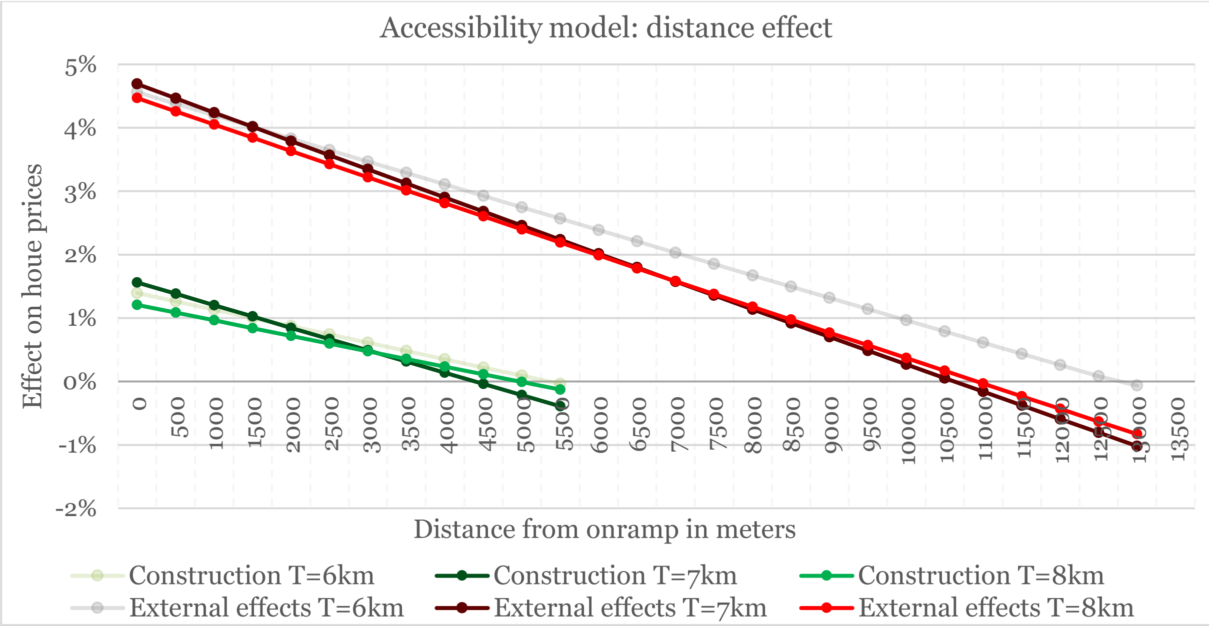

Figure 8. Distance effects of the alternative model specifications for the accessibility model.

significant positive external effects. $\text{Target}_i \times \text{After}_t \times \text{Trend}_t$ is almost identical to table 5 and, therefore, still indicates that the external effects decrease over time. $\text{Target}_i \times \text{After}_t \times \text{Distance}_i$ still indicates that the external effects are largest closest to an onramp, but the coefficient implies that it decreases faster with distance than in table 5. This is visualized in figure 8, where the grey lines are identical to figure 4 for the ease of comparison. The trend is visualized in figure 9. The externality dummies are insignificant and, therefore, still imply that they do not influence house prices in this sample. Column (2) presents the regression results for the accessibility model using a target area of 8 km. The R-squared is identical to the R-squared in column (4) of table 5. The coefficients are similar to column (1), and overall, slightly lower than in column (4) of table 5. The results of column (1) and (2) indicate that the results of the complete and preferred model specification of table 5 are robust.

Column (3) shows the regression results for the road distance model using a target area of 2 km. An R-squared of 0.9235 is observed. Not all coefficients are similar to the complete and preferred model of table 6. $\text{Target}_i \times \text{Construction}_t$ has become insignificant, meaning that no effect on house prices is measured during the construction period of the dual carriageways. $\text{Target}_i \times \text{After}_t$ indicates similar negative external effects on house prices but has become slightly lower and lies just outside of the 90% significance level ($P>|t| = 0.103$). The negative external effects still become stronger over time (see figure 11) but the coefficient of $\text{Target}_i \times \text{After}_t \times \text{Distance}_i$ is no longer significant. Being located within 500-1,000 m of a dual carriageway access point has a similar coefficient as in table 6 and indicates a positive effect on house prices. The external effects of the 2 km and 3 km target area are visualized in figure 10.

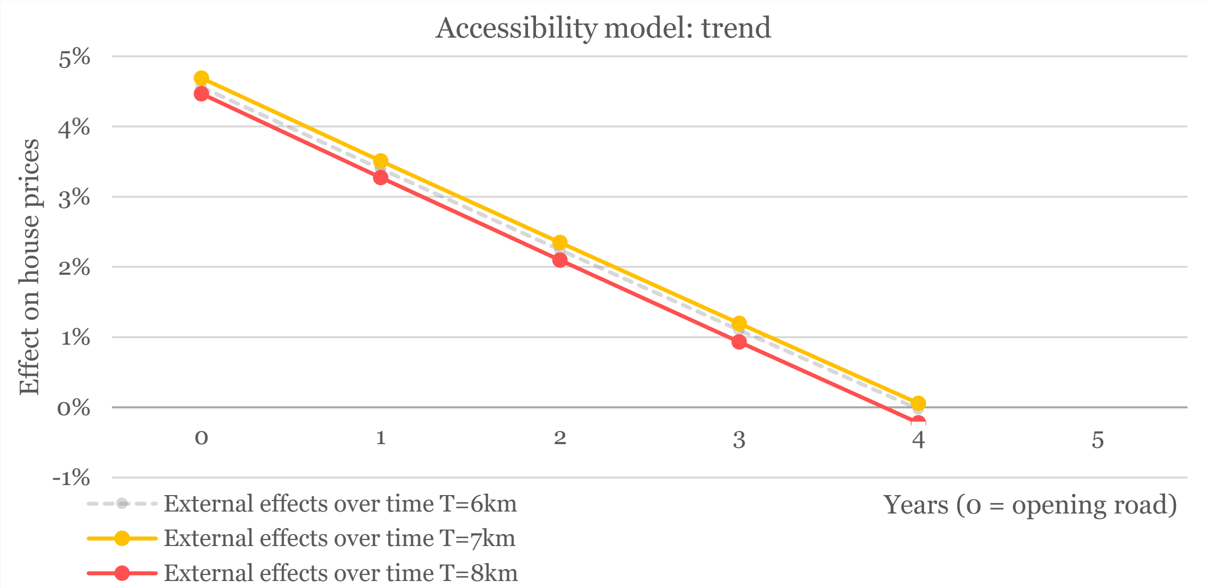

Figure 9. Target area trend effect comparison of the accessibility model.

Column (4) reports the results for the road distance model using a target area of 3 km. Results are similar to column (4) of table 6. The construction period has a negative effect of 2.4% on house prices, which fades away with distance. The external effects have become weaker but are still negative. The traffic intensity dummy is slightly lower, but still indicates a positive effect of being located within 500-1,000 m of an onramp. The distance effects of the regression results from column (3) and (4) are visualized in figure 9. Please note that for column (3) no distance effect is be visualized because of insignificant coefficients. Column (3) and (4) suggest that the findings of the road distance model are less robust than the accessibility model. The findings are somewhat robust because in column (3) differences are observed, but column (4) is similar to the complete and preferred model specification of table 6.

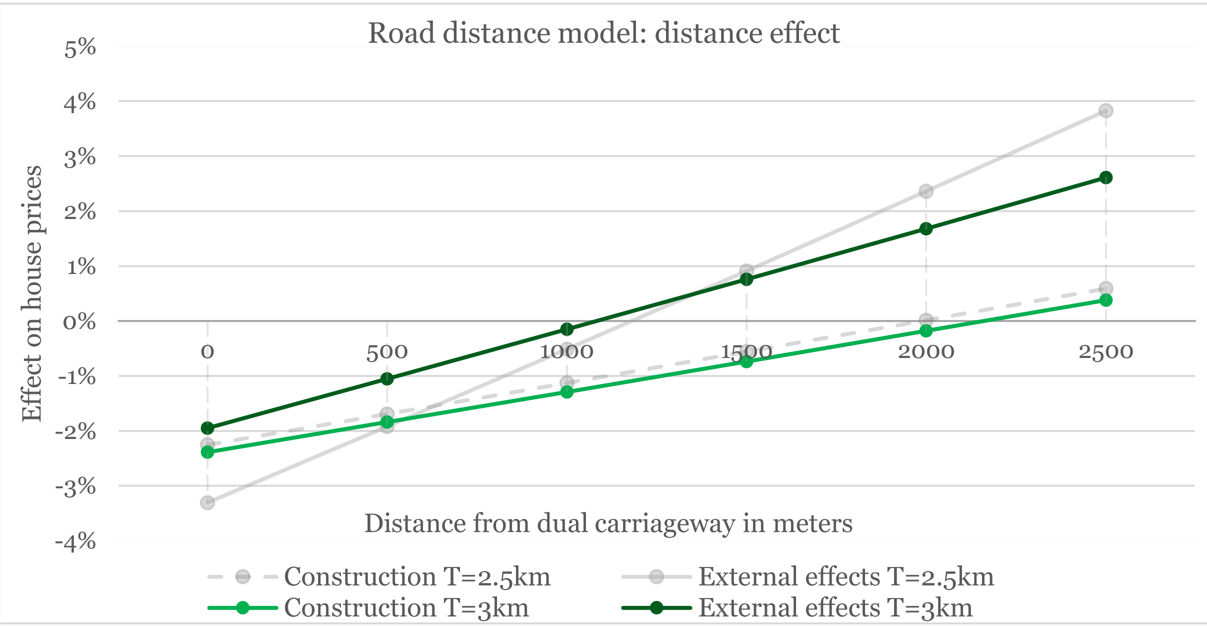

Figure 10. Distance effects of the alternative model specifications for the road distance model.

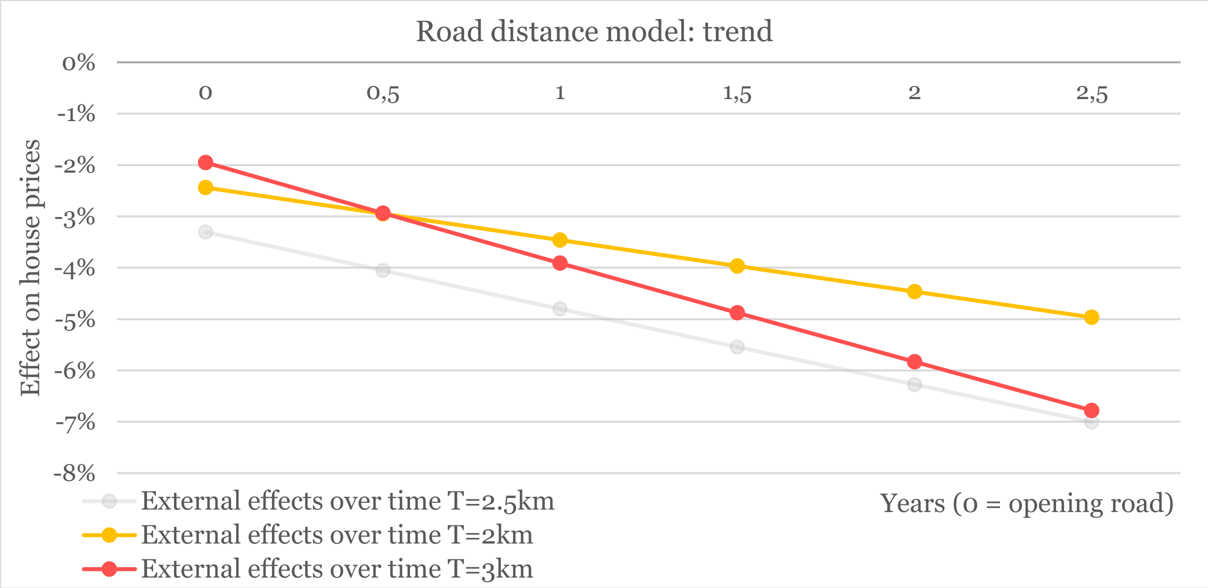

Figure 11. Target area trend effect comparison of the road distance model.

5.3 Heterogeneity

Heterogeneity may exist in the effects of road infrastructure developments on house prices. Property prices in urban and rural areas are heterogeneous (DiPasquale & Wheaton, 1996), leading to a possible difference in valuation of infrastructural developments by residents from urban and rural residents. Especially accessibility may be valued higher in rural areas, as urban areas usually already provide sufficient road infrastructure networks. Another aspect is the difference between short and long dual carriageways, as dual carriageways reaching over a longer distance may provide areas with more accessibility than short dual carriageway projects, meaning that the larger accessibility benefits of long dual carriageways might be valued higher than of short ones. Therefore, heterogeneity is tested for by using model specifications that divide the complete and preferred model specifications into groups. Table 10 reports the regression results. In column (1) to (4) differences between smaller dual carriageway projects and larger projects are analyzed. Based on the average project length, calculated using table 1, it has been decided upon short projects being below 22.5 km road distance and that long projects are above 22.5 km road distance. In column (5) to (8) differences between the urban core of the Netherlands, the *Randstad*, and other, rather rural, regions are analyzed. Only project #5, as indicated in figure 3, is located in the urban core and, therefore, will be compared to all other projects combined.

Column (1) and (2) report the regression results for the accessibility model, comparing short projects to long projects. $\text{Target}_i \times \text{Construction}_t$ is only significant for long projects, indicating that the construction period has a positive effect of 1.8% on surrounding house prices. Distance does not seem to have an effect during the construction period in both column (1) and (2).

$Target_i \times After_t$ is positive and significant for both short and long roads. For short roads, the positive external effects on house prices are 2.3% and for long roads 5.4%. This might be the result of longer dual carriageways providing areas with more accessibility benefits, as more distant areas can be reached more easily. For both short and long roads the effect fades away over time, but almost twice as fast for long roads. Only long roads see a significant effect for $Target_i \times After_t \times Distance_i$, indicating that the external effects are the highest for properties located closer to an onramp. The noise 100 m dummy is significant for short projects only and indicates a negative price effect on house prices of 22.2%. The traffic intensity dummy is significant for short roads and lies just outside of the 90% significance level for long roads ($P>|t| = 0.101$). Being located within 1 km of an onramp after the opening has a negative effect on house prices of 2.3% for short roads and a positive effect on house prices of 0.95% for long roads. Interestingly, the direction of the traffic intensity dummy differs in direction between the project lengths. Near short road onramps increased traffic intensity after the road opens may cause a negative effect on house prices, while for long roads the accessibility benefits coming from the onramps may override the negative externalities.

Column (3) and (4) report on the regression results for the road distance model, comparing short projects to long projects. The construction period is insignificant for long roads but has a negative effect of 5.5% on house prices for short roads, which fades away with distance from the dual carriageway. $Target_i \times After_t$ is negative and significant for long roads only and indicates negative external effects of 2.9% on house prices. The external effects of long road become stronger over time but fade away over distance. Similar to the accessibility model, the noise 100 m dummy is only significant for short projects and indicates a negative effect of 22.8% on house prices. The traffic intensity dummy is significant for both short and long projects but differ in direction. Being located within 500-1,000 m of an onramp of a short project has a negative effect of 2.3% on house prices, identical to the accessibility model. Being located within 500-1,000 m of an onramp of a long project has a positive effect of 3.7% on house prices. Apparently, properties near short roads are negatively impacted by being close to an onramp, which could be a result of increased traffic flow after opening of the road, while properties near long roads are positively impacted by being close to an onramp, which may be caused by accessibility benefits overriding the negative externalities after the road opening.

