# What are the effects of highway tunnelling and green space development on house prices?

A case study of the Gaasperdammertunnel and Brasapark project.

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# A case study of the Gaasperdammertunnel and Brasapark project.

By

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# Preface

The subject of this thesis delves into the fascinating nature of how spatial projects influence external factors. I have always been intrigued by how everything in the world is interconnected and affects each other in complex ways. In economic terms, these effects can be described as 'externalities'. This concept, firstly introduced by Alfred Marshall in the 1890s, has evolved significantly since then. Statistical analyses that seemed impossible in Marshall's time are now achievable with advanced statistical programs like SPSS and Stata. Today, economists have the resources to compute complex models with advanced computing power to estimate these externalities.

In my thesis, I have explored this very topic. Investigating the impact of changing hard and green infrastructure on house prices is the subject that I have passionately engaged with. My interest in understanding spatial processes and their influence on the economy began at the start of the bachelor’s program for which I am writing this thesis. Learning about terrestrial processes and their interaction with the economy and humanity is what makes this study so special to me. This same study introduced me to statistical software, and the opportunity to showcase this in my own thesis is one that I embrace wholeheartedly.

I would like to express my gratitude to all the professors who have guided me throughout this bachelor’s program. In particular, I extend my heartfelt thanks to Eric Koomen and Lynn Bouwknegt for their contributions and guidance on this thesis. Lastly, I want to thank all those who patiently listened to my extensive discussions about statistics and the case I have been working on for the past few weeks. I’m thankful I was able to share my enthusiasm throughout this thesis.

## Abstract

Urban parks enhance the quality of life for city dwellers by offering recreational services and mitigating environmental issues. When these benefits are combined with the reduction of negative externalities from highways through tunnelling, the overall welfare of citizens can improve. This thesis examines the impact of the Gaasperdammertunnel and Brasapark project in Amsterdam on well-being. To assess the extent to which these projects enhance residents' welfare, the study assumes that the improvements are reflected in the citizens' willingness to pay a housing price premium near the project area. The analysis employs a difference-in-difference (DiD) methodology. The initial model shows a significant result, indicating that houses located within 500 meters of the tunnel and park increased approximately 5.12% less in price compared to houses 500 to 1500 meters away, after 2016 relative to before 2016. A negative treatment effect was unexpected, and sensitivity analysis was conducted using a different study area, various treatment and control groups and different treatment years. The majority of the models continued to indicate a negative and significant effect. Possible causes were discussed.



## Keywords

Brasapark - Gaasperdammerweg - Highway tunnelling - Housing prices - Difference in difference method

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# 1. Introduction

Through the implementation of the social development goals, urban areas around the world are increasingly prioritizing efforts to enhance living standards (United Nations, n.d.). Living standards are defined as 'the level of material well-being of an individual or group, in terms of goods and services available to them, and a measure of quality of life' (Oxford, 2024). The process of capitalization causes housing prices to reflect various measures of living standards, including air quality, (green) infrastructure, and the quality of schools (Banzhaf & Farooque, 2013). Therefore, changes in the living standards of a particular place can lead to changes in property values. The aim of this study is to analyse the value that housing consumers connect to improvements in liveability resulting from the Gaasperdammerweg-highway tunnelling and the Brasapark development project. This project involves the construction of the largest land tunnel in the Netherlands, alongside the creation of a park on its roof.

## 1.1 Social relevance

This analysis holds relevance for society as it offers insights for future urban planning, public policy, and quality of life within cities. With 50% of the world's population currently residing in cities, a figure projected to rise to 85% by 2100 (OECD, 2015), these factors become increasingly important.

## 1.2 Literature review

In research regarding the housing market, hedonic regression models are extensively employed to estimate property values (Herath & Maier, 2010). The concept of the Hedonic Pricing Model (HPM) is that goods are defined by their individual attributes, so that the total value of a good can be determined by summing the estimated values of its individual attributes (Rosen, 1974). Due to the endogeneity issues that arise when certain characteristics are unobserved in the Hedonic Pricing Model, new econometric methods have been implemented in the model (Banzhaf, 2019; Greenstone, 2017). The Difference in Differences (DiD) model helps to disregard fixed characteristics that influence property prices and may have been omitted from the hedonic regression.

The DiD estimator is employed when a research aims to compare the temporal effects between a treated group and a control group and has been used in multiple studies regarding infrastructural projects and their effect on house prices (Dubé et al., 2014; C. chang Lee et al., 2017; Tijm et al., 2018). By subtracting the time difference observed in the control group from that of the treatment group, the estimator isolates the treatment effects from other unrelated time-based effects (Levkovich et al., 2016). This effect is visualised in figure 1.

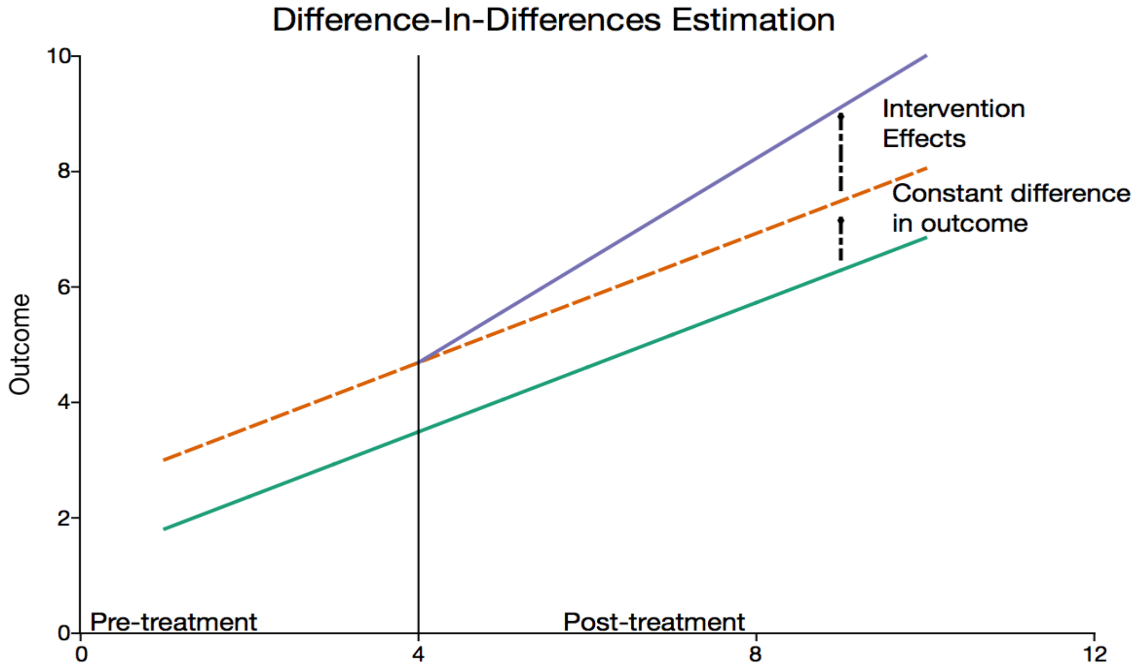


***Figure 1.*** *Visualisation of the Difference in Differences model. The x-axis represents time, divided into pre-treatment and post-treatment periods, while the y-axis indicates the outcome variable. The solid green line shows the control group's outcome trend over time. The dashed orange line represents the treatment group's expected outcome trend without intervention. The solid blue line depicts the treatment group's actual outcome trend post-intervention. The vertical distance between the blue and orange lines post-treatment measures the intervention effect, isolated by accounting for the constant difference in outcomes between groups pre-treatment. Source: (Aptech, n.d.)*

Regarding highways, literature has shown that they positively affect housing prices trough accessibility gains and negatively affect house prices trough noise pollution, air pollution and barrier- and visual effects (Hamersma, 2017). Tunnelling a highway in cities reduces the negative externalities of highways such as noise and air pollution (Koopmans, 2022). This improvement in the living environment can contribute to an increase in property prices in the area. One study examined the impact of these highway tunnelling externalities on house prices, focusing on the A2 highway in Maastricht, The Netherlands (Tijm et al., 2018). The study compared house price trends further than 2km from the highway segment with house prices trends of houses closer than 2km to the tunnelled highway segment. This study utilized a hedonic pricing model to determine the impact on house prices, incorporating an interaction (DiD) term to assess the effect of proximity to the tunnel. The announcement of the tunnel construction in November 2010 caused the study to compare house prices from 2010 to 2017 against pre-2010 levels as it assumed anticipation effects might begin to manifest from 2010 onward. The results indicated that with each halving of the distance to the tunnelled segment, house prices increased by 3.5%. No significant effects were observed for the years prior to 2016, although estimates for 2014-2015 suggested a similar positive trend.