In column (5) and (6) the regression results for the accessibility model can be observed, comparing the urban core to other regions. $Target_i \times Construction_t$ is only significant for the other regions, indicating a positive effect on house prices during the construction period of 1.9%. $Target_i \times Construction_t \times Distance_i$ is statistically insignificant for both columns. The external effects on house prices for the urban core are 3%, and for the other regions 5.1%. This effect fades away over time for both regions, and over distance for the other regions only. The slightly lower external effects in the urban core may be explained by there are already sufficient road infrastructure available in the urban core, meaning that dual carriageway development might not have such a significant impact as in the other, more rural, areas. In the more rural areas, the accessibility benefits may be valued more positively, causing higher positive external effects. The noise 100 m is statistically significant for the urban core only and indicates that being located within 100 m of a dual carriageway has a negative effect on house prices of 22.7%. The traffic intensity dummy is significant for the urban core and lies just outside of the 90% significance level for the other regions (P>|t| = 0.105). Being located within 1 km of a dual carriageway onramp has a negative effect on house prices of 2.0% in the urban core, possibly caused by increased traffic after opening of the road. In the other regions combined, a positive effect of 0.93% on house prices is found within 1 km of a dual carriageway onramp, which may indicate that in more rural areas accessibility is valued more positively than in the urban core, causing the positive effects to override the negative externalities, while in the urban core within 1 km of a dual carriageway onramp the negative externalities dominate the positive effects.

Finally, column (7) and (8) present the regression results for the road distance model, in which the urban core is compared to the other regions. $\text{Target}_i \times \text{Construction}_t$ is not statistically significant for both columns but lies just outside of the 90% significance level for the urban area (P>|t| = 0.120). $\text{Target}_i \times \text{Construction}_t$ indicates a negative effect of 4.0% on house prices during the construction period in the urban core. $\text{Target}_i \times \text{Construction}_t \times \text{Distance}_i$ lies just outside of the 90% significance level as well for the urban core (P>|t| = 0.123) and indicates that the effect during the construction period fades away with distance from the dual carriageway in the urban core. No statistically significant external effects are indicated for the urban core. However, for the other regions the external effects indicate a negative effect of 3.1% on house prices, which becomes stronger over time, and fades away over distance, similarly to the complete and preferred model in table 6. For the urban core, being located within 100 m of a dual carriageway generates a negative effect of 25.8% on house prices. For other regions, a positive effect of 3.6% is observed for properties located within 500-1,000 m of an onramp, possibly caused by accessibility benefits being valued more positively in the more rural regions.

The results of table 10 indicate that in both the accessibility and road distance model heterogeneity exists. Most of the findings from the accessibility model are considered logical and to a certain extent match the complete and preferred specification of table 5, making them robust. The results of the road distance model are less robust than the accessibility model as differences between the heterogeneity regression results and table 6 are present more often. However, the road distance model is considered fairly robust as logical findings are present.

Table 10. Heterogeneity analysis difference-in-difference regression results

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Model	**Accessibility**	**Accessibility**	**Road Distance**	**Road Distance**	**Accessibility**	**Accessibility**	**Road Distance**	**Road Distance**
Group	**Short < 22.5 km**	**Long > 22.5 km**	**Short < 22.5 km**	**Long > 22.5 km**	**Urban Core**	**Outside**	**Urban Core**	**Outside**
Sample	**<10,000 m**	**<10,000 m**	**<4,000 m**	**<4,000 m**	**<10,000 m**	**<10,000 m**	**<4,000 m**	**<4,000 m**
Target Area	**0-6,000 m**	**0-6,000 m**	**0-2,500 m**	**0-2,500 m**	**0-6,000 m**	**0-6,000 m**	**0-2,500 m**	**0-2,500 m**
Control Area	**6,000-10,000 m**	**6,000-10,000 m**	**2,500-4,000 m**	**2,500-4,000 m**	**6,000-10,000 m**	**6,000-10,000 m**	**2,500-4,000 m**	**2,500-4,000 m**
Target	-0.0311	-0.102	-0.0234	-0.247***	-0.0399	-0.0892	-0.144	-0.213***
	(0.0440)	(0.0992)	(0.114)	(0.0820)	(0.0422)	(0.0960)	(0.118)	(0.0791)
Target x Trend	-0.0228***	0.00668	-0.00589	0.0138*	-0.0277***	0.00643	-0.0151	0.0131*
	(0.00549)	(0.00415)	(0.0124)	(0.00740)	(0.00624)	(0.00393)	(0.0126)	(0.00717)
Target x Distance	-0.00294	0.0204	-0.0203	0.0961***	-0.00443	0.0176	0.0239	0.0804**
	(0.00769)	(0.0162)	(0.0453)	(0.0337)	(0.00741)	(0.0157)	(0.0482)	(0.0325)
Target x Trend x Distance	0.00332***	-0.00157	-0.00439	-0.00867**	0.00405***	-0.00176	-0.000467	-0.00982**
	(0.00126)	(0.00126)	(0.00677)	(0.00434)	(0.00141)	(0.00113)	(0.00707)	(0.00423)
Target x Construction	0.00953	0.0182***	-0.0562**	-0.0148	0.0158	0.0193***	-0.0407	-0.0166
	(0.0112)	(0.00694)	(0.0249)	(0.0123)	(0.0131)	(0.00666)	(0.0262)	(0.0120)
Target x Construction x Distance	-0.000162	-0.00218	0.0271**	0.00882	0.00162	-0.00261	0.0227	0.0107
	(0.00264)	(0.00219)	(0.0137)	(0.00740)	(0.00297)	(0.00201)	(0.0147)	(0.00720)
Target x After	0.0232*	0.0522***	-0.0390	-0.0292**	0.0300**	0.0502***	-0.0358	-0.0314**
	(0.0128)	(0.00790)	(0.0289)	(0.0140)	(0.0148)	(0.00759)	(0.0314)	(0.0137)
Target x After x Trend	-0.00857***	-0.0158***	-0.0108**	-0.0188***	-0.00934**	-0.0128***	-0.0194***	-0.0164***
	(0.00329)	(0.00206)	(0.00541)	(0.00285)	(0.00429)	(0.00197)	(0.00651)	(0.00277)
Target x After x Distance	0.00128	-0.00558**	0.0210	0.0285***	0.00490	-0.00558***	0.0234	0.0299***
	(0.00287)	(0.00227)	(0.0154)	(0.00784)	(0.00326)	(0.00209)	(0.0168)	(0.00764)
Noise 100 m	-0.251***	0.00223	-0.259***	-0.0434	-0.257***	0.00766	-0.261***	-0.0442
	(0.0416)	(0.0447)	(0.0406)	(0.0786)	(0.0391)	(0.0444)	(0.0409)	(0.0784)
Noise 300 m	-0.0313	-0.00773	-0.00374	-0.00320	0.0428	-0.0115	0.105	-0.00925
	(0.0698)	(0.0252)	(0.0686)	(0.0266)	(0.0798)	(0.0248)	(0.0878)	(0.0261)
Traffic intensity 1 km	-0.0229**	0.00945	-0.0229*	0.0364***	-0.0206**	0.00930	-0.0119	0.0354***
	(0.0104)	(0.00575)	(0.0137)	(0.00768)	(0.0104)	(0.00573)	(0.0144)	(0.00762)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Building period property	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Property characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Noise externality dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PC6 fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	45,038	75,998	13,854	37,335	35,869	85,167	11,334	39,855
R^2	0.9337	0.9261	0.9278	0.9218	0.9288	0.9265	0.9265	0.9216

Note: Dependent variable is the natural logarithm of transaction price.
No F-statistic for the Chow Test can be produced due to the usage of robust standard errors.
Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

6. DISCUSSION

Findings from the complete and preferred model specification of the accessibility model indicate that dual carriageway development leads to an increase in house prices during and after the construction period of dual carriageways. This is in line with various authors who have performed similar research on highway infrastructure, as dual carriageways have not been researched in this setting before. Mikelbank (2004) and Chalermpong (2001) find a positive effect on house prices in the United States, Paliska & Drobne (2020) find a positive effect on house prices in Slovenia, Theisen & Emblem (2020) find a positive effect on house prices in Norway, Bao et al. (2020) find a positive effect on house prices in Hong Kong, and Levkovich et al. (2016) find a positive effect on house prices in the Netherlands. The sensitivity analysis has shown that the results for both the accessibility and road distance model might not be as linear with distance as found by Mikelbank (2004) and Paliska & Drobne (2020). However, the results not being linear over distance is in line with Chernobai et al. (2020), who observe lower price increases for properties sold closer and much further away of highways in California.

Findings from the complete and preferred model specification of the road distance model indicate that the external effects of dual carriageway development on surrounding house prices are negative. This is line with numerous studies, such as performed on motorways by Huang (1994) and Martínez & Viegas (2009). Also during the construction period, a negative effect on house prices is observed. This is in line with the assumption of an anticipation effect found by Bao et al. (2020) and Levkovich et al. (2016). An anticipation effect is also found for the accessibility model, but the effect of onramps on house prices during the construction period is positive. However, the heterogeneity test has shown that an anticipation effect might not apply to all dual carriageway developments, depending on the type of development, length of the road, and whether the project is located within an urban or rural area. Both models indicated heterogeneity to some extent. However, most findings are considered to be logical. Results from the road distance model have also shown not to be linear with distance, as even a positive effect can be found within 2,000-2,500 m from the dual carriageways. The average trend of the road distance model is negative, indicating that the external effects become stronger over time for the 2.5 years after the opening of the road. However, it would not be realistic to assume that such a trend effect carries on forever. More intensive research into the trend effect, over a longer timeframe, would be useful in future research.

No significant coefficients are observed for the 300 m noise dummy in both the accessibility and road distance model, which is in line with Paliska & Drobne (2020), who could not find a significant result within 300 m of a motorway in Slovenia. However, when splitting the data into groups, significant results are found for properties within 100 m of a dual carriageway for a number of groups. The traffic intensity dummy indicates no significant coefficient in the complete and preferred model of the accessibility but has a positive effect on house prices in the road distance model. This contradicts Levkovich et al. (2016), who find a negative effect on house prices if a property is located within 1 km of an intersection. This seems not to be the case for dual carriageways.

Furthermore, no evidence has been found that the optimal location for residential properties opposed to a dual carriageway are in line with the optimal location opposed to a highway as proposed by Tillema et al. (2012). Findings from earlier sections indicate that the most optimal location opposed to a dual carriageway would be further away from both the dual carriageway and its access point, which is house number 1 observed in figure 1. However, based on the results, no precise outcomes can be given on the exact optimal location of residential real estate opposed to dual carriageways, nor the implications for each individual property of figure 1.

Throughout the research process various limitations have come up. The availability of the transaction data used in this research was Q1 2004 until Q1 2021. This prevents projects completed a few decades ago to be included in the sample and means that the period before and after construction had to be limited to three and two and a half years, respectively, to keep as many projects and observations as possible. The lack of data on project announcements and the lack of exact dates on construction periods and official road openings meant that months were used for the start and end of the construction period. To prevent the overlap of target areas, five out of fourteen initial projects were removed from the sample. Data availability and time constraints, furthermore, prevented some projects in the south to be included in the sample. In consequence, findings might not apply to the whole country, but only to areas similar to the included samples. Furthermore, the lack of data on externalities, especially noise disturbances and air pollution, resulted in the use of distance dummies. Therefore, no in-depth understanding on the externalities can be provided. Furthermore, limitations in terms of the findings exist, as the sensitivity analysis has shown that the road distance model might not be as robust as desired. Findings from the accessibility model are robust. Moreover, especially within 100 m, there is a lack of sufficient number of observations for some of the groups, which could distort the findings. Finally, Euclidean distance has been used to calculate the distance between properties and the nearest dual carriageway and the dual carriageway nearest access point. This is suitable for the distance to the road, as negative externalities tend to travel by air. However, the distance to a dual carriageway access point would be better represented if the distance was calculated by using the road distance instead of the Euclidean distance. However, due to technical limitations, this was not within the possibilities within this paper.

7. CONCLUSION

This research aims to identify to what extent dual carriageway development affects surrounding house prices in the Netherlands. This research contributes to the existing literature, as dual carriageways have not been analyzed in this setting before. Using two models, the accessibility model and the road distance model, transaction data of residential properties from the Netherlands between 2004 and 2021 have been analyzed for eight dual carriageway projects. The analysis applies a hedonic price model with difference-in-difference specifications to compare property prices between target and control areas before, during, and after the construction of the dual carriageways.

Existing literature shows that not all authors come to the same conclusion when it comes to the effect of road infrastructure development on house prices. The review of existing literature indicates that on average authors argue that prices appreciate closer to highway onramps, while negative externalities might exist near highways itself. Some authors indicate the presence of a public anticipation effect, meaning that infrastructural developments are capitalized into house prices well before the actual opening of the project.

Findings from the accessibility model indicate that accessibility to a dual carriageway onramp has a positive effect of on average 1.4% and 4.6% on surrounding housing prices during the construction period and after the opening of the dual carriageway, respectively. These effects are not linear with distance, as the highest external effects after opening can be found within two and three kilometers from the onramp. Findings indicate that on average the positive effect during the construction period becomes zero at approximately 5.5 km and that the external effects fade away at approximately 13 km. Evidence suggests that this does not happen linearly.

Results from the road distance model indicate that being located near a dual carriageway section has a negative effect of on average 2.3% and 3.3% on surrounding house prices during the construction period and after the opening of the dual carriageway, respectively. These findings are not linear with distance. Results indicate that on average the negative effect during the construction period becomes zero at approximately 2 km and that the external effects fade away at approximately 1.2 km. Being located within 500-1,000 m of an onramp after road opening has a positive effect of 2.8% on property prices in the road distance model.

This research also focuses on differences between newly constructed and redeveloped dual carriageways. Evidence suggests that differences exist. For both the accessibility and road distance model, the construction period coefficients are only significant for newly developed roads. This can be explained by the fact that newly constructed roads create new externalities and nuisances, while a redeveloped road produced externalities and nuisances already before the construction period, meaning that residents may not experience significant differences during the construction period. When it comes to the accessibility model, the positive external effects on house prices are 5.7% for newly constructed roads and 3.6% for redeveloped roads. In the road distance model, only newly constructed roads indicate negative and significant external effects on house prices of 5.8%, indicating that overall the external effects of the road distance model are largely driven by newly constructed roads. In both models, the external effects fade away faster over time for redeveloped dual carriageways and only for newly constructed roads a distance effect is observed, similar to the complete and preferred model specifications. Being located within 100 m of a newly constructed road generates a negative effect on house prices in both models. Being within 500-1,000 m of an onramp generates a positive effect on house prices for redeveloped roads in the road distance model only.

Based on the results it can be argued that properties are most likely to experience the highest positive effect from dual carriageway development if they are located within 2 and 3 km of an onramp and within 2 and 2.5 km of the road itself. It is at these distances that the regression coefficients are the highest and positive in both the accessibility and road distance model.

The results from this research have implications for the residential property market. It shows how different perspectives and development types have varying outcomes on the housing market. The results highlight the importance of assessing the potential impacts new construction or redevelopment of dual carriageways can have on residential property prices from different perspectives. For real estate investors and developers the results could give a valuable insight into the most profitable and least profitable property to invest in, especially when it is known that there are plans for a new or redeveloped dual carriageway, as findings have shown that depending on the development type and heterogeneity group the effects of infrastructural developments on property prices may differ. Dual carriageway development multiple effects on house prices. Different perspectives exist and should be taken into account.

Recommendations for future research include a more extensive analysis including data on externalities, a proposal or announcement period, a longer post construction period, more infrastructural projects, varying target and control areas, projects outside of the Netherlands, and transaction data on other real estate segments to create a deeper understanding into how infrastructural developments, other than highways, influence real estate markets. Moreover, more research is necessary into whether the findings apply to other regions of the Netherlands, as well as into identifying the drivers of the varying results between development types, particularly with regard to newly constructed and redeveloped dual carriageways.

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Appendix A: Study area of the accessibility and road distance model

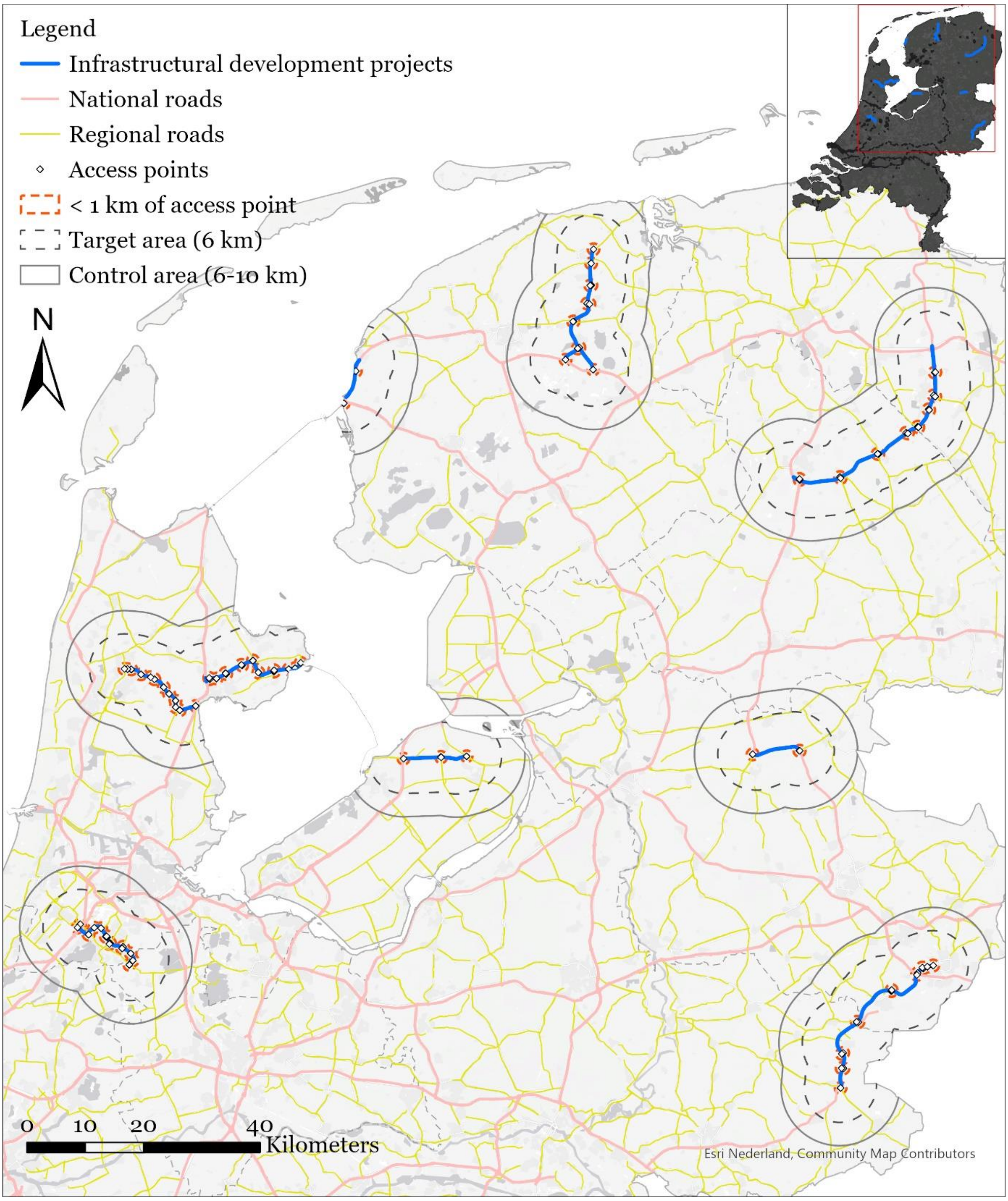

Figure A1. Study area of the accessibility model.

The study area of the accessibility model consists of a target area reaching from 0-6 km and a control area reaching from 6-10 km. The infrastructural projects are indicating with a blue line. The dual carriageway onramps are indicated by the white dots. The traffic intensity dummy, indicating the properties within 1 km of an onramp, are shown in orange. National roads are shown in pink (mostly highways). Regional roads are shown in yellow (mostly carriageways).

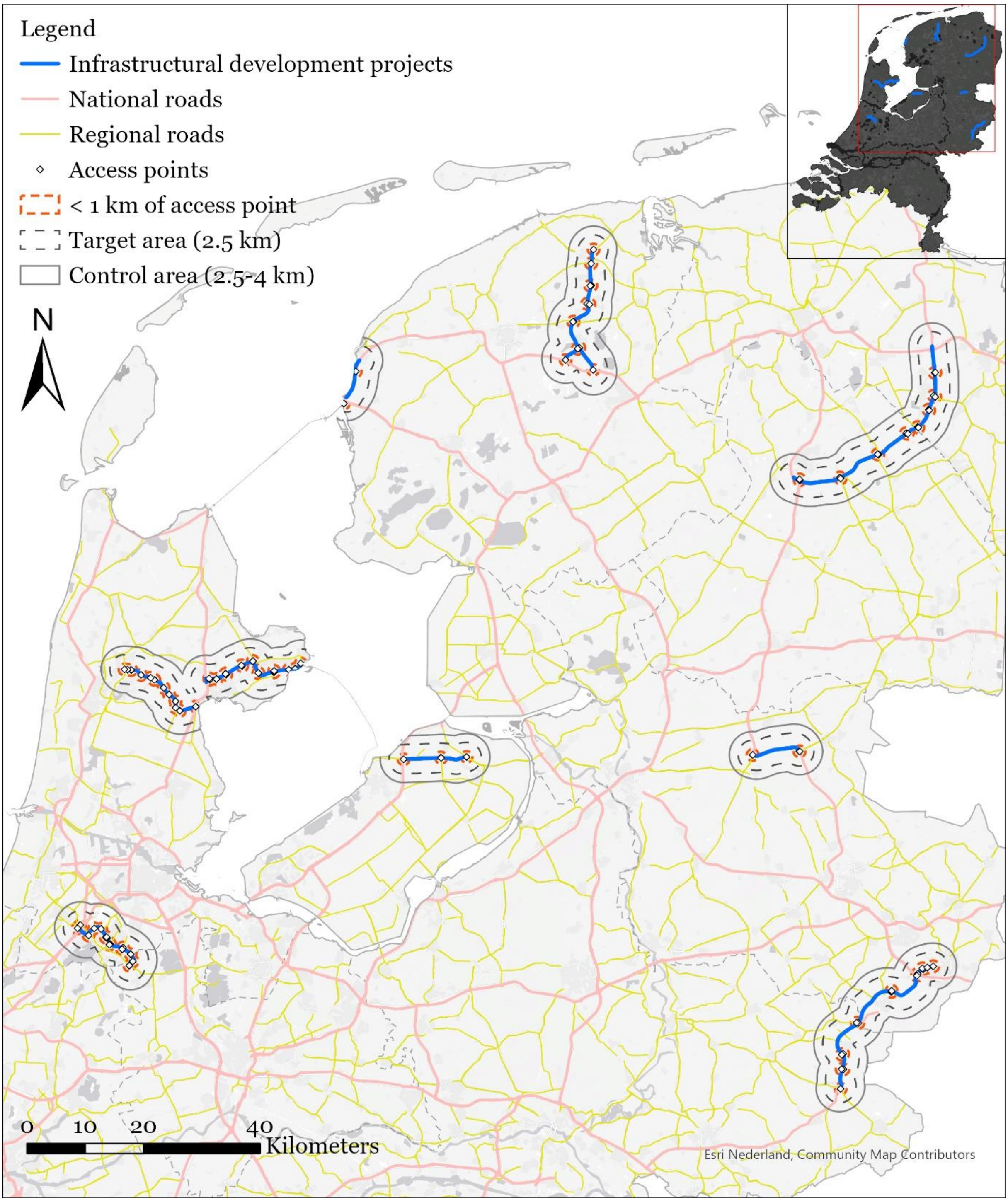

Figure A2. Study area of the road distance model.

The study area of the road distance model consists of a target area reaching from 0-2.5 km and a control area reaching from 2.5-4 km. The infrastructural projects are shown in blue. The dual carriageway onramps are indicated by the white dots. The traffic intensity dummy, indicating the properties within 500-1,000 m of an onramp, are shown in orange. National roads are shown in pink (mostly highways). Regional roads are shown in yellow (mostly carriageways).

Appendix B: Development of property prices in the target and control areas

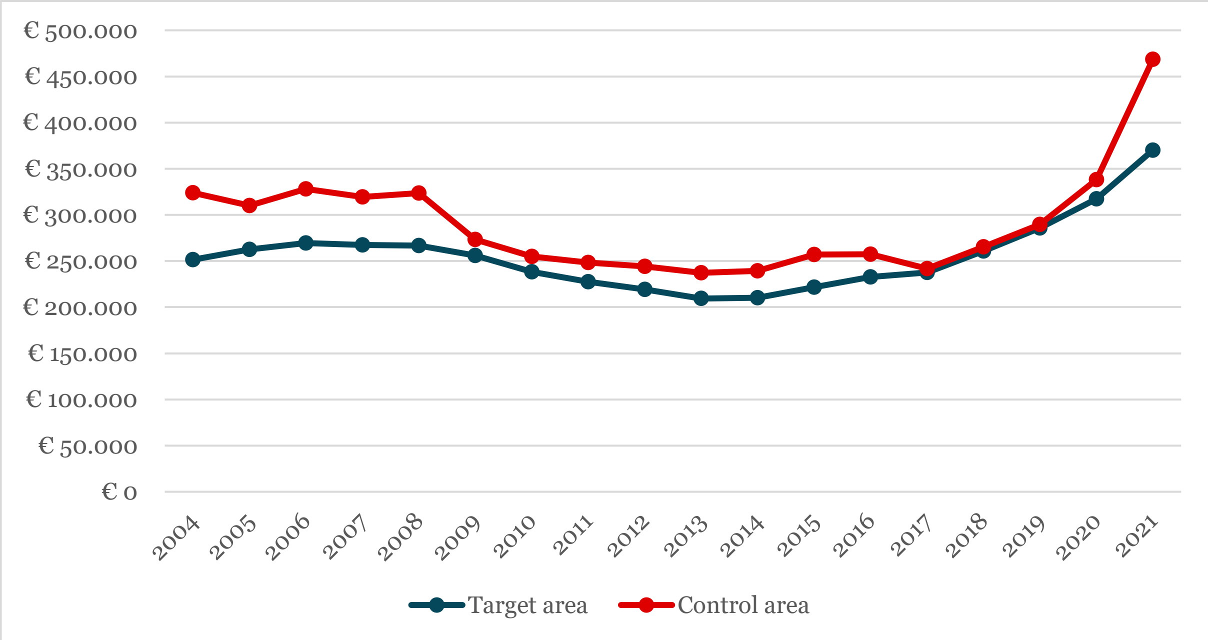

Figure B1. Development of property prices in the accessibility model.

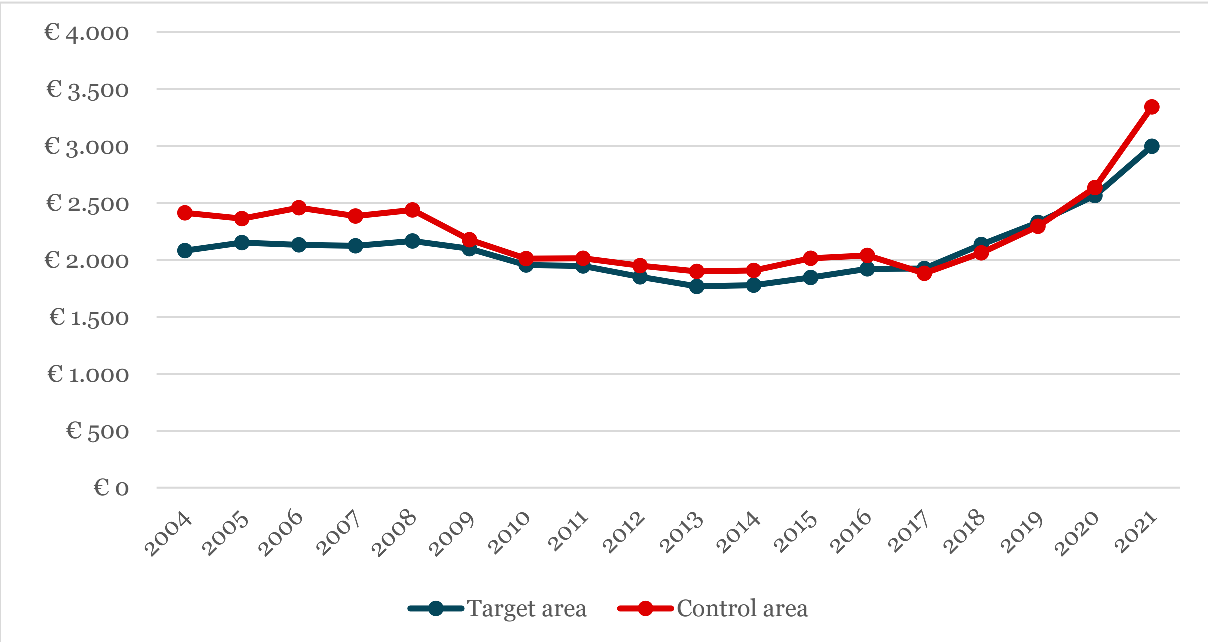

Figure B2. Development of property prices per square meter in the accessibility model.

On average, the property prices in the target and control area follow the same pattern in the accessibility model. The property prices are calculated using the sample from table 6.

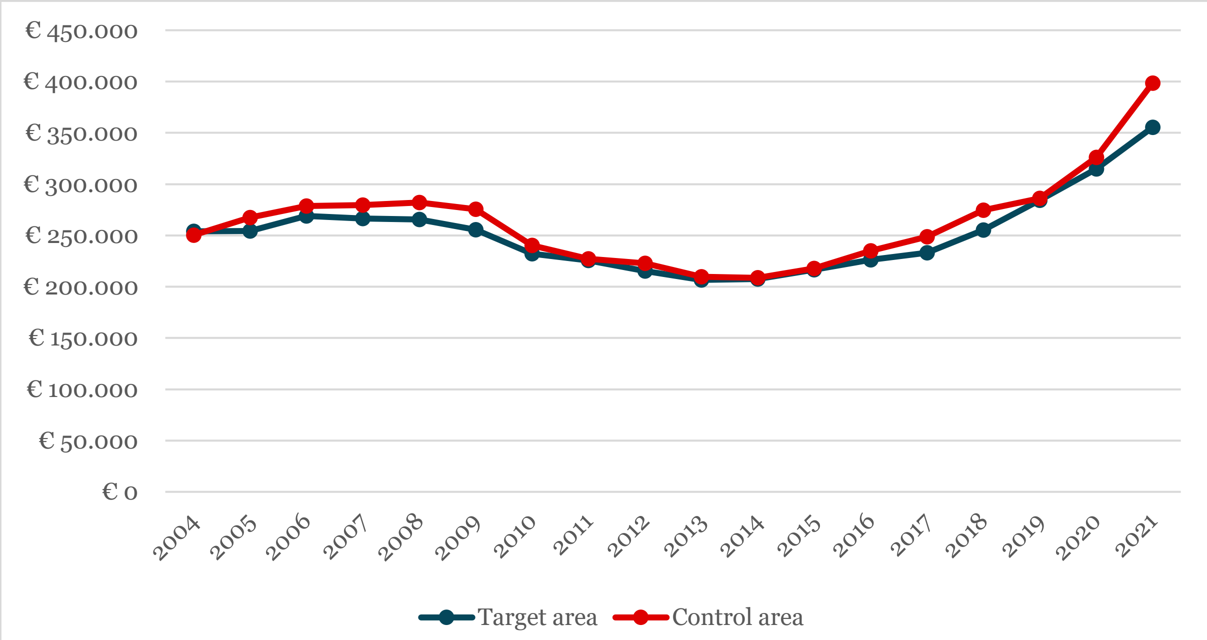

Figure B3. Development of property prices in the road distance model.