Although the externalities of living close to a railway are different than highways, a study conducted on a railway tunnelling in Delft, The Netherlands, can provide valuable insights. This study by Van Ruijven & Tijm (2021) examines a tunnelling project with the goal of reducing noise pollution, vibrations and increasing railroad capacity. It makes use of a difference-in-difference approach with a synthetic control group and resulted in the conclusion that the tunnelling project mitigated the decrease in house prices caused by being close to the railroad by approximately 5 percentage points. This indicates that the project improved the desirability and value of homes near the railroad.

There is an extensive body of literature available on the effects of urban parks on house prices. According to a review of literature conducted by Konijnendijk et al. (2013), there is moderate to strong evidence suggesting that urban parks have a mostly positive influence on housing prices. This indicates that people seem to value the presence of parks. Crompton (2005) supports this finding; in an analysis of 33 studies in the U.S. regarding the effects of parks on house prices, only 3 studies showed a significant negative impact or no impact of parks on house prices. This was attributed to factors such as noise, congestion, and decreased privacy. Additionally, a premium of 8 to 10 percent on property values neighbouring or facing a park in urban settings could serve as a reasonable guideline for estimating property values. A study by Crompton & Nicholls (2022) looked at findings from twelve European, eleven Chinese, and three other international studies done since the year 2000. Among the European studies, it was clear that prices went down as you moved further from parks. Five studies definitely showed this. The other seven studies said that in some cases, there was a significant connection, but not always. None of the studies found a negative premium.

In American research, there is a general agreement indicating that parks influence house prices up to a distance of approximately 150 to 180 meters. However, beyond 150 meters the impact was little to non (Crompton, 2005). Studies conducted outside the United States do not present a unanimous conclusion. Nevertheless, the majority of these studies suggest that if there is a price premium associated with proximity to parks, it is most pronounced within a radius of 500 meters (Crompton & Nicholls, 2022).

## 1.3 Research problem statement

As has become clear in the introduction and the review of existing literature. There has not been a study that examines the combined effect of highway tunnelling and park development on house prices. Furthermore, there has been no prior research on the impact of the Gaasperdammertunnel and Brasapark project on house prices. The tunnelling of the A9 Gaasperdammerweg was a costly project, amounting to 800 million euros (Berents, 2014). While aimed at improving accessibility to the Randstad and enhancing the liveability of Amsterdam Zuidoost, these developments do not yield directly monetizable benefits. This analysis will investigate whether there are financial benefits in the form of increased property values to compensate this cost. This will be examined through the central research question: “What is the effect of the Gaasperdammertunnel and Brasapark project on house prices?”. The knowledge gained by answering this question could contribute to the understanding of how housing prices are influenced by a combination of spatial projects. Additionally, it could give insights on the methodologies that can be employed for such research, possibly offering guidance for future studies. Analysing this project may also contribute to understanding whether this development project is positively or negatively valued, which is key for policy evaluation.

## 1.4 Expectations

It is expected that the Gaasperdammertunnel and Brasapark project have led to an increase in the prices of nearby houses. This expectation is based on studies discussed in the literature review, which indicate that infrastructure tunnelling positively influences house prices, while proximity to green spaces, in most cases, positively affects house prices too.

## 1.5 Research design

This paper uses a causal study design. With the help of big data and a difference in difference regression an attempt to identify causal relations between the development of a large-scale infrastructural project and house prices in Amsterdam was made.

## 1.6 Reading guide

Firstly, the research dives into the study area. This section provides a comprehensive overview of the Gaasperdammertunnel and Brasapark project, alongside key aspects of the region. Visualizations accompany the descriptions, offering a compact and insightful understanding of the research context.

Secondly, the focus shifts to data acquisition. Here, the report prioritizes transparency and replicability. The rationale behind choosing specific variables is explained, ensuring the reader possesses a clear understanding of the data used in the analysis.

Thirdly, the methodology section delves into the chosen methods. The report details how the variables are tested. Additionally, it introduces the empirical model with clear explanations for each included variable. The results themselves are then presented with the help of tables and with concise descriptions.

Following this, a sensitivity analysis is conducted. This analysis tests the robustness of the results by using a different study area and different parameters and configurations for the base model.

Finally, the report interprets the results. Both positive and negative aspects are discussed, along with potential explanations for the observed trends. The research concludes by highlighting the main findings in a dedicated conclusion section.

# 2. Case description

## 2.1 The Gaasperdammertunnel

The Gaasperdammertunnel, located in the Netherlands, is a highway tunnel that forms part of the A9 highway connecting Holendrecht and Diemen in Amsterdam-Zuidoost. The tunnel measures at 3 kilometers, making it the country's longest land tunnel (Rijkswaterstaat, n.d.). Originally conceived as part of the Schiphol-Amsterdam-Almere (SAA) Route Decision, a major scheme to upgrade the A1, A6, A9 and A10 highways, the project began in 2006 after it became clear that linking the A6 and A9 directly was not politically possible (Wegenwiki, 2022). The plan underwent several adjustments, and the 'streamline alternative', which included the Gaasperdammertunnel, was ultimately signed in 2008. The plan became irrevocable in 2012 (Hertogh et al., 2017). The aim of the SAA project is to improve traffic flow, travel time and provide better access to the Northern part of the Randstad (Berents, 2014). In addition, it was proposed that the road construction would improve the quality of life in Amsterdam-Zuidoost. The preparatory work for the tunnel began at the end of 2013, including the laying of pipes and cables. Raw construction of the tunnel structure began in 2016. Eventually, the tunnel was opened to traffic in 2020 through four phases (Rijkswaterstaat, n.d.).

## 2.2 The Brasapark

On top of the tunnel, the Brasapark has been created. The idea of this park was conceived and published in 2014 (Berents, 2014). Subsequently, the park's development began in November 2020. Bounded by the Gaasp River and the Amsterdam-Utrecht railway line, the park is situated between the urban neighbourhoods of Bijlmermeer and Holendrecht, adjacent to Nellestijn. The park spans approximately 65 meters wide and stretches for 3 kilometres in length, making a surface area of 19,5 hectares (see figure 2).