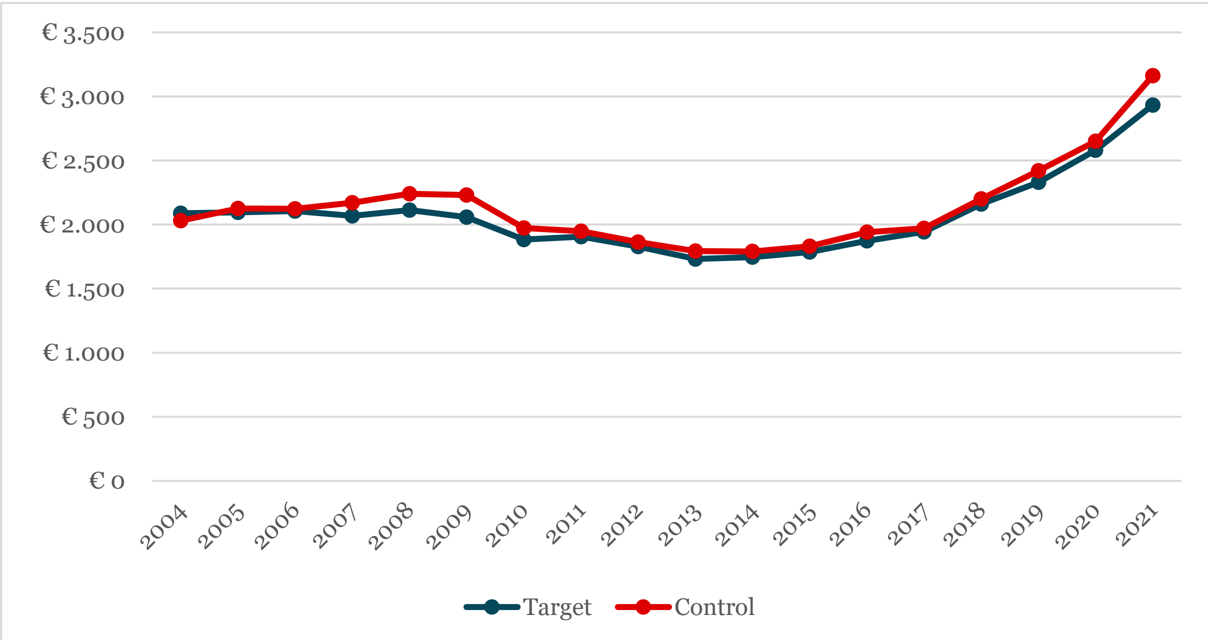

Figure B4. Development of property prices per square meter in the road distance model.

On average, the property prices in the target and control area follow the same pattern in the road distance model. The property prices are calculated using the sample from table 7.

Appendix C: OLS assumption testing

Since this research considers two separate models for measuring the effects of infrastructural development on house prices, the OLS assumptions are tested for the models separately as well. Table C1 indicates assumptions that have been tested.

Table C1. OLS Assumptions by Brooks & Tsolacos (2010)

Assumption	Technical Notation	Interpretation
1. Linearity	$E(u_t) = 0$	The errors have a mean that equals zero.
2. Homoscedasticity	$\text{var}(u_t) = \sigma^2 < \infty$	The variance of the errors is constant and finite over all values of x_t.
3. No autocorrelation	$\text{cov}(u_i, u_j) = 0$	The errors are statistically independent of one another.
4. Independence	$\text{cov}(u_t, x_t) = 0$	There is no relationship between the error and corresponding x variable.
5. Normality	$u_t \sim N(0, \sigma^2)$	Ut is normally distributed.

<u>Assumption 1. Linearity.</u>

For the assumption of linearity to hold it is important to have a mean of approximately zero for the errors, or residuals. This assumption in principle does not need testing, as Brooks & Tsolacos (2010) argue that the assumption of linearity will never be violated if a constant term is included. STATA in fact automatically adds a constant to the regression, meaning that the first assumption is not violated. However, for the sake of testing this assumption by hand too, the following two steps are taken: 1. Table C2 presents the descriptive statistics of the residuals for both models, in which it becomes clear that the means of the residuals are extremely close to zero. 2. Figure C1 & C2 present histograms of the residuals for both models, in which one can see that the approximately normally distributed residuals have their peak around zero.

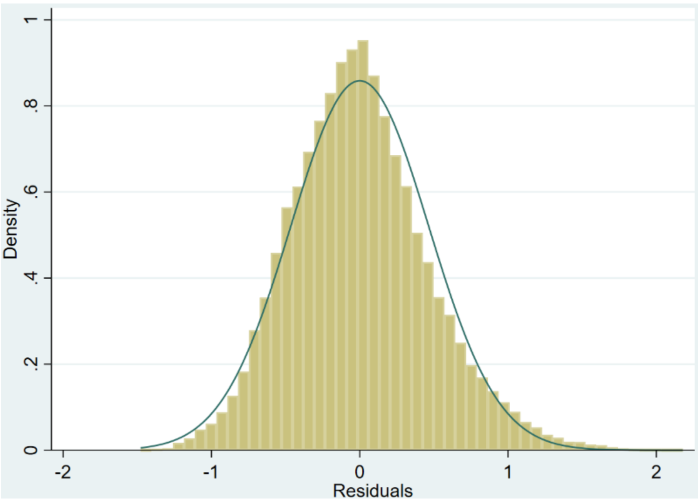

Figure C1. Residuals accessibility model.

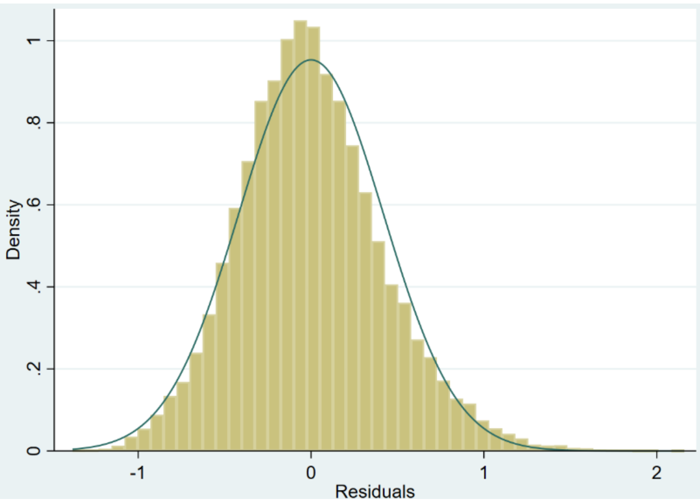

Figure C2. Residuals road distance model.

Table C2. Residual means

Model	Observations	Mean of errors
Accessibility model	121,036	1.05e-10
Road distance model	51,189	3.57e-11

<u>Assumption 2. Homoscedasticity.</u>

For the assumption of homoscedasticity to hold it is important for the errors to have a constant variance. This assumption will also be tested in two ways. The first method is to perform a visual inspection of the residuals versus the fitted values, as seen in the residuals-versus-fitted plot (rvfplot) in figures C3 & C4. A pattern in the data is visible in both models, indicating heteroscedasticity and, therefore, violating the assumption of homoscedasticity. The second method is to use the Breusch-Pagan/Cook-Weisberg test for heteroscedasticity. The null hypothesis for this test is that the variance is constant. As the test results present a highly significant p-value for both models, the null hypothesis is rejected, indicating that the variance is not constant. This assumption is dealt with by including heteroscedasticity-constant standard error estimates, or robust standard errors, in both models (Brooks & Tsolacos, 2010).

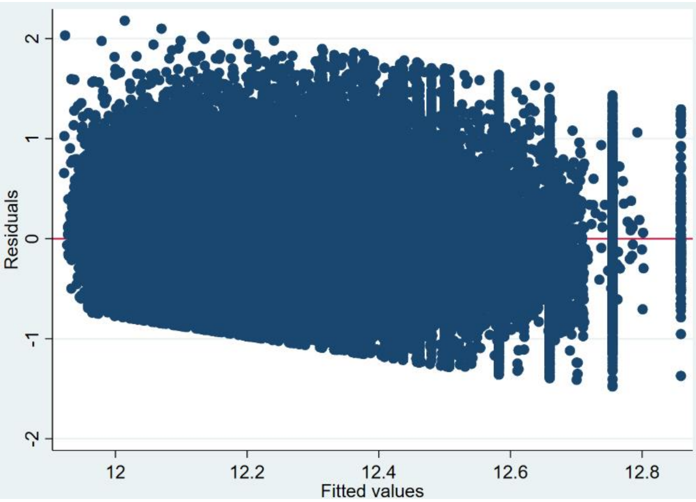

Figure C3. Rvfplot accessibility model.

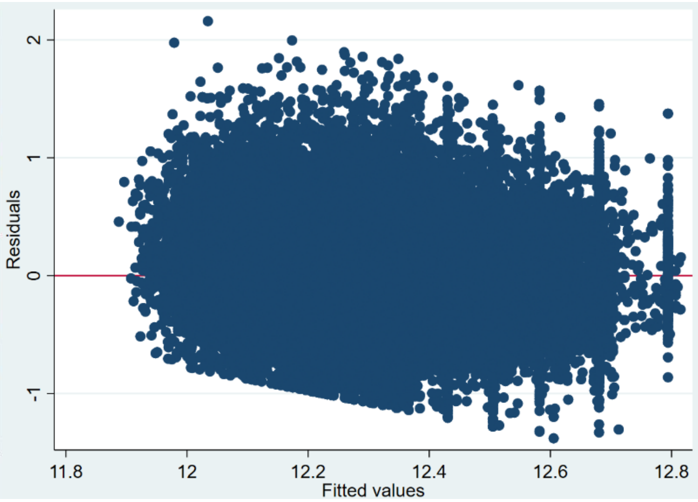

Figure C4. Rvfplot road distance model.

<u>Assumption 3. No autocorrelation.</u>

The assumption of autocorrelation assumes that the errors are statistically independent of each other, and thus uncorrelated with one another. According to Brooks & Tsolacos (2010) autocorrelation can be found to some extent in almost every regression in real estate. Autocorrelation can be detected by the Durbin-Watson test. If the outcome of the Durban-Watson test is 2, there is no autocorrelation in the residuals. With the outcome of 0, the residuals show perfect positive autocorrelation and with the outcome of 4, the residuals show perfect negative autocorrelation (Brooks & Tsolacos, 2010). The Durban-Watson d-statistic indicates 1.931135 for the accessibility model and 1.919441 for the road distance model, indicating that there is nearly no autocorrelation present.

Assumption 4. Independence.

A correlation matrix has been produced to check for independency between variables and between variables and the residuals for the preferred model specification. For variables to be independent of each other they should not be correlated with each other, which means that the coefficient should lie below the threshold of 0.8. High correlations can be found between a variety of variables starting with 'Target', which are the interaction variables measuring the effects of the infrastructural development in the target area. Naturally, these show high correlations between each other as similar interactions are repeated for these variables. These correlation coefficients are not seen as an issue as such because of the considerable number of interaction variables which, for the sake of the results, consist of similar components. No correlations above the threshold of 0.8 are found for the remaining variables in both models (see table C5 & C6). Another way independence has been tested is by checking the VIF value (Variance Inflation Factor). The VIF has been checked for the preferred model specifications for both models and showed a VIF of 11.62 for building period "1951-1975" in the road distance model. In the accessibility model it showed VIF of 11.10 for "1951-1975" and 12.54 for "1976-2000". Since the VIF should not exceed 10 to be acceptable, this building period variable had to be transformed. This issue has been solved by changing this variable from 25-year intervals into 10-year intervals. The VIF results can be found in Table C3 & C4.

Assumption 5. Normality

For the assumption of normality, it is important that the errors are normally distributed. Figure C1 & C2 indicate that the residuals are normally distributed. The Jarque-Bera normality test is also a method to test for normality. The null hypothesis for this test is that the variable is normally distributed. The results of the Jarque-Bera normality test indicates a significant result for both models, indicating that the residuals are not normally distributed. However, as the sample sizes consist of 126,278 and 51,189 observations, it is considered as being sufficiently large, meaning that violation of the normality assumption is virtually inconsequential and will thus have no consequences (Brooks & Tsolacos, 2010).

Table C3. VIF accessibility Model

Variable	VIF	1/VIF
Target	26.44	0.037816
TargetxTrend	16.26	0.061496
TargetxDistanceA	34.74	0.028783
TargetxTrendxDistanceA	18.09	0.055293
TargetxConstruction	22.98	0.043514
TargetxConstructionxD~A	23.96	0.041733
TargetxAfter	27.05	0.036962
TargetxAfterxTrend	4.31	0.232088
TargetxAfterxDistanceA	24.41	0.040968
Noise 100 m	1.29	0.774828
Noise 300 m	1.28	0.780702
Traffic Intensity 1km	1.45	0.690316
House	4.89	0.204330
lnLiving Area	2.24	0.445892
lnMarket Days	1.14	0.877501
lnRooms	2.25	0.445372
Building Category		
Corner house	1.56	0.642775
Terraced house	1.21	0.829007
Townhouse	1.96	0.508984
Detached house	1.87	0.533820
Downstairs apartment	1.45	0.689353
Upstairs apartment	1.65	0.606000
Apartment building	1.41	0.709101
Penthouse	2.24	0.445651
Floor/story	1.14	0.876868
Building Period		
1901-1910	1.99	0.502505
1911-1920	1.79	0.557273
1921-1930	3.28	0.304560
1931-1940	2.89	0.345606
1941-1950	1.86	0.538631
1951-1960	4.22	0.237165
1961-1970	6.24	0.160305
1971-1980	8.66	0.115471
1981-1990	6.93	0.144222
1991-2000	6.92	0.144555
2001-2010	6.60	0.151470
2010<	4.04	0.247278
Transaction Year		
2005	2.32	0.430522
2006	2.79	0.358817
2007	3.05	0.328381
2008	2.92	0.342717
2009	2.52	0.397197
2010	3.07	0.326132
2011	3.12	0.320348
2012	3.42	0.292594
2013	3.53	0.283364
2014	5.05	0.198149
2015	5.79	0.172620
2016	6.79	0.147277
2017	5.64	0.177176
2018	5.48	0.182586
2019	4.69	0.213311
2020	4.81	0.208032
2021	1.45	0.691772
Mean VIF	6.47	

Table C4. VIF road distance model

Variable	VIF	1/VIF
Target	35.97	0.027801
TargetxTrend	21.35	0.046848
TargetxDistanceR	43.77	0.022846
TargetxTrendxDistanceR	21.85	0.045764
TargetxConstruction	35.00	0.028575
TargetxConstructionxD~R	35.95	0.027818
TargetxAfter	41.75	0.023952
TargetxAfterxTrend	4.46	0.224375
TargetxAfterxDistanceR	38.41	0.026037
Noise 100 m	1.31	0.761986
Noise 300 m	1.36	0.737598
Traffic Intensity 1 km	1.83	0.547322
House	5.37	0.186170
lnLiving Area	2.21	0.451922
lnMarket Days	1.18	0.850343
lnRooms	2.13	0.469087
Building Category		
Corner house	1.56	0.642136
Terraced house	1.21	0.827600
Townhouse	1.98	0.505554
Detached house	1.87	0.533401
Downstairs apartment	1.51	0.661988
Upstairs apartment	1.77	0.565862
Apartment building	1.46	0.683670
Penthouse	2.47	0.404848
Floor/story	1.18	0.846425
Building Period		
1901-1910	1.99	0.503260
1911-1920	1.73	0.578493
1921-1930	2.83	0.353167
1931-1940	2.53	0.395827
1941-1950	1.69	0.591712
1951-1960	3.14	0.318941
1961-1970	5.56	0.179981
1971-1980	8.19	0.122160
1981-1990	6.22	0.160700
1991-2000	6.93	0.144340
2001-2010	5.82	0.171800
2010<	4.56	0.219471
Transaction Year		
2005	2.29	0.435935
2006	2.74	0.365468
2007	2.86	0.350227
2008	2.71	0.368921
2009	2.42	0.412914
2010	3.22	0.310534
2011	3.16	0.316511
2012	3.88	0.257732
2013	4.22	0.237233
2014	6.23	0.160437
2015	7.34	0.136202
2016	8.62	0.115945
2017	7.59	0.131744
2018	7.52	0.133010
2019	6.83	0.146323
2020	6.99	0.142960
2021	1.77	0.563900
Mean VIF	8.17	

Table C5. Correlation matrix accessibility model[3]

	lnTra~n	Target	Targ~d	Targ~A	Targ~A	Targ~n	Targ~A	Targe~r	Tare~d	Targ~A	Nois~m	Nois~m	Traf~m	Woo~s	lnArea	lnMa~s	lnRo~s	Build~t	Build~p	Trans~r	PC6
lnTransaction	1.000																				
Target	-0.0564	1.000																			
TargetxTrend	0.0781	-0.2825	1.000																		
TargetxDistanA	-0.0477	0.7706	-0.2733	1.000																	
TargetxTrendx~A	0.0624	-0.2513	0.8979	-0.3618	1.000																
TargetxConstru~n	-0.0255	0.4422	0.1939	0.3213	0.1725	1.000															
TargetxConstru~A	-0.0129	0.3777	0.1656	0.4809	0.1474	0.8542	1.000														
TargetxAfter	0.0607	0.4253	0.1865	0.3109	0.1659	-0.2919	-0.2493	1.000													
TargetxAfterxTr~d	0.0837	0.3501	0.1535	0.2438	0.1366	-0.2403	-0.2053	0.8232	1.000												
TargetxAfterxDi~A	0.0345	0.3658	0.1604	0.4608	0.1427	-0.2511	-0.2145	0.8603	0.6919	1.000											
Noise100m	-0.0002	0.0242	0.0102	-0.0172	0.0092	-0.0101	-0.0116	0.0490	0.0513	-0.0011	1.000										
Noise300m	-0.0124	0.0534	0.0054	-0.293	0.0156	0.0155	-0.0154	0.0506	0.0467	-0.0071	0.4531	1.000									
TrafficIntensity~m	0.0299	0.1174	0.0515	-0.0901	0.0458	-0.0806	-0.0688	0.2761	0.2395	0.0010	0.1715	0.1678	1.000								
Woonhuis	0.1907	-0.0273	0.0138	-0.0324	0.0148	-0.0352	-0.0411	0.0062	0.0183	0.0032	0.0127	0.0223	0.0168	1.000							
lnArea	0.6778	-0.0504	0.0034	-0.0304	0.0003	-0.0416	-0.0333	-0.0121	0.0004	-0.0072	0.0090	0.0097	-0.0046	0.4498	1.000						
lnMarketDays	-0.0050	-0.0445	-0.0641	-0.0087	-0.0490	-0.0035	0.0111	-0.1183	-0.1171	-0.0809	0.0210	0.0076	-0.0520	-0.0144	0.0961	1.000					
lnRooms	0.3760	-0.0478	0.0315	-0.0376	0.0268	-0.0355	-0.0358	0.0054	0.0127	0.0077	-0.0104	0.0039	0.0050	0.5753	0.6569	0.0609	1.000				
BuildingCat	0.0232	0.0157	0.0023	0.0159	0.0022	0.0216	0.0226	0.0053	0.0016	0.0057	-0.0121	-0.0091	-0.0053	-0.5047	-0.1148	0.0630	-0.2465	1.000			
BuildingPeriod	0.0787	0.0584	0.0019	0.0481	-0.0068	0.0406	0.0324	0.0295	0.0300	0.0267	0.0283	0.0086	0.0079	-0.1610	0.0231	-0.0148	-0.0968	0.0265	1.000		
TransactionYear	0.0019	0.0771	0.4093	-0.0551	0.3888	-0.0057	-0.0607	0.4240	0.3967	0.3295	0.0119	0.0324	0.1450	0.0788	-0.0105	-0.1561	0.0728	-0.0220	0.0064	1.000	
PC6	-0.3428	-0.1141	-0.0410	-0.0013	-0.0522	-0.1911	-0.1259	0.0230	0.0202	0.0682	0.0401	0.0237	-0.0477	0.1652	0.0475	0.1098	0.0986	-0.0684	-0.0238	0.0697	1.000

[3] Variable order: lnTransaction; Target; TargetxTrend; TargetxDistanceA; TargetxTrendxDistanceA; TargetxConstruction; TargetxConstructionxDistanceA; TargetxAfter; TargetxAfterxTrend; TargetxAfterxDistanceA; Noise100m; Noise300m; TrafficIntensity1km; Woonhuis; lnArea; lnMarketDays; lnRooms; BuildingCat; BuildingPeriod; TransactionYear; PC6.

Table C6. Correlation matrix road distance model[4]

	lnTra~n	Target	Targ~d	Targ~A	Targ~A	Targ~n	Targ~A	Targe~r	Tare~d	Targ~A	Nois~m	Nois~m	Traf~m	Woo~s	lnArea	lnMa~s	lnRo~s	Build~t	Build~p	Trans~r	PC6
lnTransaction	1.000																				
Target	-0.0269	1.000																			
TargetxTrend	0.0852	-0.2457	1.000																		
TargetxDistanA	-0.0037	0.8316	-0.2192	1.000																	
TargetxTrendx~A	0.0741	-0.2281	0.9283	-0.2834	1.000																
TargetxConstru~n	-0.0442	0.4299	0.1955	0.3534	0.1815	1.000															
TargetxConstru~A	-0.0284	0.3913	0.1780	0.4640	0.1652	0.9103	1.000														
TargetxAfter	0.1214	0.4181	0.1902	0.3425	0.1765	-0.3327	-0.3029	1.000													
TargetxAfterxTr~d	0.1377	0.3455	0.1571	0.2766	0.1459	-0.2749	-0.2503	0.8264	1.000												
TargetxAfterxDi~A	0.1174	0.3790	0.1724	0.4570	0.1600	-0.3016	-0.2745	0.9065	0.7412	1.000											
Noise100m	0.0016	0.0341	0.0148	-0.0478	0.0144	-0.0175	-0.0243	0.0698	0.0713	-0.0186	1.000										
Noise300m	-0.163	0.0755	0.0046	-0.0938	0.0279	0.0180	-0.0448	0.0691	0.0614	-0.0397	0.4520	1.000									
TrafficIntensity~m	0.0486	0.1466	0.0667	-0.0755	0.0619	-0.1167	-0.1062	0.3507	0.2934	0.0799	0.1928	0.1845	1.000								
Woonhuis	0.2032	0.0331	-0.0169	-0.0101	-0.0085	-0.0113	-0.0211	0.0251	0.0331	-0.0034	0.0200	0.0354	0.0187	1.000							
lnArea	0.6833	-0.0036	-0.0103	-0.0081	-0.0107	-0.0280	-0.0273	0.0184	0.0249	0.0096	0.0161	0.0196	0.0012	0.4559	1.000						
lnMarketDays	-0.0039	0.0075	-0.0929	0.0048	-0.0836	0.0234	0.0230	-0.1085	-0.1081	-0.1015	0.0340	0.0163	-0.0474	-0.0181	0.1041	1.000					
lnRooms	0.3755	0.0208	0.0095	0.0030	0.0078	-0.0022	-0.0070	0.0324	0.0374	0.0175	-0.0139	0.0101	0.0081	0.5694	0.6401	0.0737	1.000				
BuildingCat	0.0148	-0.0254	0.0151	-0.0188	0.0192	0.0033	0.0000	-0.0061	-0.0040	0.0041	-0.0189	-0.0151	-0.0045	-0.5435	-0.1364	0.0585	-0.2545	1.000			
BuildingPeriod	0.1539	-0.0208	0.0474	0.0407	0.0295	0.0141	0.0444	-0.0016	0.0038	0.0215	0.0406	0.0084	-0.0048	-0.2091	0.0256	-0.0097	-0.0961	0.0320	1.000		
TransactionYear	0.0872	0.0913	0.4063	0.0674	0.3778	-0.0099	-0.0136	0.4229	0.3981	0.3847	0.0104	0.0340	0.1623	0.0453	-0.0248	-0.2246	0.0563	-0.0266	-0.0275	1.000	
PC6	-0.2916	-0.0761	-0.0615	-0.0580	-0.0664	-0.1697	-0.1565	0.0326	0.0230	0.0265	0.0629	0.0424	-0.0331	0.0948	0.0409	0.1038	0.0721	-0.0696	-0.1070	0.0174	1.000

[4] Variable order: lnTransaction; Target; TargetxTrend; TargetxDistanceR; TargetxTrendxDistanceR; TargetxConstruction; TargetxConstructionxDistanceR; TargetxAfter; TargetxAfterxTrend; TargetxAfterxDistanceR; Noise100m; Noise300m; TrafficIntensity1km; Woonhuis; lnArea; lnMarketDays; lnRooms; BuildingCat; BuildingPeriod; TransactionYear; PC6.

Appendix D: Stata syntax accessibility model

The Stata syntax has been color coded to recognize the model specifications. The colors are as follows:
Black – commands used in all model specifications
Green – preferred model specification
Red – adjusted target and control areas
**--Breaks--* – Seperating sections of the analysis*