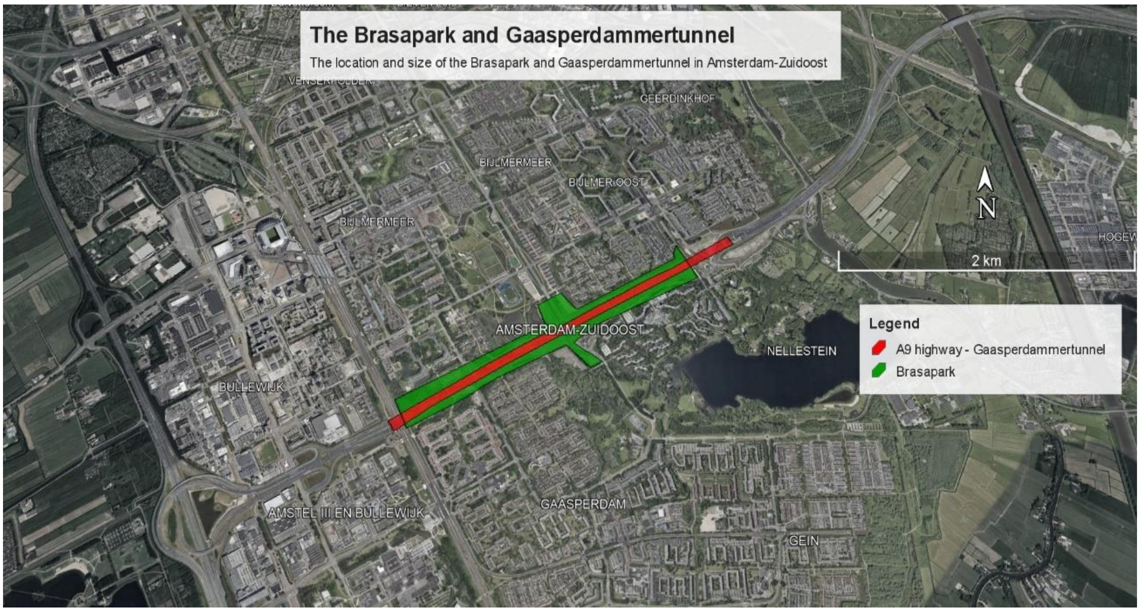


***Figure 2.***

## 2.3 Study area description

The area directly north of the Gaasperdammerweg will be used for the analysis, with a maximum range of 1500 meters (see figure 5). This area is located in the southeastern part of Amsterdam, adjacent to the Gaasperplas and the Gaasperzoom. The region is situated in the Bijlmer, covering most of Amsterdam-Zuidoost and including neighbourhoods like Bijlmer-Centrum, D-buurt, E-buurt, F-buurt, G-buurt, H-buurt and K-buurt..

The area has a negative stigma within Dutch society. This is caused by a historically high level of poverty and crime, but it also involves a racial component (Pinkster et al., 2019). The area is characterized by a relatively high percentage of residents with a migrant background, and also contains a high share of students (CBS, 2016).

Between 1992 and 2010, the area underwent a urban renewal project that transformed its landscape. High-rise buildings were replaced with low-rise structures, and the municipality aimed to diversify the population and create a better living environment (de Groot, 2012). Consequently, many of the homes in the area date from this period (see figure 3).

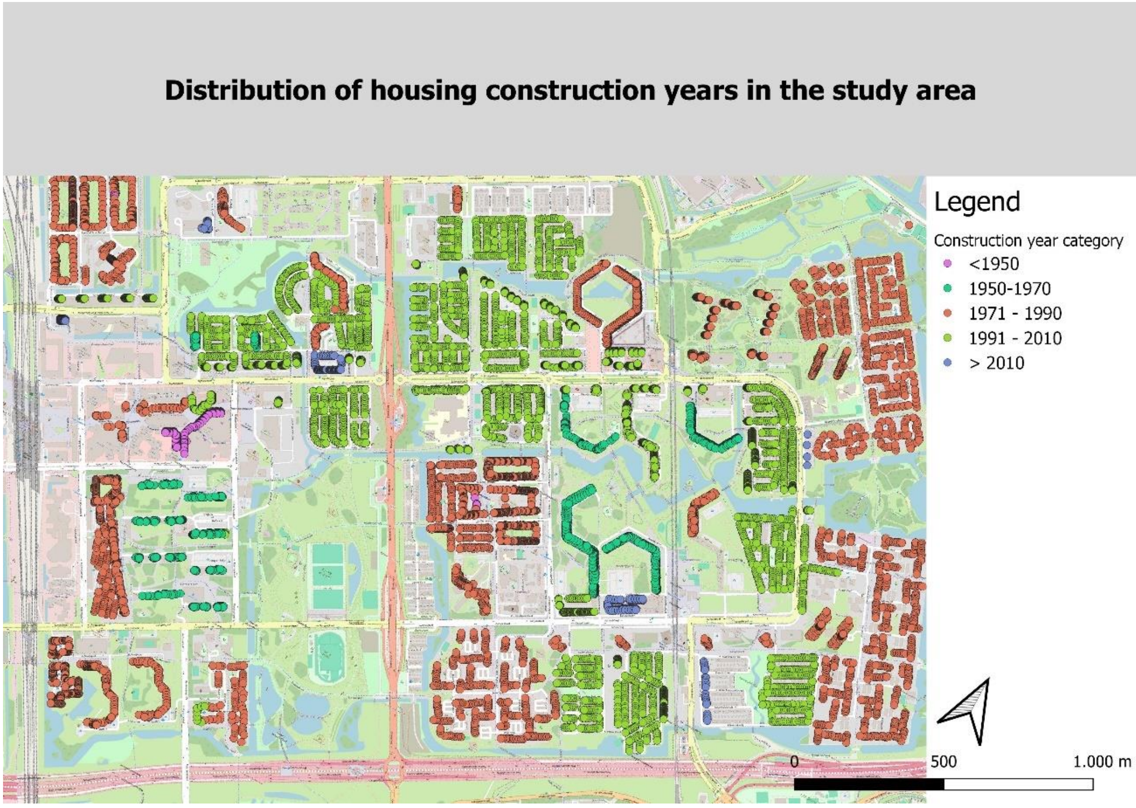


*Figure 3.*

The area features a variety of housing types, ranging from apartments to detached houses. Apartments are the most dominant type of housing in the area, followed by terraced houses, this is visualised in figure 4.

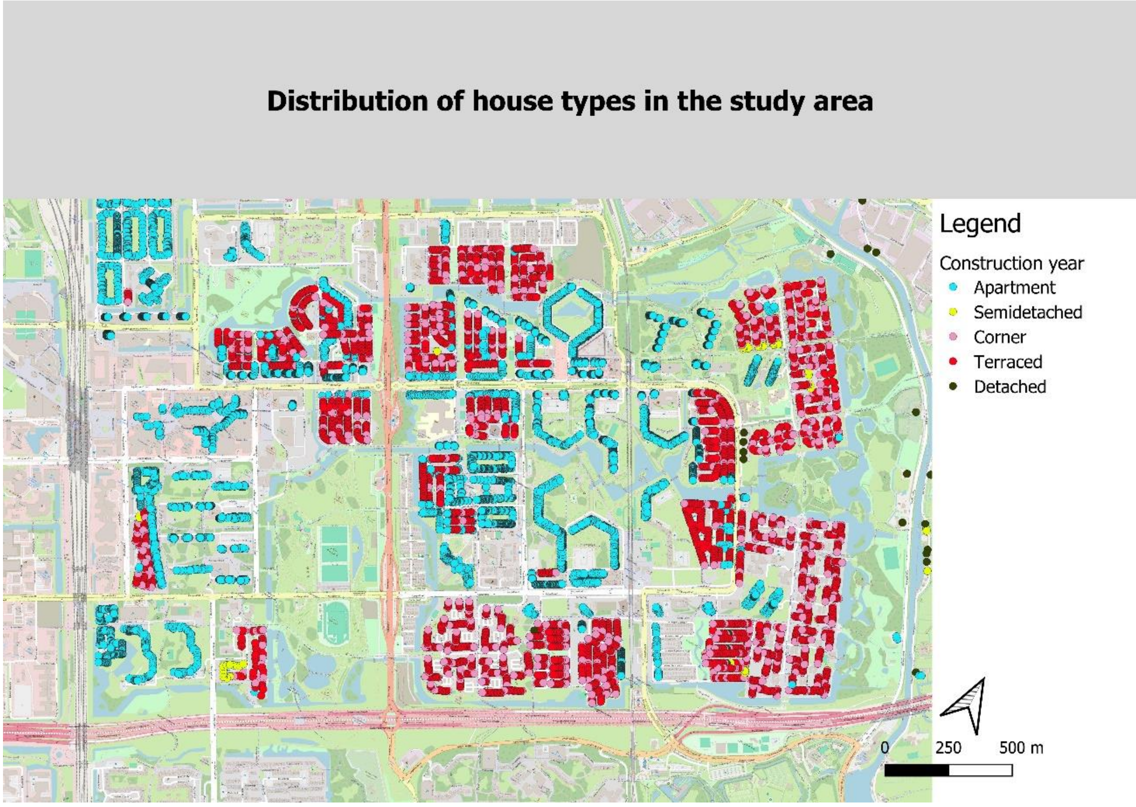


*Figure 4.*

In addition to the Gaasperdammerweg, the Gooiseweg and the Muntbergweg are important roads that run through the study area. The area is also surrounded by the A1, A2 and A10 highways, in addition to the A9. The area is served by various bus, train and metro lines, including metro lines 50 and 53 and NS station Amsterdam Bijlmer Arena. This infrastructure provides direct connections to Amsterdam Centraal, Amsterdam Zuid and Utrecht. These major infrastructure lines are shown in figure 5 along with the parks exceeding 20 hectares.

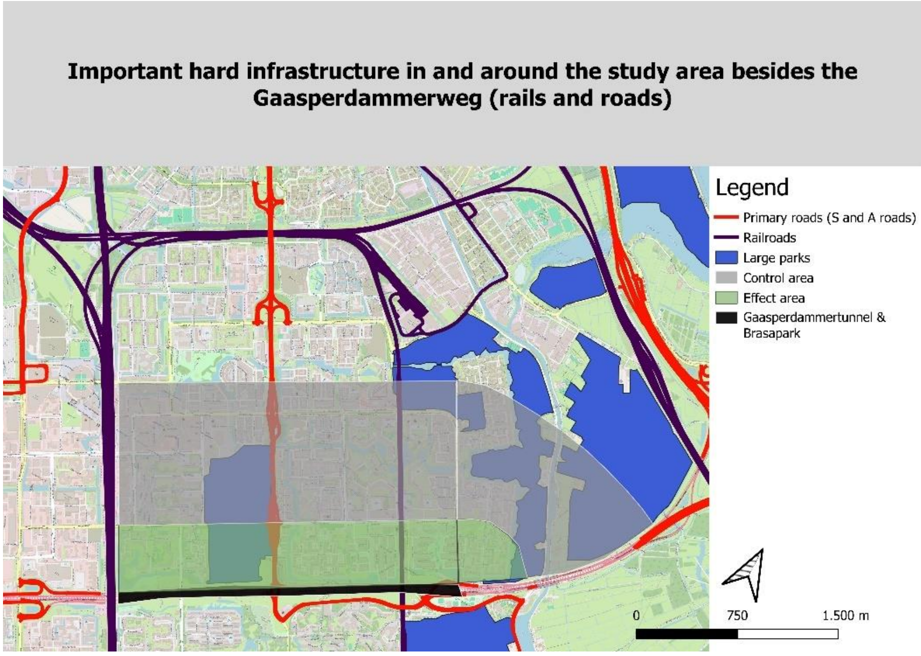


*Figure 5.*

The study area encompasses four postal code districts: 1102, 1103, 1104, and 1112. Identifying these districts will be valuable for the thesis analysis. The districts are shown in figure 6.

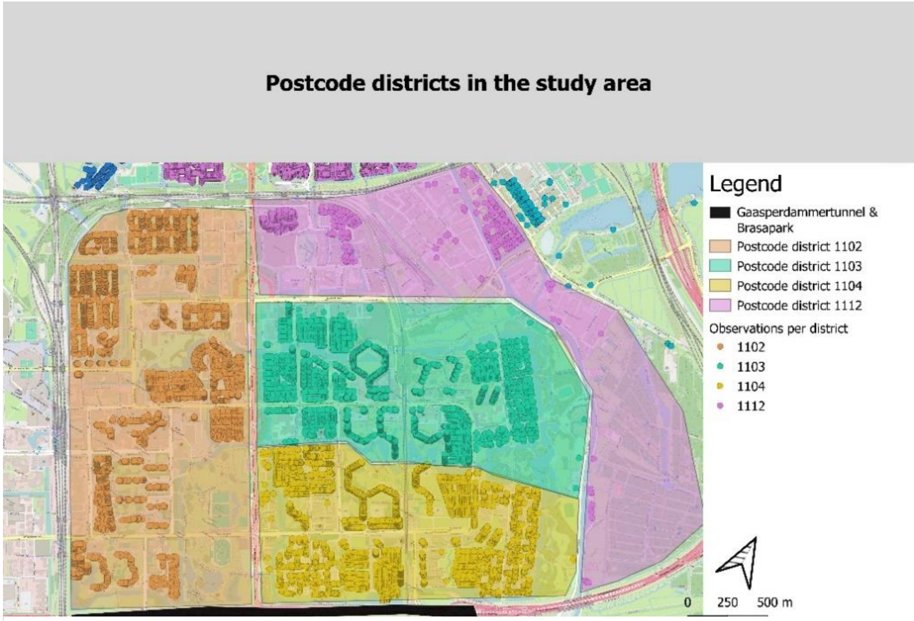


*Figure 6.*

## 3. Data acquisition

The house prices data that was used in this study was provided by the VU Amsterdam and consists of the property value that is stated on the annual municipal tax bill for every house in the Netherlands. This data has one observation per year and reaches from the 1st of January 2014 to the 1st of January 2022. This data was scraped from the wozwaardeloket.nl website. Every house was identified with a x and y coordinate, using the 28992 – Amersfoort RD new projection. Furthermore, the used dataset consisted of housing characteristic variables such as year of construction and housing type. These housing characteristics where extracted from Basic Registration of Addresses and Buildings (BAG) data.

Descriptive statistics table 1 shows all the used variables.

***Table 1.*** *Descriptive Statistics of the variables used in this study*

| Variable | Observations | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| **Transaction characteristics** | | | | | |
| Woz (€) | 130,328 | 214,769 | 96,752.96 | 46000 | 1529000 |
| Ln(Woz) (€) | 130,328 | 12.18 | 0.43 | 10.73 | 14.24 |
| Year | 130,328 | 2018 | 2.58 | 2014 | 2022 |
| **Housing characteristics** | | | | | |
| Housing type | 130,328 | 5 types | | | |
| Size ($m^2$) | 130,328 | 85.56 | 27.51 | 12 | 1034 |
| Construction year | 130,328 | 5 categories | | | |
| **Spatial characteristics** | | | | | |
| Dist. Gaasperdammerweg (m) | 130,328 | 848.75 | 404.56 | 27 | 1500 |
| Dist. Primary road (m) | 130,328 | 592.14 | 293.45 | 48 | 1380 |
| Large park within 100m (0/1) | 130,328 | 0.09 | 0.28 | 0 | 1 |
| Railroad within 300m (0/1) | 130,328 | 0.37 | 0.48 | 0 | 1 |
| Postal code fixed effects | 130,328 | 4 districts | | | |

While the descriptive statistics table shows 130,328 observations, it's important to consider that this is panel data. Panel data refers to datasets where observations are collected for the same units (in this case, houses) over multiple time periods (years). Therefore, to determine the number of unique houses (samples) in the dataset, the amount of samples is divided by the number of years. Doing this yields 14,481 samples.