Other sections of the syntax will be recognized by using a line to divide them from each other.

```
use "C:\Users\david\OneDrive\Master’s Thesis\STATA\Data Thesis 2022.dta"

ssc install outreg2
ssc install asdoc
ssc install winsor2
ssc install jb

*Drop observations*
drop if missing(PC_4)
drop if PC_4==0 | PC_4==0000 | PC_4==9999
drop if missing(PC_6)
drop if length(PC_6)<6
drop if length(PC_6)>6
drop if missing(TransactionPrice)
drop if missing(DatumAfmelding)
drop if missing(TransYear)
drop if missing(DagenOpMarkt)
drop if missing(WoonOppervlakte)
drop if WoonOppervlakte<10 | WoonOppervlakte>990
drop if missing(Bouwjaar)
drop if Bouwjaar>2030
drop if missing(AantalKamers)
drop if AantalKamers==0
drop if missing(Woonhuis_Appartement)
drop if missing(HouseTypeSTATA)

*Drop transactions by transaction date*
drop if NEAR_FID_R==1 & DatumAfmelding>=td(01/06/2011)
drop if NEAR_FID_R==1 & DatumAfmelding<=td(30/06/2004)
drop if NEAR_FID_R==2 & DatumAfmelding>=td(01/04/2019)
drop if NEAR_FID_R==2 & DatumAfmelding<=td(31/08/2009)
drop if NEAR_FID_R==3 & DatumAfmelding>=td(01/05/2021)
drop if NEAR_FID_R==3 & DatumAfmelding<=td(31/10/2011)
drop if NEAR_FID_R==4 & DatumAfmelding>=td(01/11/2014)
drop if NEAR_FID_R==4 & DatumAfmelding<=td(30/11/2006)
```

```
drop if NEAR_FID_R==5 & DatumAfmelding>=td(01/11/2016)
drop if NEAR_FID_R==5 & DatumAfmelding<=td(01/01/2004)
drop if NEAR_FID_R==6 & DatumAfmelding>=td(01/11/2020)
drop if NEAR_FID_R==6 & DatumAfmelding<=td(30/09/2013)
drop if NEAR_FID_R==7 & DatumAfmelding>=td(01/12/2012)
drop if NEAR_FID_R==7 & DatumAfmelding<=td(31/01/2006)
drop if NEAR_FID_R==8 & DatumAfmelding>=td(01/03/2017)
drop if NEAR_FID_R==8 & DatumAfmelding<=td(28/02/2010)

*Drop Transaction Price*
sum TransactionPrice, detail
histogram TransactionPrice, normal
drop if TransactionPrice > 1500000 | TransactionPrice < 75000
histogram TransactionPrice, normal
sum TransactionPrice, detail

*Drop distance to access point*
drop if NEAR_DIST_ACCESS>10000

*BuildingPeriod*
recode Bouwjaar 0/1900 = 0 1901/1910 = 1 1911/1920 = 2 1921/1930 = 3 1931/1940 = 4 1941/1950 = 5 1951/1960
= 6 1961/1970 = 7 1971/1980 = 8 1981/1990 = 9 1991/2000 = 10 2001/2010 = 11 2011/max = 12,
generate(BuildingPeriod)
label define BuildingPeriod 0 "<1901" 1 "1901-1910" 2 "1911-1920" 3 "1921-1930" 4 "1931-1940" 5 "1941-1950" 6
"1951-1960" 7 "1961-1970" 8 "1971-1980" 9 "1981-1990" 10 "1991-2000" 11 "2001-2010" 12 "2010<"
label values BuildingPeriod BuildingPeriod
tabulate BuildingPeriod

*Create dummy variable - 0=Apartment 1=House*
encode Woonhuis_Appartement, generate(Woonhuis_r)
tabulate Woonhuis_r
gen Woonhuis = 1
replace Woonhuis = 0 if Woonhuis_r==1
tabulate Woonhuis
label define Woonhuis 0 "Appartement" 1 "Woonhuis"
label values Woonhuis Woonhuis
tabulate Woonhuis

*Recode house types*
encode HouseTypeSTATA, generate (BuildingType)
tabulate BuildingType

numlabel BuildingType, add
gen BuildingCat = 1
replace BuildingCat = 1 if BuildingType==1 | BuildingType==3
```

```
replace BuildingCat = 2 if BuildingType==2 | BuildingType==6
replace BuildingCat = 3 if BuildingType==4 | BuildingType==5
replace BuildingCat = 4 if BuildingType==7 | BuildingType==8 | BuildingType==10
replace BuildingCat = 5 if BuildingType==9
replace BuildingCat = 6 if BuildingType==11
replace BuildingCat = 7 if BuildingType==12
replace BuildingCat = 8 if BuildingType==14 | BuildingType==17
replace BuildingCat = 9 if BuildingType==16
replace BuildingCat = 10 if BuildingType==19 | BuildingType==15 | BuildingType==18
label define BuildingCat 1 "2-onder-1-kap woning" 2 "Hoekwoning" 3 "Geschakelde woning" 4 "Tussenwoning" 5 "Vrijstaande woning" 6 "Benedenwoning" 7 "Bovenwoning" 8 "Flat" 9 "Penthouse" 10 "Portiek/verdieping"
label values BuildingCat BuildingCat
tabulate BuildingCat

*Create Project labels*
gen Project = NEAR_FID_R
label define Project 1 "N31_ZurichHarlingen" 2 "N356_CentraleAs" 3 "N23_Hoorn" 4 "N23_LelystadDronten" 5 "N201_SchipholUithoorn" 6 "N18_GroenloEnschede" 7 "N36_Ommen" 8 "N33_AssenZuidbroek"
label values Project Project
tabulate Project

*Create dummy variable for newly constructed roads*
gen NewRoad = 1
replace NewRoad = 0 if NEAR_FID_R==1
replace NewRoad = 0 if NEAR_FID_R==3
replace NewRoad = 0 if NEAR_FID_R==8
label define NewRoad 0 "redeveloped" 1 "new road"
label values NewRoad NewRoad
tabulate NewRoad

*Create dummy variable for redeveloped roads*
gen Redeveloped = 0
replace Redeveloped = 1 if NEAR_FID_R==1
replace Redeveloped = 1 if NEAR_FID_R==3
replace Redeveloped = 1 if NEAR_FID_R==8
label define Redeveloped 0 "new road" 1 "redeveloped"
label values Redeveloped Redeveloped
tabulate Redeveloped

*Spatially Fixed Effects: Postcode*
encode PC_6, generate (PC6)

*Time Fixed Effects: Transaction Year*
gen TransactionYear = TransYear
```

```
*Target and Control Area*
gen Target = 1
replace Target = 0 if NEAR_DIST_ACCESS>6000 / 7000 / 8000

*Construction years*
gen ConstructionStart = 2007
replace ConstructionStart = 2012 if NEAR_FID_R==2
replace ConstructionStart = 2014 if NEAR_FID_R==3
replace ConstructionStart = 2013 if NEAR_FID_R==8
replace ConstructionStart = 2009 if NEAR_FID_R==7
replace ConstructionStart = 2016 if NEAR_FID_R==6
replace ConstructionStart = 2007 if NEAR_FID_R==5
replace ConstructionStart = 2009 if NEAR_FID_R==4
tabulate ConstructionStart

gen ConstructionEnd = 2008
replace ConstructionEnd = 2016 if NEAR_FID_R==2
replace ConstructionEnd = 2018 if NEAR_FID_R==3
replace ConstructionEnd = 2014 if NEAR_FID_R==8
replace ConstructionEnd = 2010 if NEAR_FID_R==7
replace ConstructionEnd = 2018 if NEAR_FID_R==6
replace ConstructionEnd = 2014 if NEAR_FID_R==5
replace ConstructionEnd = 2012 if NEAR_FID_R==4
tabulate ConstructionEnd

*Interaction Periods for Difference-In-Difference*
format %tdDD/NN/CCYY DatumAfmelding

gen TrendYear = TransactionYear

gen TrendBefore = 0
replace TrendBefore = TrendYear - ConstructionStart if NEAR_FID_R==1 & DatumAfmelding<td(01/07/2007)
replace TrendBefore = TrendYear - ConstructionStart if NEAR_FID_R==2 & DatumAfmelding<td(01/09/2012)
replace TrendBefore = TrendYear - ConstructionStart if NEAR_FID_R==3 & DatumAfmelding<td(01/11/2014)
replace TrendBefore = TrendYear - ConstructionStart if NEAR_FID_R==4 & DatumAfmelding<td(01/12/2009)
replace TrendBefore = TrendYear - ConstructionStart if NEAR_FID_R==5 & DatumAfmelding<td(01/01/2007)
replace TrendBefore = TrendYear - ConstructionStart if NEAR_FID_R==6 & DatumAfmelding<td(01/10/2016)
replace TrendBefore = TrendYear - ConstructionStart if NEAR_FID_R==7 & DatumAfmelding<td(01/02/2009)
replace TrendBefore = TrendYear - ConstructionStart if NEAR_FID_R==8 & DatumAfmelding<td(01/03/2013)

gen TrendAfter = 0
replace TrendAfter = TrendYear - ConstructionEnd if NEAR_FID_R==1 & DatumAfmelding>=td(01/12/2008)
replace TrendAfter = TrendYear - ConstructionEnd if NEAR_FID_R==2 & DatumAfmelding>=td(01/10/2016)
replace TrendAfter = TrendYear - ConstructionEnd if NEAR_FID_R==3 & DatumAfmelding>=td(01/11/2018)
replace TrendAfter = TrendYear - ConstructionEnd if NEAR_FID_R==4 & DatumAfmelding>=td(01/05/2012)
```

```
replace TrendAfter = TrendYear - ConstructionEnd if NEAR_FID_R==5 & DatumAfmelding>=td(01/05/2014)
replace TrendAfter = TrendYear - ConstructionEnd if NEAR_FID_R==6 & DatumAfmelding>=td(01/05/2018)
replace TrendAfter = TrendYear - ConstructionEnd if NEAR_FID_R==7 & DatumAfmelding>=td(01/06/2010)
replace TrendAfter = TrendYear - ConstructionEnd if NEAR_FID_R==8 & DatumAfmelding>=td(01/09/2014)

gen Construction = 0
replace Construction = 1 if NEAR_FID_R==1 & DatumAfmelding>=td(01/07/2007) &
DatumAfmelding<td(01/12/2008)
replace Construction = 1 if NEAR_FID_R==2 & DatumAfmelding>=td(01/09/2012) &
DatumAfmelding<td(01/10/2016)
replace Construction = 1 if NEAR_FID_R==3 & DatumAfmelding>=td(01/11/2014) &
DatumAfmelding<td(01/11/2018)
replace Construction = 1 if NEAR_FID_R==4 & DatumAfmelding>=td(01/12/2009) &
DatumAfmelding<td(01/05/2012)
replace Construction = 1 if NEAR_FID_R==5 & DatumAfmelding>=td(01/01/2007) &
DatumAfmelding<td(01/05/2014)
replace Construction = 1 if NEAR_FID_R==6 & DatumAfmelding>=td(01/10/2016) &
DatumAfmelding<td(01/05/2018)
replace Construction = 1 if NEAR_FID_R==7 & DatumAfmelding>=td(01/02/2009) &
DatumAfmelding<td(01/06/2010)
replace Construction = 1 if NEAR_FID_R==8 & DatumAfmelding>=td(01/03/2013) &
DatumAfmelding<td(01/09/2014)
tabulate Construction

gen After = 0
replace After = 1 if NEAR_FID_R==1 & DatumAfmelding>=td(01/12/2008)
replace After = 1 if NEAR_FID_R==2 & DatumAfmelding>=td(01/10/2016)
replace After = 1 if NEAR_FID_R==3 & DatumAfmelding>=td(01/11/2018)
replace After = 1 if NEAR_FID_R==4 & DatumAfmelding>=td(01/05/2012)
replace After = 1 if NEAR_FID_R==5 & DatumAfmelding>=td(01/05/2014)
replace After = 1 if NEAR_FID_R==6 & DatumAfmelding>=td(01/05/2018)
replace After = 1 if NEAR_FID_R==7 & DatumAfmelding>=td(01/06/2010)
replace After = 1 if NEAR_FID_R==8 & DatumAfmelding>=td(01/09/2014)
tabulate After

*Difference-In-Difference interactions*
gen DistanceAccessKM = NEAR_DIST_ACCESS/1000
gen DistanceRoadKM = NEAR_DIST_ROAD/1000

gen TargetxTrend = Target*TrendBefore
gen TargetxConstruction = Target*Construction
gen TargetxAfter = Target*After
gen TargetxAfterxTrend = Target*After*TrendAfter
```

```
*Accessibility Model Distance*
gen TargetxDistanceA = Target*DistanceAccessKM
gen TargetxTrendxDistanceA = Target*TrendBefore*DistanceAccessKM
gen TargetxConstructionxDistanceA = Target*Construction*DistanceAccessKM
gen TargetxAfterxDistanceA = Target*After*DistanceAccessKM

*Variable transformations*
histogram DagenOpMarkt, normal
gen lnMarketDays = ln(DagenOpMarkt)
histogram lnMarketDays, normal
kdensity lnMarketDays, normal

histogram WoonOppervlakte, normal
sum WoonOppervlakte, detail
gen lnArea = ln(WoonOppervlakte)
histogram lnArea, normal

histogram AantalKamers, normal
sum AantalKamers, detail
gen lnRooms = ln(AantalKamers)
histogram lnRooms, normal

*Create dependent variable*
histogram TransactionPrice, normal
gen lnTransaction = ln(TransactionPrice)
histogram lnTransaction, normal
kdensity lnTransaction, normal

*Create dummies for negative externalities*
gen Noise300m = 0
replace Noise300m = 1 if (NEAR_DIST_ROAD<300.01 & Redeveloped==1)
replace Noise300m = 1 if (NEAR_DIST_ROAD<300.01 & NewRoad==1 & Construction)
replace Noise300m = 1 if (NEAR_DIST_ROAD<300.01 & NewRoad==1 & After)
replace Noise300m = 0 if NEAR_DIST_ACCESS<500

gen Noise100m = 0
replace Noise100m = 1 if (NEAR_DIST_ROAD<100.01 & Redeveloped==1)
replace Noise100m = 1 if (NEAR_DIST_ROAD<100.01 & NewRoad==1 & Construction)
replace Noise100m = 1 if (NEAR_DIST_ROAD<100.01 & NewRoad==1 & After)
replace Noise100m = 0 if NEAR_DIST_ACCESS<500

gen TrafficIntensity1km = 0
replace TrafficIntensity1km = 1 if (NEAR_DIST_ACCESS<1000.01 & After)

*-----------------------------------End of variable creation------------------------------------*
```

Model specifications

1: Baseline
reg lnTransaction Target TargetxTrend TargetxDistanceA TargetxTrendxDistanceA TargetxConstruction TargetxConstructionxDistanceA TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceA i.TransactionYear, vce(robust)

2: Housing Characteristics
reg lnTransaction Target TargetxTrend TargetxDistanceA TargetxTrendxDistanceA TargetxConstruction TargetxConstructionxDistanceA TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceA Woonhuis lnArea lnMarketDays lnRooms i.BuildingCat i.BuildingPeriod i.TransactionYear, vce(robust)

3: Noise
reg lnTransaction Target TargetxTrend TargetxDistanceA TargetxTrendxDistanceA TargetxConstruction TargetxConstructionxDistanceA TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceA Noise100m Noise300m TrafficIntensity1km Woonhuis lnArea lnMarketDays lnRooms i.BuildingCat i.BuildingPeriod i.TransactionYear, vce(robust)

4: PC6 - location fixed effects
reg lnTransaction Target TargetxTrend TargetxDistanceA TargetxTrendxDistanceA TargetxConstruction TargetxConstructionxDistanceA TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceA Noise100m Noise300m TrafficIntensity1km Woonhuis lnArea lnMarketDays lnRooms i.BuildingCat i.BuildingPeriod i.TransactionYear, absorb(PC6) vce(robust)

-----------------------------------Newly constructed versus Redeveloped-----------------------------------

* 1. Redeveloped *
reg lnTransaction Target TargetxTrend TargetxDistanceA TargetxTrendxDistanceA TargetxConstruction TargetxConstructionxDistanceA TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceA Noise100m Noise300m TrafficIntensity1km Woonhuis lnArea lnMarketDays lnRooms i.BuildingCat i.BuildingPeriod i.TransactionYear if NewRoad==0, absorb(PC6) vce(robust)

* 2. Newly constructed *
reg lnTransaction Target TargetxTrend TargetxDistanceA TargetxTrendxDistanceA TargetxConstruction TargetxConstructionxDistanceA TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceA Noise100m Noise300m TrafficIntensity1km Woonhuis lnArea lnMarketDays lnRooms i.BuildingCat i.BuildingPeriod i.TransactionYear if NewRoad==1, absorb(PC6) vce(robust)

-----------------------------------Distance rings-----------------------------------