Descriptive statistics table 1 also reveals four distance variables: 'distance to Gaasperdammerweg', 'distance to primary road', 'railroad within 300 meters' and 'large park within 100 meters'. These variables were added using GIS software.

The variable ‘distance to Gaasperdammerweg’ was calculated by using a polygon of the entire length of the Gaasperdammertunnel, coloured red in figure 2. Furthermore, the ‘distance to primary road’ and the ‘railroad within 300 meters’ variables were calculated with data from the open-access OSM data via the Overpass Turbo website using the query in figure 7.

```
[out:json][timeout:25];

(
  way["railway"](52.2800, 4.8900, 52.3800, 5.0500);
  relation["railway"](52.2800, 4.8900, 52.3800, 5.0500);
);
out body;
>;
out skel qt;


(
  way["highway"~"motorway|trunk|primary"](52.2800, 4.8900, 52.3800, 5.0500);
  relation["highway"~"motorway|trunk|primary"](52.2800, 4.8900, 52.3800, 5.0500);
);
out body;
>;
out skel qt;
```

***Figure** 7. The query used to access GIS data for the study area, specifically regarding railroads and primary roads.*

The variable representing the distance to the railroad was included, because a study conducted in the Netherlands in 2021 discovered that approximately 11 percent of Dutch individuals aged 16 and older who lived within 300 meters of a railway experienced significant annoyance from train-induced vibrations (van Kempen et al., 2023). Due to the substantial presence of railroads in the study area (see figure 5) this was seen as a mandatory control variable. Regarding the primary roads variable, the Gaasperdammerweg was deleted from the data.

The variable ‘large park within 100 meters’ was calculated using data that provided all parks within the municipalities of Amsterdam, Ouder-Amstel, and Diemen, excluding the Brasapark. This data was also extracted from the open access OSM data via the Overpass Turbo website using the query in figure 8:

```
(
  area[name="Amsterdam"];
  area[name="Diemen"];
  area[name="Ouder-Amstel"];
);
way
  [leisure=park]
  (area);
(._;>;);
out body;
```

***Figure 8**. The query used to access GIS data for the study area, specifically regarding parks.*

The provided data contained small parks and gardens (<1ha) and big parks such as the Nelson-Mandelapark, reaching 43ha (Wikipedia, 2021). Numerous studies indicate that larger parks have a greater impact on housing prices. For instance, the paper by Ma et al. (2024), indicates that in Beijing parks larger than 20 hectares are seen to increase house prices by a as large as 6-7%.

While the average house price increase for all park sizes are smaller than 1%. Also, Crompton (2020) states that larger parks often command a greater premium. He states that this phenomenon might be attributed to the larger parks providing increased buffers, which help shield adjacent residents from potential adverse influences of parks.

Previous studies classified parks of different magnitudes. This was done through the use of four classes: class 1 with an area between 0.1 to 2 hectares; these were assumed to be the street corner parks, class 2 with an area between 2 and 20 hectares, class 3 with an area between 20 and 100 hectares, and class 4 with an area over 100 hectares (Cheng et al., 2021; Fan et al., 2017). As mentioned before, small (corner) parks have less of an influence on house prices. For this reason, only large parks were of interest for this study. Classes 3 and 4 were considered large parks, and smaller parks were excluded from the data. Consequently, the variable 'large park within 100 meters' included parks exceeding 20 hectares. As a result, the variable contained the Professor Joop van Stigtpark, Penbos, Nelson Mandelapark, Bijlmerweide, Gaasperpark, and Diemerbos, with respective areas of around 20 hectares, 29 hectares (Waarneming.nl, n.d.), 43 hectares (Wikipedia, 2021), 50 hectares (Landschap Noord-Holland, n.d.), 79 hectares (Buurtje.nl, n.d.), and 244 hectares (Waarneming.nl, 2024).

In the study area, the Joop van Stigtpark contains houses within its premises. These specific observations were manually assigned a zero value for the park variable.

After all the variables were added, outliers were identified. By reviewing the dataset, WOZ values above 2,000,000 Euros or below 30,000 Euros were seen as outliers and were excluded. Samples that missed one or more year (observation) for the Woz variable were also removed. This ensured continuity of the data.

The settings and definitions of the variables discussed in this chapter are summarized in table 3**.**

# 4. Methods

This study aimed to explore the effect of the Gaasperdammertunnel and Brasapark project on house prices. In order to investigate this effect, an OLS difference in difference model was performed.

## 4.1 Correlation testing

Firstly, the independent variables underwent correlation testing, a critical step in regression analysis. Multicollinearity among independent variables can distort coefficient estimates, obscuring the true relationship between independent variables and the dependent variable. By identifying and addressing multicollinearity early on, the reliability of the regression models are ensured. Continuous and dichotomous variables were assessed using Pearson’s r, yielding generally weak to moderate correlations. All correlation coefficients were significant at $p<0.01$ and ranged from -0.150 between the variables ‘railroad within 300m’ and ‘park within 100 meters’ to 0.273 between the variables ‘distance to primary road’ and ‘railroad within 300m’. While various thresholds exist to interpret Pearson's correlation coefficients, values between -0.3 and 0.3 are commonly considered indicative of weak correlation in diverse scientific disciplines (Akoglu, 2018; Asuero et al., 2006; Schober & Schwarte, 2018).

Nominal categorical variables, such as ‘construction year’ and ‘housing type’, were evaluated using Cramer’s V to explore associations with other categorical and binary variables. This approach was chosen because Pearson’s correlation assumes a linear relationship, which is not valid for categorical variables (Akoglu, 2018). Cramer's V, ranging from 0 to 1, where 0 signifies no association and 1 denotes a perfect association, is based on Pearson's chi-squared statistic. The coefficients resulting from the test ranged from a minimum of 0,0512 between the variables ‘construction year’ and ‘housing type’ to a maximum of 0.2995 between the variables ‘housing type’ and ‘large park within 100 meters’. Several studies suggest a Cramer’s V value of 0.25 to 0.3 or higher indicates strong association (Akoglu, 2018; D. K. Lee, 2016). An additional pairwise correlation with categorical variables represented as dummies was conducted to assess all Pearson’s correlation values. Again, many weak correlations are observed. Notably, housing types show strong negative correlations with each other. This means that if a property is of a certain type, it is very unlikely to be of another. This is observed because these dummies are mutually exclusive. Furthermore, it is notable that ‘Size’ and ‘Apartment’ have a moderate negative correlation of -0.467, suggesting that larger properties are less likely to be apartments.

In conclusion, the correlation analysis reveals generally weak to moderate Pearson’s relationships among independent variables, while Cramer’s V values suggest some stronger associations, implying multicollinearity among categorical variables should be considered. Therefore, the model will include regressions with and without control variables. Appendix A contains all the correlation results.

## 4.2 Treatment and control groups

To assess the effect of the Brasapark and Gaasperdammertunnel, properties within 500 meters of the project were designated as the treatment group and those at 500 to 1500 meters away as the control group. Both groups are located in Amsterdam-Zuidoost. Table 2 shows that the treatment and control group contain 3,531 and 10,950 samples, respectively.

***Table 2.*** *Amount of observations for the treatment (< 500m of Gaasperdammerweg) and control group (500-1500 meters away from Gaasperdammerweg).*

| Group | Observations |
|---|---|
| Treatment | 3,531 |
| Control | 10,950 |

A 500-meter threshold for the treatment group is implemented to evaluate the collective impact of the Brasapark and Gaasperdammerweg. As stated in the introduction (pg.7), the influence of parks in Europe on property values is most notable within a radius of 500 meters. Furthermore, multiple studies on urban development using a Difference-in-Differences (DiD) method have used a 500-meter radius to define the treatment group and examine the effects on nearby house prices. Li et al. (2022) investigated the spillover effects of urban redevelopment projects and utilised a 500-meter distance to define the treatment group. Dempsey & Plantinga (2013) looked at urban growth boundaries and used a 500-meter radius for the treatment group to examine the effect on house prices.
For the main model, 2016 was chosen as the treatment year. This is the year in which construction started. This is done because this study assumes that homebuyers and investors adjust their valuations based on visible progress and the perceived confidence that the project will be completed. Furthermore, because the project was announced several years before data collection began, the data is insufficient for capturing the project's effects on house prices throughout its entire duration. This limitation made it difficult to fully account for anticipation effects.

## 4.3 Empirical model

The effect of the Brasapark and Gaasperdammertunnel was examined using a difference-in-difference method. This model is expressed as follows:

$$ln(P_{it}) = \beta_0 + \beta_1 treated_i + \beta_2 post\_effectyear_t + \delta(treated_i \times post\_effectyear_t) + \gamma FE_{it} + \alpha CV_{it} + \epsilon_{it}$$

where the dependent variable $\ln(P_{it})$ represents the logarithm of the house price of house *i* at time *t*. The variable $treated_i$ is a dummy variable indicating whether house *i* is located within 500 meters of the Gaasperdammerweg, and $post\_effectyear_t$ is a dummy variable representing the period after 2016. The interaction term ($treated_i \times post\_effectyear_t$) measures the combined effect of being within the treatment area and the post-treatment period on house prices. The term $\gamma FE_{it}$ captures the combined fixed effects for year and postal code, and $\alpha CV_{it}$ represents the combined control variables including house size, housing type, construction year category, distance to primary road, within 100 meters of a railroad, and within 100 meters of a large park. The error term $\epsilon_{it}$ is assumed to be normally distributed with variance $\sigma^2$ and mean 0. The key parameter of interest is $\delta$, which estimates the causal effect of the treatment on house prices in the post-treatment period. Table 3 shows the variable settings and explanations.

***Table 3**: Variable setting and explanations*

| Variable | Label | Definition | Expectation |
|---|---|---|---|
| Woz | Woz | The property value that is stated in the annual municipal tax bill for every house in the Netherlands. Measured in Euro's. | |
| Ln(Woz) | Ln_price | The natural logarithm of the variable 'Woz'. | |
| Year | Year | Year of observation, with 2014 serving as the reference point for comparisons. Values range from 2014 to 2022. | |
| Housing type | Housing_type_cat | Categorial/Nominal variable indicating five different types of houses:<br>1. Apartment<br>2. Semidetached<br>3. Corner<br>4. Terraced<br>5. Detached | +<br>*Reference: Apartment* |
| Size | Size | Continuous variable, indicating the size of the house, measured in square meters. | + |
| Construction year | Constr_year_cat | Categorial/Nominal variable indicating five different categories of house construction years.<br>1. < 1950<br>2. 1950 - 1970<br>3. 1971 - 1990<br>4. 1991 - 2010<br>5. > 2010 | <br><br><br>-<br>-<br>*Reference*<br>+<br>+ |
| Dist. Gaasperdammerweg | Distance_gaasperdammerweg | Continuous variable measuring the distance of all houses to the Gaasperdammerweg. Is used to define control/treatment groups. Measured in meters. | - |
| Dist. Primary road | Near_primaryroad | Binary variable indicating if a house is within 100 meters of a primary road. In the Netherlands, primary roads are classified as S-roads and A-roads. S-roads are the main roads within the city, while A-roads are highways. | - |
| Large park within 100m | Near_largepark | Binary variable indicating if a house is within 100 meters of a park larger than 20 hectares. | + |
| Railroad within 300m | Near_railroad | Binary variable indicating if a house is within 300 meters of a metro-or train rails. | - |

### 4.4 Heteroskedasticity testing

The final test conducted to ensure the validity of the model was the Breusch–Pagan test. This test is designed to detect heteroskedasticity in any linear form (Williams, 2020). Testing for heteroskedasticity is crucial because the regression model used in this paper, Ordinary Least Squares (OLS), assumes that the residuals are drawn from observations with constant variance (CFI, n.d.). When heteroskedasticity is present, this assumption is violated. For the Breusch-Pagan test this study uses a cut-off p-value of less than 0.05, this is the most common used value in scientific literature. The test resulted in 4 out of 5 regressions with a p-value under 0.05. Hence, the null hypothesis of constant variance was rejected, indicating that heteroskedasticity is present. Therefore, robust standard errors were used.

## 5. Results

Table 4 displays the results of five different DiD models estimating the impact of various factors on the natural logarithm of house prices (Ln of Woz).

***Table 4.*** *Difference in difference regression results*

| Model<br>VARIABLES | (1)<br>Ln of Woz | (2)<br>Ln of Woz | (3)<br>Ln of Woz | (4)<br>Ln of Woz | (5)<br>Ln of Woz |
|---|---|---|---|---|---|
| Treated | 0.0323*** | 0.0633*** | 0.00339 | 0.0333*** | -0.00557** |
| | (0.00361) | (0.00369) | (0.00231) | (0.00365) | (0.00241) |
| Post-effect year | 0.530*** | 0.872*** | 0.872*** | 0.872*** | 0.872*** |
| | (0.00234) | (0.00391) | (0.00197) | (0.00365) | (0.00194) |
| Interaction (Treated*Post effect year) | -0.0512*** | -0.0512*** | -0.0512*** | -0.0512*** | -0.0512*** |
| | (0.00471) | (0.00449) | (0.00186) | (0.00421) | (0.00183) |
| Size ($m^2$) | | | 0.00685*** | | 0.00681*** |
| | | | (0.000361) | | (0.000359) |
| ***House type – Reference: Apartment*** | | | | | |
| Semidetached | | | 0.441*** | | 0.425*** |
| | | | (0.0228) | | (0.0219) |
| Corner | | | 0.240*** | | 0.222*** |
| | | | (0.00985) | | (0.00957) |
| Terraced | | | 0.207*** | | 0.189*** |
| | | | (0.0100) | | (0.00974) |
| Detached | | | 0.286*** | | 0.264*** |
| | | | (0.0503) | | (0.0488) |
| ***Construction year – Reference: 1971 – 1990*** | | | | | |
| <1950 | | | 0.100*** | | 0.115*** |
| | | | (0.00343) | | (0.00308) |
| 1950 - 1970 | | | 0.0165*** | | 0.0152*** |
| | | | (0.00484) | | (0.00476) |
| 1991 - 2010 | | | 0.161*** | | 0.159*** |
| | | | (0.00616) | | (0.00647) |
| >2010 | | | 0.177*** | | 0.162*** |
| | | | (0.00843) | | (0.00838) |
| Distance to non-tunnelled primary road | | | | -0.000330*** | -6.35e-05*** |
| | | | | (3.87e-06) | (2.61e-06) |
| Railway closer than 300m | | | | -0.0184*** | 0.0300*** |
| | | | | (0.00204) | (0.00121) |
| Park within 100m (>20ha) | | | | 0.312*** | 0.108*** |
| | | | | (0.00361) | (0.00276) |
| **Year fixed effect** | NO | YES | YES | YES | YES |
| **Postal code fixed effect** | NO | YES | YES | YES | YES |
| Constant | 11.83*** | 11.82*** | 11.09*** | 12.06*** | 11.12*** |
| | (0.00181) | (0.00318) | (0.0254) | (0.00364) | (0.0239) |
| Observations | 130,329 | 130,329 | 130,329 | 130,329 | 130,329 |
| R-squared | 0.311 | 0.450 | 0.860 | 0.518 | 0.864 |

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Dependent variable is the natural logarithm of house prices (Woz). The coefficients are the effect of being within 500 meters from the Gaasperdammertunnel and Brasapark within a specified time period compared to houses at 500 to 1500 meters away from the tunnel. Heteroskedasticity robust standard errors in parentheses.