Distance dummies Target
gen Target500 = 0
replace Target500 = 1 if (NEAR_DIST_ACCESS<500.001)
gen Target1000 = 0
replace Target1000 = 1 if (NEAR_DIST_ACCESS>500 & NEAR_DIST_ACCESS<1000.001)

```
gen Target2000 = 0
replace Target2000 = 1 if (NEAR_DIST_ACCESS>1000 & NEAR_DIST_ACCESS<2000.001)
gen Target3000 = 0
replace Target3000 = 1 if (NEAR_DIST_ACCESS>2000 & NEAR_DIST_ACCESS<3000.001)
gen Target4000 = 0
replace Target4000 = 1 if (NEAR_DIST_ACCESS>3000 & NEAR_DIST_ACCESS<4000.001)
gen Target5000 = 0
replace Target5000 = 1 if (NEAR_DIST_ACCESS>4000 & NEAR_DIST_ACCESS<5000.001)
gen Target6000 = 0
replace Target6000 = 1 if (NEAR_DIST_ACCESS>5000 & NEAR_DIST_ACCESS<6000.001)

*Distance dummies Construction*
gen Target500C = 0
replace Target500C = 1 if (NEAR_DIST_ACCESS<500.001 & Construction)
gen Target1000C = 0
replace Target1000C = 1 if (NEAR_DIST_ACCESS>500 & NEAR_DIST_ACCESS<1000.001 & Construction)
gen Target2000C = 0
replace Target2000C = 1 if (NEAR_DIST_ACCESS>1000 & NEAR_DIST_ACCESS<2000.001 & Construction)
gen Target3000C = 0
replace Target3000C = 1 if (NEAR_DIST_ACCESS>2000 & NEAR_DIST_ACCESS<3000.001 & Construction)
gen Target4000C = 0
replace Target4000C = 1 if (NEAR_DIST_ACCESS>3000 & NEAR_DIST_ACCESS<4000.001 & Construction)
gen Target5000C = 0
replace Target5000C = 1 if (NEAR_DIST_ACCESS>4000 & NEAR_DIST_ACCESS<5000.001 & Construction)
gen Target6000C = 0
replace Target6000C = 1 if (NEAR_DIST_ACCESS>5000 & NEAR_DIST_ACCESS<6000.001 & Construction)

*Distance dummies construction*
gen Target500A = 0
replace Target500A = 1 if (NEAR_DIST_ACCESS<500.001 & After)
gen Target1000A = 0
replace Target1000A = 1 if (NEAR_DIST_ACCESS>500 & NEAR_DIST_ACCESS<1000.001 & After)
gen Target2000A = 0
replace Target2000A = 1 if (NEAR_DIST_ACCESS>1000 & NEAR_DIST_ACCESS<2000.001 & After)
gen Target3000A = 0
replace Target3000A = 1 if (NEAR_DIST_ACCESS>2000 & NEAR_DIST_ACCESS<3000.001 & After)
gen Target4000A = 0
replace Target4000A = 1 if (NEAR_DIST_ACCESS>3000 & NEAR_DIST_ACCESS<4000.001 & After)
gen Target5000A = 0
replace Target5000A = 1 if (NEAR_DIST_ACCESS>4000 & NEAR_DIST_ACCESS<5000.001 & After)
gen Target6000A = 0
replace Target6000A = 1 if (NEAR_DIST_ACCESS>5000 & NEAR_DIST_ACCESS<6000.001 & After)
```

```
*Interaction distance dummies*
gen Target500xTrend = Target500*TrendBefore
gen Target1000xTrend = Target1000*TrendBefore
gen Target2000xTrend = Target2000*TrendBefore
gen Target3000xTrend = Target3000*TrendBefore
gen Target4000xTrend = Target4000*TrendBefore
gen Target5000xTrend = Target5000*TrendBefore
gen Target6000xTrend = Target6000*TrendBefore
gen Target500AxTrend = Target500A*TrendAfter
gen Target1000AxTrend = Target1000A*TrendAfter
gen Target2000AxTrend = Target2000A*TrendAfter
gen Target3000AxTrend = Target3000A*TrendAfter
gen Target4000AxTrend = Target4000A*TrendAfter
gen Target5000AxTrend = Target5000A*TrendAfter
gen Target6000AxTrend = Target6000A*TrendAfter

*Alternative specification*
reg lnTransaction Target500 Target1000 Target2000 Target3000 Target4000 Target5000 Target6000
Target500xTrend Target1000xTrend Target2000xTrend Target3000xTrend Target4000xTrend
Target5000xTrend Target6000xTrend Target500C Target1000C Target2000C Target3000C Target4000C
Target5000C Target6000C Target500A Target1000A Target2000A Target3000A Target4000A Target5000A
Target6000A Target500AxTrend Target1000AxTrend Target2000AxTrend Target3000AxTrend
Target4000AxTrend Target5000AxTrend Target6000AxTrend Noise100m Noise300m TrafficIntensity1km
Woonhuis lnArea lnMarketDays lnRooms i.BuildingCat i.BuildingPeriod i.TransactionYear, absorb(PC6)
vce(robust)

*-----------------------------------Heterogeneity-----------------------------------*

*Create Short/Long Road*
gen ShortRoad = 0
replace ShortRoad = 1 if Project==1
replace ShortRoad = 1 if Project==4
replace ShortRoad = 1 if Project==5
replace ShortRoad = 1 if Project==7
label define ShortRoad 0 "Long" 1 "Short"
label values ShortRoad ShortRoad

*Short & Long roads specifications*
reg lnTransaction Target TargetxTrend TargetxDistanceA TargetxTrendxDistanceA TargetxConstruction
TargetxConstructionxDistanceA TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceA Noise100m
Noise300m TrafficIntensity1km Woonhuis lnArea lnMarketDays lnRooms i.BuildingCat i.BuildingPeriod
i.TransactionYear if ShortRoad==1, absorb(PC6) vce(robust)
```

```
reg lnTransaction Target TargetxTrend TargetxDistanceA TargetxTrendxDistanceA TargetxConstruction
TargetxConstructionxDistanceA TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceA Noise100m
Noise300m TrafficIntensity1km Woonhuis lnArea lnMarketDays lnRooms i.BuildingCat i.BuildingPeriod
i.TransactionYear if ShortRoad==0, absorb(PC6) vce(robust)

*Urban – Randstad versus Other Regions *
reg lnTransaction Target TargetxTrend TargetxDistanceA TargetxTrendxDistanceA TargetxConstruction
TargetxConstructionxDistanceA TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceA Noise100m
Noise300m TrafficIntensity1km Woonhuis lnArea lnMarketDays lnRooms i.BuildingCat i.BuildingPeriod
i.TransactionYear if Project==5, absorb(PC6) vce(robust)

drop if Project==5

reg lnTransaction Target TargetxTrend TargetxDistanceA TargetxTrendxDistanceA TargetxConstruction
TargetxConstructionxDistanceA TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceA Noise100m
Noise300m TrafficIntensity1km Woonhuis lnArea lnMarketDays lnRooms i.BuildingCat i.BuildingPeriod
i.TransactionYear, absorb(PC6) vce(robust)

*-----------------------------------OLS Assumptions Testing-----------------------------------*
*OLS Assumptions Testing*
reg lnTransaction Target TargetxTrend TargetxDistanceA TargetxTrendxDistanceA TargetxConstruction
TargetxConstructionxDistanceA TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceA i.TransactionYear,
absorb(PC6)
predict r, resid

*Assumption 1: Linearity*
histogram r, normal
kdensity r, normal
pnorm r
qnorm r
sum r

*Assumption 2: Homoscedasticity*
rvfplot, yline(0)
estat hettest

*Assumption 3: No autocorrelation*
sort DatumAfmelding
reg lnTransaction Target TargetxTrend TargetxDistanceA TargetxTrendxDistanceA TargetxConstruction
TargetxConstructionxDistanceA TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceA i.TransactionYear,
absorb(PC6) robust
predict r1, resid
gen time=_n
tsset time
dwstat
```

```
*Assumption 4: Independence*
reg lnTransaction Target TargetxTrend TargetxDistanceA TargetxTrendxDistanceA TargetxConstruction
TargetxConstructionxDistanceA TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceA Noise100m
Noise300m TrafficIntensity1km Woonhuis lnArea lnMarketDays lnRooms i.BuildingCat i.BuildingPeriod
i.TransactionYear, absorb(PC6) vce(robust)
vif

corr lnTransaction Target TargetxTrend TargetxDistanceA TargetxTrendxDistanceA TargetxConstruction
TargetxConstructionxDistanceA TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceA Noise100m
Noise300m TrafficIntensity1km Woonhuis lnArea lnMarketDays lnRooms BuildingCat BuildingPeriod
TransactionYear PC6

*Assumption 5: Normality*
histogram r, normal
histogram r1, normal
jb r
jb r1

*-----------------------------------Descriptives Final Specification-----------------------------------*

summarize TransactionPrice lnTransaction TransactionYear Bouwjaar DagenOpMarkt AantalKamers
WoonOppervlakte lnMarketDays lnRooms lnArea NEAR_DIST_ACCESS NEAR_DIST_ROAD Noise100m
Noise300m TrafficIntensity1km Woonhuis i.BuildingCat i.BuildingPeriod Target

summarize TransactionPrice lnTransaction TransactionYear Bouwjaar DagenOpMarkt AantalKamers
WoonOppervlakte lnMarketDays lnRooms lnArea NEAR_DIST_ACCESS NEAR_DIST_ROAD Noise100m
Noise300m TrafficIntensity1km Woonhuis i.BuildingCat i.BuildingPeriod Target if NEAR_DIST_ACCESS<6000

summarize TransactionPrice lnTransaction TransactionYear Bouwjaar DagenOpMarkt AantalKamers
WoonOppervlakte lnMarketDays lnRooms lnArea NEAR_DIST_ACCESS NEAR_DIST_ROAD Noise100m
Noise300m TrafficIntensity1km Woonhuis i.BuildingCat i.BuildingPeriod Target if NEAR_DIST_ACCESS>6000
```

Appendix E: Stata syntax road distance model

The Stata syntax has been color coded to recognize the model specifications. The colors are as follows:
Black – commands used in all model specifications
Green – preferred model specification
Red – adjusted target and control areas
**--Breaks--* – Seperating sections of the analysis*

Other sections of the syntax will be recognized by using a line to divide them from each other.

```
use "C:\Users\david\OneDrive\Master's Thesis\STATA\Data Thesis 2022.dta"

ssc install outreg2
ssc install asdoc
ssc install winsor2
ssc install jb

*Drop observations*
drop if missing(PC_4)
drop if PC_4==0 | PC_4==0000 | PC_4==9999
drop if missing(PC_6)
drop if length(PC_6)<6
drop if length(PC_6)>6
drop if missing(TransactionPrice)
drop if missing(DatumAfmelding)
drop if missing(TransYear)
drop if missing(DagenOpMarkt)
drop if missing(WoonOppervlakte)
drop if WoonOppervlakte<10 | WoonOppervlakte>990
drop if missing(Bouwjaar)
drop if Bouwjaar>2030
drop if missing(AantalKamers)
drop if AantalKamers==0
drop if missing(Woonhuis_Appartement)
drop if missing(HouseTypeSTATA)

*Drop transactions by transaction date*
drop if NEAR_FID_R==1 & DatumAfmelding>=td(01/06/2011)
drop if NEAR_FID_R==1 & DatumAfmelding<=td(30/06/2004)
drop if NEAR_FID_R==2 & DatumAfmelding>=td(01/04/2019)
drop if NEAR_FID_R==2 & DatumAfmelding<=td(31/08/2009)
drop if NEAR_FID_R==3 & DatumAfmelding>=td(01/05/2021)
drop if NEAR_FID_R==3 & DatumAfmelding<=td(31/10/2011)
drop if NEAR_FID_R==4 & DatumAfmelding>=td(01/11/2014)
drop if NEAR_FID_R==4 & DatumAfmelding<=td(30/11/2006)
```

```
drop if NEAR_FID_R==5 & DatumAfmelding>=td(01/11/2016)
drop if NEAR_FID_R==5 & DatumAfmelding<=td(01/01/2004)
drop if NEAR_FID_R==6 & DatumAfmelding>=td(01/11/2020)
drop if NEAR_FID_R==6 & DatumAfmelding<=td(30/09/2013)
drop if NEAR_FID_R==7 & DatumAfmelding>=td(01/12/2012)
drop if NEAR_FID_R==7 & DatumAfmelding<=td(31/01/2006)
drop if NEAR_FID_R==8 & DatumAfmelding>=td(01/03/2017)
drop if NEAR_FID_R==8 & DatumAfmelding<=td(28/02/2010)

*Drop Transaction Price*
sum TransactionPrice, detail
histogram TransactionPrice, normal
drop if TransactionPrice > 1500000 | TransactionPrice < 75000
histogram TransactionPrice, normal
sum TransactionPrice, detail

*Drop distances*
drop if NEAR_DIST_ACCESS<500
drop if NEAR_DIST_ROAD>4000

*BuildingPeriod*
recode Bouwjaar 0/1900 = 0 1901/1910 = 1 1911/1920 = 2 1921/1930 = 3 1931/1940 = 4 1941/1950 = 5 1951/1960
= 6 1961/1970 = 7 1971/1980 = 8 1981/1990 = 9 1991/2000 = 10 2001/2010 = 11 2011/max = 12,
generate(BuildingPeriod)
label define BuildingPeriod 0 "<1901" 1 "1901-1910" 2 "1911-1920" 3 "1921-1930" 4 "1931-1940" 5 "1941-1950" 6
"1951-1960" 7 "1961-1970" 8 "1971-1980" 9 "1981-1990" 10 "1991-2000" 11 "2001-2010" 12 "2010<"
label values BuildingPeriod BuildingPeriod
tabulate BuildingPeriod

*Create dummy variable - 0=Apartment 1=House*
encode Woonhuis_Appartement, generate(Woonhuis_r)
tabulate Woonhuis_r
gen Woonhuis = 1
replace Woonhuis = 0 if Woonhuis_r==1
tabulate Woonhuis
label define Woonhuis 0 "Appartement" 1 "Woonhuis"
label values Woonhuis Woonhuis
tabulate Woonhuis

*Recode house types*
encode HouseTypeSTATA, generate (BuildingType)
tabulate BuildingType

numlabel BuildingType, add
gen BuildingCat = 1
```

```
replace BuildingCat = 1 if BuildingType==1 | BuildingType==3
replace BuildingCat = 2 if BuildingType==2 | BuildingType==6
replace BuildingCat = 3 if BuildingType==4 | BuildingType==5
replace BuildingCat = 4 if BuildingType==7 | BuildingType==8 | BuildingType==10
replace BuildingCat = 5 if BuildingType==9
replace BuildingCat = 6 if BuildingType==11
replace BuildingCat = 7 if BuildingType==12
replace BuildingCat = 8 if BuildingType==14 | BuildingType==17
replace BuildingCat = 9 if BuildingType==16
replace BuildingCat = 10 if BuildingType==19 | BuildingType==15 | BuildingType==18
label define BuildingCat 1 "2-onder-1-kap woning" 2 "Hoekwoning" 3 "Geschakelde woning" 4 "Tussenwoning" 5
"Vrijstaande woning" 6 "Benedenwoning" 7 "Bovenwoning" 8 "Flat" 9 "Penthouse" 10 "Portiek/verdieping"
label values BuildingCat BuildingCat
tabulate BuildingCat

*Create Project labels*
gen Project = NEAR_FID_R
label define Project 1 "N31_ZurichHarlingen" 2 "N356_CentraleAs" 3 "N23_Hoorn" 4 "N23_LelystadDronten" 5
"N201_SchipholUithoorn" 6 "N18_GroenloEnschede" 7 "N36_Ommen" 8 "N33_AssenZuidbroek"
label values Project Project
tabulate Project

*Create dummy variable for newly constructed roads*
gen NewRoad = 1
replace NewRoad = 0 if NEAR_FID_R==1
replace NewRoad = 0 if NEAR_FID_R==3
replace NewRoad = 0 if NEAR_FID_R==8
label define NewRoad 0 "redeveloped" 1 "new road"
label values NewRoad NewRoad
tabulate NewRoad

*Create dummy variable for redeveloped roads*
gen Redeveloped = 0
replace Redeveloped = 1 if NEAR_FID_R==1
replace Redeveloped = 1 if NEAR_FID_R==3
replace Redeveloped = 1 if NEAR_FID_R==8
label define Redeveloped 0 "new road" 1 "redeveloped"
label values Redeveloped Redeveloped
tabulate Redeveloped

*Spatially Fixed Effects: Postcode*
encode PC_6, generate (PC6)

*Time Fixed Effects: Transaction Year*
gen TransactionYear = TransYear
```

```
*Target and Control Area*
gen Target = 1
replace Target = 0 if NEAR_DIST_ACCESS>2500 / 2000 / 3000

*Construction years*
gen ConstructionStart = 2007
replace ConstructionStart = 2012 if NEAR_FID_R==2
replace ConstructionStart = 2014 if NEAR_FID_R==3
replace ConstructionStart = 2013 if NEAR_FID_R==8
replace ConstructionStart = 2009 if NEAR_FID_R==7
replace ConstructionStart = 2016 if NEAR_FID_R==6
replace ConstructionStart = 2007 if NEAR_FID_R==5
replace ConstructionStart = 2009 if NEAR_FID_R==4
tabulate ConstructionStart

gen ConstructionEnd = 2008
replace ConstructionEnd = 2016 if NEAR_FID_R==2
replace ConstructionEnd = 2018 if NEAR_FID_R==3
replace ConstructionEnd = 2014 if NEAR_FID_R==8
replace ConstructionEnd = 2010 if NEAR_FID_R==7
replace ConstructionEnd = 2018 if NEAR_FID_R==6
replace ConstructionEnd = 2014 if NEAR_FID_R==5
replace ConstructionEnd = 2012 if NEAR_FID_R==4
tabulate ConstructionEnd

*Interaction Periods for Difference-In-Difference*
format %tdDD/NN/CCYY DatumAfmelding

gen TrendYear = TransactionYear

gen TrendBefore = 0
replace TrendBefore = TrendYear - ConstructionStart if NEAR_FID_R==1 & DatumAfmelding<td(01/07/2007)
replace TrendBefore = TrendYear - ConstructionStart if NEAR_FID_R==2 & DatumAfmelding<td(01/09/2012)
replace TrendBefore = TrendYear - ConstructionStart if NEAR_FID_R==3 & DatumAfmelding<td(01/11/2014)
replace TrendBefore = TrendYear - ConstructionStart if NEAR_FID_R==4 & DatumAfmelding<td(01/12/2009)
replace TrendBefore = TrendYear - ConstructionStart if NEAR_FID_R==5 & DatumAfmelding<td(01/01/2007)
replace TrendBefore = TrendYear - ConstructionStart if NEAR_FID_R==6 & DatumAfmelding<td(01/10/2016)
replace TrendBefore = TrendYear - ConstructionStart if NEAR_FID_R==7 & DatumAfmelding<td(01/02/2009)
replace TrendBefore = TrendYear - ConstructionStart if NEAR_FID_R==8 & DatumAfmelding<td(01/03/2013)

gen TrendAfter = 0
replace TrendAfter = TrendYear - ConstructionEnd if NEAR_FID_R==1 & DatumAfmelding>=td(01/12/2008)
replace TrendAfter = TrendYear - ConstructionEnd if NEAR_FID_R==2 & DatumAfmelding>=td(01/10/2016)
replace TrendAfter = TrendYear - ConstructionEnd if NEAR_FID_R==3 & DatumAfmelding>=td(01/11/2018)
replace TrendAfter = TrendYear - ConstructionEnd if NEAR_FID_R==4 & DatumAfmelding>=td(01/05/2012)
```

```
replace TrendAfter = TrendYear - ConstructionEnd if NEAR_FID_R==5 & DatumAfmelding>=td(01/05/2014)
replace TrendAfter = TrendYear - ConstructionEnd if NEAR_FID_R==6 & DatumAfmelding>=td(01/05/2018)
replace TrendAfter = TrendYear - ConstructionEnd if NEAR_FID_R==7 & DatumAfmelding>=td(01/06/2010)
replace TrendAfter = TrendYear - ConstructionEnd if NEAR_FID_R==8 & DatumAfmelding>=td(01/09/2014)

gen Construction = 0
replace Construction = 1 if NEAR_FID_R==1 & DatumAfmelding>=td(01/07/2007) &
DatumAfmelding<td(01/12/2008)
replace Construction = 1 if NEAR_FID_R==2 & DatumAfmelding>=td(01/09/2012) &
DatumAfmelding<td(01/10/2016)
replace Construction = 1 if NEAR_FID_R==3 & DatumAfmelding>=td(01/11/2014) &
DatumAfmelding<td(01/11/2018)
replace Construction = 1 if NEAR_FID_R==4 & DatumAfmelding>=td(01/12/2009) &
DatumAfmelding<td(01/05/2012)
replace Construction = 1 if NEAR_FID_R==5 & DatumAfmelding>=td(01/01/2007) &
DatumAfmelding<td(01/05/2014)
replace Construction = 1 if NEAR_FID_R==6 & DatumAfmelding>=td(01/10/2016) &
DatumAfmelding<td(01/05/2018)
replace Construction = 1 if NEAR_FID_R==7 & DatumAfmelding>=td(01/02/2009) &
DatumAfmelding<td(01/06/2010)
replace Construction = 1 if NEAR_FID_R==8 & DatumAfmelding>=td(01/03/2013) &
DatumAfmelding<td(01/09/2014)
tabulate Construction

gen After = 0
replace After = 1 if NEAR_FID_R==1 & DatumAfmelding>=td(01/12/2008)
replace After = 1 if NEAR_FID_R==2 & DatumAfmelding>=td(01/10/2016)
replace After = 1 if NEAR_FID_R==3 & DatumAfmelding>=td(01/11/2018)
replace After = 1 if NEAR_FID_R==4 & DatumAfmelding>=td(01/05/2012)
replace After = 1 if NEAR_FID_R==5 & DatumAfmelding>=td(01/05/2014)
replace After = 1 if NEAR_FID_R==6 & DatumAfmelding>=td(01/05/2018)
replace After = 1 if NEAR_FID_R==7 & DatumAfmelding>=td(01/06/2010)
replace After = 1 if NEAR_FID_R==8 & DatumAfmelding>=td(01/09/2014)
tabulate After

*Difference-In-Difference interactions*
gen DistanceAccessKM = NEAR_DIST_ACCESS/1000
gen DistanceRoadKM = NEAR_DIST_ROAD/1000

gen TargetxTrend = Target*TrendBefore
gen TargetxConstruction = Target*Construction
gen TargetxAfter = Target*After
gen TargetxAfterxTrend = Target*After*TrendAfter
```

```
*Accessibility Model Distance*
gen TargetxDistanceR = Target*DistanceRoadKM
gen TargetxTrendxDistanceR = Target*TrendBefore*DistanceRoadKM
gen TargetxConstructionxDistanceR = Target*Construction*DistanceRoadKM
gen TargetxAfterxDistanceR = Target*After*DistanceRoadKM

*Variable transformations*
histogram DagenOpMarkt, normal
gen lnMarketDays = ln(DagenOpMarkt)
histogram lnMarketDays, normal
kdensity lnMarketDays, normal

histogram WoonOppervlakte, normal
sum WoonOppervlakte, detail
gen lnArea = ln(WoonOppervlakte)
histogram lnArea, normal

histogram AantalKamers, normal
sum AantalKamers, detail
gen lnRooms = ln(AantalKamers)
histogram lnRooms, normal

*Create dependent variable*
histogram TransactionPrice, normal
gen lnTransaction = ln(TransactionPrice)
histogram lnTransaction, normal
kdensity lnTransaction, normal

*Create dummies for negative externalities*
gen Noise300m = 0
replace Noise300m = 1 if (NEAR_DIST_ROAD<300.01 & After)
replace Noise300m = 1 if (NEAR_DIST_ROAD<300.01 & Construction)
replace Noise300m = 0 if NEAR_DIST_ACCESS<500

gen Noise100m = 0
replace Noise100m = 1 if (NEAR_DIST_ROAD<100.01 & After)
replace Noise100m = 1 if (NEAR_DIST_ROAD<100.01 & Construction)
replace Noise100m = 0 if NEAR_DIST_ACCESS<500

gen TrafficIntensity1km = 0
replace TrafficIntensity1km = 1 if (NEAR_DIST_ACCESS<1000.01 & After)

*-----------------------------------End of variable creation-----------------------------------*
```

Model specifications

1: Baseline
reg lnTransaction Target TargetxTrend TargetxDistanceR TargetxTrendxDistanceR TargetxConstruction TargetxConstructionxDistanceR TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceR i.TransactionYear, vce(robust)

2: Housing Characteristics
reg lnTransaction Target TargetxTrend TargetxDistanceR TargetxTrendxDistanceR TargetxConstruction TargetxConstructionxDistanceR TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceR Woonhuis lnArea lnMarketDays lnRooms i.BuildingCat i.BuildingPeriod i.TransactionYear, vce(robust)

3: Noise
reg lnTransaction Target TargetxTrend TargetxDistanceR TargetxTrendxDistanceR TargetxConstruction TargetxConstructionxDistanceR TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceR Noise100m Noise300m TrafficIntensity1km Woonhuis lnArea lnMarketDays lnRooms i.BuildingCat i.BuildingPeriod i.TransactionYear, vce(robust)

4: PC6
reg lnTransaction Target TargetxTrend TargetxDistanceR TargetxTrendxDistanceR TargetxConstruction TargetxConstructionxDistanceR TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceR Noise100m Noise300m TrafficIntensity1km Woonhuis lnArea lnMarketDays lnRooms i.BuildingCat i.BuildingPeriod i.TransactionYear, absorb(PC6) vce(robust)

-----------------------------------Newly constructed versus Redeveloped-----------------------------------

* 1. Redeveloped *
reg lnTransaction Target TargetxTrend TargetxDistanceR TargetxTrendxDistanceR TargetxConstruction TargetxConstructionxDistanceR TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceR Noise100m Noise300m TrafficIntensity1km Woonhuis lnArea lnMarketDays lnRooms i.BuildingCat i.BuildingPeriod i.TransactionYear if NewRoad==0, absorb(PC6) vce(robust)

* 2. Newly constructed *
reg lnTransaction Target TargetxTrend TargetxDistanceR TargetxTrendxDistanceR TargetxConstruction TargetxConstructionxDistanceR TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceR Noise100m Noise300m TrafficIntensity1km Woonhuis lnArea lnMarketDays lnRooms i.BuildingCat i.BuildingPeriod i.TransactionYear if NewRoad==1, absorb(PC6) vce(robust)

-----------------------------------Distance rings-----------------------------------

Distance dummies Target
gen Target500 = 0
replace Target500 = 1 if (NEAR_DIST_ROAD<500.001)
gen Target1000 = 0
replace Target1000 = 1 if (NEAR_DIST_ROAD>500 & NEAR_DIST_ROAD<1000.001)

```
gen Target1500 = 0
replace Target1500 = 1 if (NEAR_DIST_ROAD>1000 & NEAR_DIST_ROAD<1500.001)
gen Target2000 = 0
replace Target2000 = 1 if (NEAR_DIST_ROAD>1500 & NEAR_DIST_ROAD<2000.001)
gen Target2500 = 0
replace Target2500 = 1 if (NEAR_DIST_ROAD>2000 & NEAR_DIST_ROAD<2500.001)

*Distance dummies Construction*
gen Target500C = 0
replace Target500C = 1 if (NEAR_DIST_ROAD<500.001 & Construction)
gen Target1000C = 0
replace Target1000C = 1 if (NEAR_DIST_ROAD>500 & NEAR_DIST_ROAD<1000.001 & Construction)
gen Target1500C = 0
replace Target1500C = 1 if (NEAR_DIST_ROAD>1000 & NEAR_DIST_ROAD<1500.001 & Construction)
gen Target2000C = 0
replace Target2000C = 1 if (NEAR_DIST_ROAD>1500 & NEAR_DIST_ROAD<2000.001 & Construction)
gen Target2500C = 0
replace Target2500C = 1 if (NEAR_DIST_ROAD>2000 & NEAR_DIST_ROAD<2500.001 & Construction)

*Distance dummies construction*
gen Target500A = 0
replace Target500A = 1 if (NEAR_DIST_ROAD<500.001 & After)
gen Target1000A = 0
replace Target1000A = 1 if (NEAR_DIST_ROAD>500 & NEAR_DIST_ROAD<1000.001 & After)
gen Target1500A = 0
replace Target1500A = 1 if (NEAR_DIST_ROAD>1000 & NEAR_DIST_ROAD<1500.001 & After)
gen Target2000A = 0
replace Target2000A = 1 if (NEAR_DIST_ROAD>1500 & NEAR_DIST_ROAD<2000.001 & After)
gen Target2500A = 0
replace Target2500A = 1 if (NEAR_DIST_ROAD>2000 & NEAR_DIST_ROAD<2500.001 & After)

*Interaction distance dummies*
gen Target500xTrend = Target500*TrendBefore
gen Target1000xTrend = Target1000*TrendBefore
gen Target1500xTrend = Target1500*TrendBefore
gen Target2000xTrend = Target2000*TrendBefore
gen Target2500xTrend = Target2500*TrendBefore

gen Target500AxTrend = Target500A*TrendAfter
gen Target1000AxTrend = Target1000A*TrendAfter
gen Target1500AxTrend = Target1500A*TrendAfter
gen Target2000AxTrend = Target2000A*TrendAfter
gen Target2500AxTrend = Target2500A*TrendAfter
```

```
*--------------------------------Alternative specification------------------*

reg lnTransaction Target500 Target1000 Target1500 Target2000 Target2500 Target500xTrend
Target1000xTrend Target1500xTrend Target2000xTrend Target2500xTrend Target500C Target1000C
Target1500C Target2000C Target2500C Target500A Target1000A Target1500A Target2000A Target2500A
Target500AxTrend Target1000AxTrend Target1500AxTrend Target2000AxTrend Target2500AxTrend
Noise100m Noise300m TrafficIntensity1km Woonhuis lnArea lnMarketDays lnRooms i.BuildingCat
i.BuildingPeriod i.TransactionYear, absorb(PC6) vce(robust)

*----------------------------------Heterogeneity----------------------------------*

*Create Short/Long Road*
gen ShortRoad = 0
replace ShortRoad = 1 if Project==1
replace ShortRoad = 1 if Project==4
replace ShortRoad = 1 if Project==5
replace ShortRoad = 1 if Project==7
label define ShortRoad 0 "Long" 1 "Short"
label values ShortRoad ShortRoad

*Short & Long roads specifications*
reg lnTransaction Target TargetxTrend TargetxDistanceR TargetxTrendxDistanceR TargetxConstruction
TargetxConstructionxDistanceR TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceR Noise100m
Noise300m TrafficIntensity1km Woonhuis lnArea lnMarketDays lnRooms i.BuildingCat i.BuildingPeriod
i.TransactionYear if ShortRoad==1, absorb(PC6) vce(robust)

reg lnTransaction Target TargetxTrend TargetxDistanceR TargetxTrendxDistanceR TargetxConstruction
TargetxConstructionxDistanceR TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceR Noise100m
Noise300m TrafficIntensity1km Woonhuis lnArea lnMarketDays lnRooms i.BuildingCat i.BuildingPeriod
i.TransactionYear if ShortRoad==0, absorb(PC6) vce(robust)

*Urban – Randstad versus Other Regions *
reg lnTransaction Target TargetxTrend TargetxDistanceR TargetxTrendxDistanceR TargetxConstruction
TargetxConstructionxDistanceR TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceR Noise100m
Noise300m TrafficIntensity1km Woonhuis lnArea lnMarketDays lnRooms i.BuildingCat i.BuildingPeriod
i.TransactionYear if Project==5, absorb(PC6) vce(robust)

drop if Project==5

reg lnTransaction Target TargetxTrend TargetxDistanceR TargetxTrendxDistanceR TargetxConstruction
TargetxConstructionxDistanceR TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceR Noise100m
Noise300m TrafficIntensity1km Woonhuis lnArea lnMarketDays lnRooms i.BuildingCat i.BuildingPeriod
i.TransactionYear, absorb(PC6) vce(robust)
```

```
*-----------------------------------OLS Assumptions Testing-----------------------------------*
*OLS Assumptions Testing*
reg lnTransaction Target TargetxTrend TargetxDistanceR TargetxTrendxDistanceR TargetxConstruction
TargetxConstructionxDistanceR TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceR i.TransactionYear,
absorb(PC6)
predict r, resid

*Assumption 1: Linearity*
histogram r, normal
kdensity r, normal
pnorm r
qnorm r
sum r

*Assumption 2: Homoscedasticity*
rvfplot, yline(0)
estat hettest

*Assumption 3: No autocorrelation*
sort DatumAfmelding
reg lnTransaction Target TargetxTrend TargetxDistanceA TargetxTrendxDistanceA TargetxConstruction
TargetxConstructionxDistanceA TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceA i.TransactionYear,
absorb(PC6) robust
predict r1, resid
gen time=_n
tsset time
dwstat

*Assumption 4: Independence*
reg lnTransaction Target TargetxTrend TargetxDistanceR TargetxTrendxDistanceR TargetxConstruction
TargetxConstructionxDistanceR TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceR Noise100m
Noise300m TrafficIntensity1km Woonhuis lnArea lnMarketDays lnRooms i.BuildingCat i.BuildingPeriod
i.TransactionYear, absorb(PC6) vce(robust)
vif

corr lnTransaction Target TargetxTrend TargetxDistanceR TargetxTrendxDistanceR TargetxConstruction
TargetxConstructionxDistanceR TargetxAfter TargetxAfterxTrend TargetxAfterxDistanceR Noise100m
Noise300m TrafficIntensity1km Woonhuis lnArea lnMarketDays lnRooms BuildingCat BuildingPeriod
TransactionYear PC6

*Assumption 5: Normality*
histogram r, normal
histogram r1, normal
jb r
jb r1
```

```
*------------------------------------Descriptives Final Specification------------------------------------*

summarize TransactionPrice lnTransaction TransactionYear Bouwjaar DagenOpMarkt AantalKamers
WoonOppervlakte lnMarketDays lnRooms lnArea NEAR_DIST_ACCESS NEAR_DIST_ROAD Noise100m
Noise300m TrafficIntensity1km Woonhuis i.BuildingCat i.BuildingPeriod Target

summarize TransactionPrice lnTransaction TransactionYear Bouwjaar DagenOpMarkt AantalKamers
WoonOppervlakte lnMarketDays lnRooms lnArea NEAR_DIST_ACCESS NEAR_DIST_ROAD Noise100m
Noise300m TrafficIntensity1km Woonhuis i.BuildingCat i.BuildingPeriod Target if NEAR_DIST_ROAD<2500

summarize TransactionPrice lnTransaction TransactionYear Bouwjaar DagenOpMarkt AantalKamers
WoonOppervlakte lnMarketDays lnRooms lnArea NEAR_DIST_ACCESS NEAR_DIST_ROAD Noise100m
Noise300m TrafficIntensity1km Woonhuis i.BuildingCat i.BuildingPeriod Target if NEAR_DIST_ROAD>2500
```