The coefficient for the 'Treated' variable, indicating whether a house is within 500 meters of the project, is positive and significant in Models 1 through 4. This indicates that houses within 500 meters of the project have higher prices relative to houses 500 to 1500 meters away. When all control variables are added (Model 5), this coefficient becomes slightly negative but remains significant. The 'Post-effect year' variable, representing the period after 2016, shows a significant positive effect on house prices across all models, suggesting an overall increase in house prices after 2016.

The interaction (DiD) term (Treated*Post-effect year) is negative and significant in all models, suggesting that houses located within 500 meters of the tunnel and park increased approximately 5.12% less in price compared to houses 500 to 1500 meters away, after 2016 relative to before 2016.
Regarding the control variables, house size (in square meters) consistently shows a positive and significant effect on house prices. Different types of houses, compared to the reference category of apartments, generally show higher prices, with semidetached, corner, terraced, and detached houses all having positive and significant coefficients. The effect is particularly strong for semidetached and detached houses, with a 44,1 and 28,6 percent higher price, respectively.

In terms of construction year, houses built between 1971 and 1990 (the reference period) tend to be more affordable. Houses outside this range, whether older or newer, are typically at least 10% more expensive, with the most recently built houses (after 2010) commanding the highest prices.

Furthermore, distance to a non-tunnelled primary road is negatively associated with house prices, but the effect is small. Proximity to a railway (closer than 300 meters) has a negative impact on prices, whereas proximity to a large park (within 100 meters) has a positive and significant impact.

The inclusion of year fixed effects and postal code fixed effects in Models 2 through 5, and the inclusion of the control variables significantly increases the R-squared values. This improvement is largely driven by the housing characteristic variables. This can be seen by comparing Model 3 with Model 4. Overall, the R-squared values range from 0.311 in Model 1 to 0.864 in Model 5.

Year and postal code district effects are given in Appendix D.

The results of the fifth model of the difference-in-differences (DiD) analysis are visualised in figure 9. The left panel depicts the observed means of the log of house prices (ln of price) for both the control and treatment groups over time, while the right panel shows the linear-trends model for the same variables. The observed means plot provides a direct visual representation of the means of the real data points. It shows how house prices have changed over time in both groups without any smoothing or fitting of trends. This graph is important because it presents the raw data and allows us to see the actual trends and any fluctuations in the data. The linear-trends model finds the intercept and slope that make the best average fit to all the data, highlighting the underlying linear trends over time (Duke University, n.d.). This graph can be important because it helps to disregard short-term fluctuations and noise.

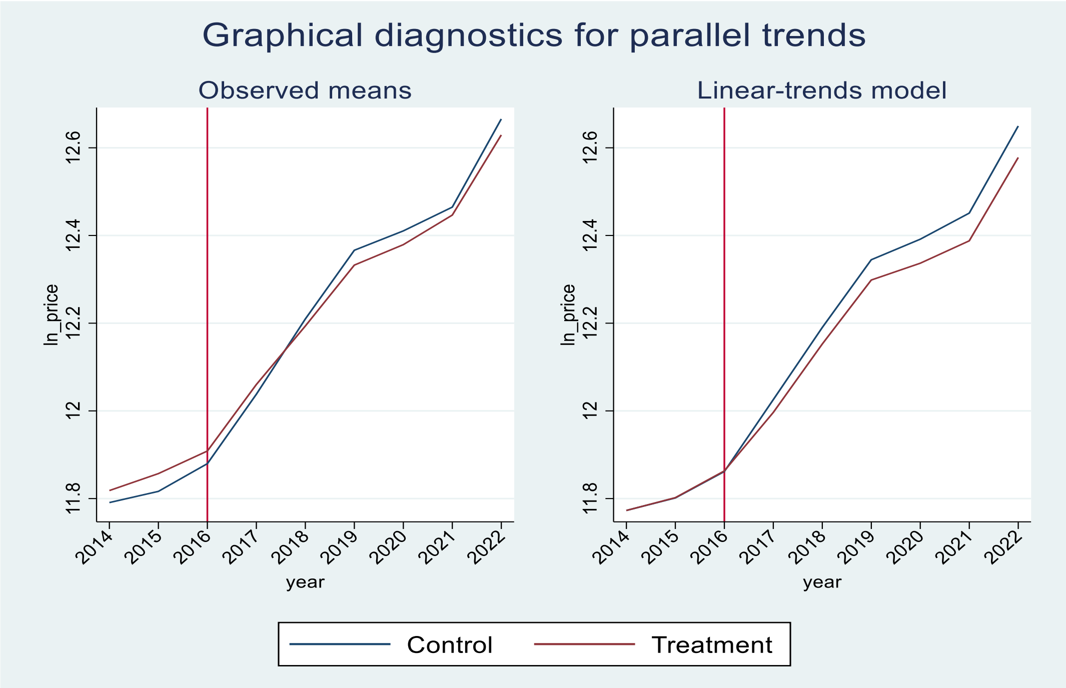


***Figure 9**. Graphical diagnostics for parallel trends. The graphs visualise the parallel trends assumption by showing the house price trends in the treatment and control group, before and after the effect year (vertical line).*

In the graphs, the blue line represents the control group, the red line represents the treatment group, and the vertical red line indicates the time point at which the treatment is applied (2016).

From 2014 to 2016, in both graphs, the lines for both the control and treatment groups are relatively parallel, indicating that both groups had similar trends in house prices before the treatment was applied. This satisfies the parallel trends assumption. The parallel trend assumption is a crucial condition for the validity of the difference-in-differences approach. It requires that, in the absence of the treatment, the average difference in the outcome variable between the treatment and control groups would have remained constant over time. In other words, both groups should have similar trends in the outcome variable before the treatment is applied (Columbia University, 2024). After 2016, both lines continue to increase, with the control group showing a slightly higher increase compared to the treatment group. This is in line with results in table 4.

# 6. Sensitivity analysis

## 6.1 Parameters and Configurations

Appendix B includes a set of robustness checks to ensure the validity of our main findings regarding the effect of the Gaasperdammertunnel and Brasapark project on house prices. First, the effects of using various definitions of treatment and control groups were tested. Specifically, houses within 500 meters of the Gaasperdammerweg (treatment group) were compared with houses situated between 500-1000 meters, 1000-1500 meters and 2000-2500 meters (control groups). This was done to gain knowledge about to what extend the effects of the projects can be measured.

Additionally, houses within 1000 meters were considered as the treatment group and were tested with houses located 1000-1500 meters away and 1500-2500 meters away as control groups. This was done with 2016 as the effect year.

Secondly, alternative effect years were considered. While the primary analysis uses 2016 as the treatment year, additional treatment years of 2017 and 2020 were tested. This method ensures that the observed impacts are robust to variations in the timing of the treatment period. It also facilitates analysis of the different periods during which the effects of the Gaasperdammertunnel and Brasapark are reflected in house prices (building phase, completion phase). This is important considering the complex evolution of house prices from project conception through construction and operation (Melser, 2020). Effect year 2017 was chosen to check for short-term fluctuations, and effect year 2020 was chosen to observe changes in prices at the completion of the Gaasperdammertunnel and Brasapark. These models, with the different treatment years, were also conducted using the same treatment and control distance groups as in the primary model in chapter 4 (500 meters treatment, 500–1500 meters control).

## 6.2 results

Appendix B table 1, 2 and 3 show the results of the sensitivity analysis. This analysis results in 15 new interaction coefficients. The interaction term ($treated_i \times post\_effectyear_t$) remains significant across 12 out of 15 models. Model 4 in Appendix B Table 1, with the treatment group including houses within 1000 meters of the Gaasperdammerweg and the control group including houses situated between 1500-2500 meters for effect year 2016, has an insignificant interaction term. Similarly, Model 5 in Appendix B Table 2, with the same distances but effect year 2017 shows an insignificant interaction term. Model 4 for effect year 2020 (Appendix B Table 3) is also insignificant. In this model, the treatment group includes houses within 1000 meters of the Gaasperdammerweg, and the control group includes houses situated between 1000-1500 meters.

Among the significant results of the interaction term, only two coefficients show a slight positive trend. Specifically, this applies to the treatment group within 1000 meters compared to the control group located 1000-1500 meters away from the Gaasperdammertunnel with effect years 2016 and 2017. These models suggests a faster increase in house prices within 1000 meters relative to those situated 1000-1500 meters away from the tunnel, by 1.7% and 1% respectively, following the effect years compared to before that period.

The ten significant negative coefficients of the interaction term in the sensitivity analysis range from -0.0755 to -0.0263.

## 6.3 Testing a new study area

Additional data from a larger area around the Gaasperdammerweg was collected, and a new analysis was conducted with this data.

In the original analysis, the study area was positioned at the edge of the Gaasperdammerweg. This may have led to a limited representation of the effects of the Gaasperdammerweg on surrounding property prices. Therefore, an additional test was conducted by revising and expanding the study area so that the Gaasperdammerweg is centrally located.

By expanding the study area, a larger number of property transactions could be included in the analysis, possibly leading to greater statistical power and more robust results. Positioning the Gaasperdammerweg in the center of the study area ensures a balanced distribution of properties on both sides of the road.

The new sample was tested using the base model with the effect year 2016. The treatment group included houses within 500 meters of the Gaasperdammerweg and Brasapark, and the control group included houses 500 to 1500 meters away from the Gaasperdammerweg. These groups contained 65,176 and 157,356 observations, respectively. This is shown in table 5.

***Table 5.*** *Amount of observations for the treatment (< 500m of Gaasperdammerweg) and control group (500-1500 meters away from Gaasperdammerweg) for the second analysis.*

| Group | Observations |
|---|---|
| Treatment | 65,176 |
| Control | 157,356 |

This control and effect group are visualized in figure 10.

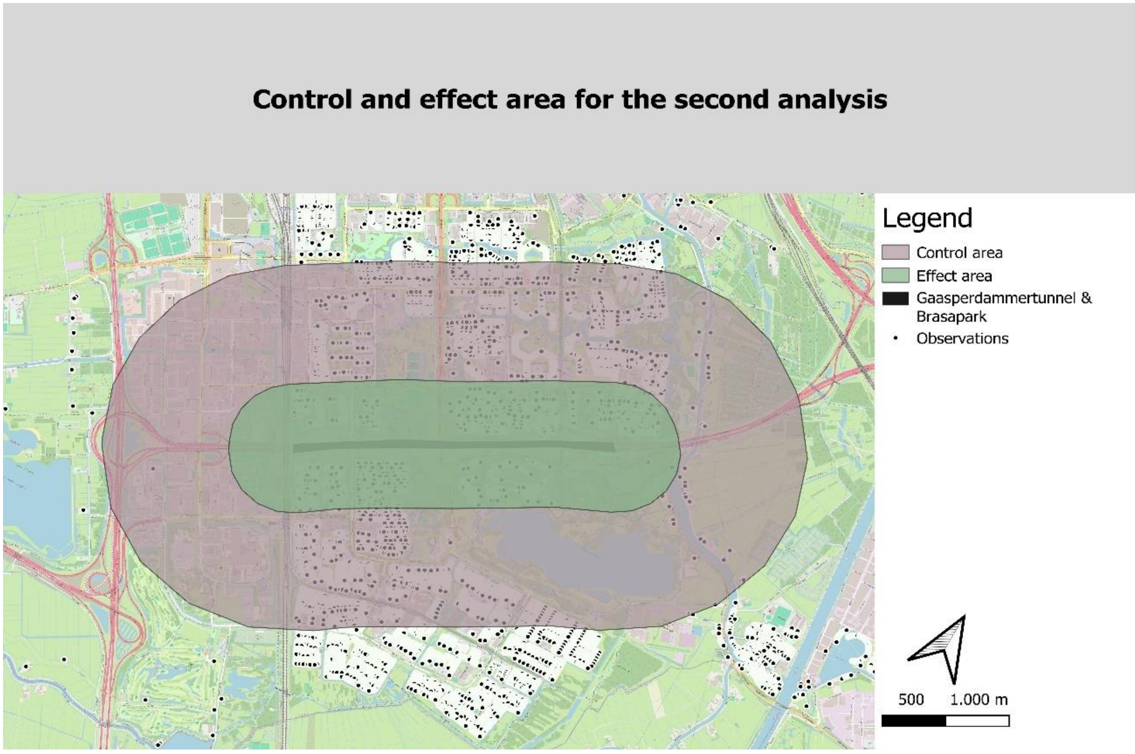


***Figure 10.***

The results of the analysis with the new study area are shown in table 6. The interaction term remains negative and significant across all models. This implies that house prices within 500 meters from the project increased approximately 0.83% to 0.85% less than those 500 to 1500 meters away, post-2016 relative to pre-2016. These findings from the expanded study area are important as they contribute to the robustness and reliability of our primary conclusions. However, Despite the robustness of the results, the small magnitude of the interaction term requires cautious interpretation.

***Table 6.*** *Difference in difference regression results of the new study area*

| Model<br>VARIABLES | (1)<br>Ln of Woz | (2)<br>Ln of Woz | (3)<br>Ln of Woz | (4)<br>Ln of Woz | (5)<br>Ln of Woz |
|---|---|---|---|---|---|
| Treated | -0.0273*** | -0.0112*** | -0.0462*** | -0.0554*** | -0.0601*** |
| | (0.00309) | (0.00320) | (0.00198) | (0.00334) | (0.00196) |
| Post-effect year | 0.474*** | 0.858*** | 0.474*** | 0.858*** | 0.859*** |
| | (0.00200) | (0.00288) | (0.00124) | (0.00281) | (0.00150) |
| Interaction (Treated*Post effect year) | -0.00841** | -0.00851** | -0.00821*** | -0.00838** | -0.00830*** |
| | (0.00373) | (0.00349) | (0.00219) | (0.00338) | (0.00169) |
| Size ($m^2$) | | | 0.00728*** | | 0.00705*** |
| | | | (0.000262) | | (0.000258) |
| ***House type – Reference: Apartment*** | | | | | |
| Semidetached | | | 0.430*** | | 0.430*** |
| | | | (0.0265) | | (0.0198) |
| Corner | | | 0.259*** | | 0.279*** |
| | | | (0.00585) | | (0.00582) |
| Terraced | | | 0.230*** | | 0.248*** |
| | | | (0.00579) | | (0.00601) |
| Detached | | | 0.430*** | | 0.430*** |
| | | | (0.0265) | | (0.0198) |
| ***Construction year – Reference: 1971 – 1990*** | | | | | |
| <1950 | | | 0.0890*** | | 0.0803*** |
| | | | (0.00714) | | (0.00337) |
| 1950 - 1970 | | | -0.0416*** | | 0.00430 |
| | | | (0.00330) | | (0.00322) |
| 1991 - 2010 | | | 0.0737*** | | 0.123*** |
| | | | (0.00447) | | (0.00480) |
| >2010 | | | 0.0956*** | | 0.164*** |
| | | | (0.00774) | | (0.00652) |
| Distance to non-tunnelled primary road | | | | -0.000191*** | -1.06e-05*** |
| | | | | (3.45e-06) | (2.08e-06) |
| Railway closer than 300m | | | | -0.0891*** | -0.0138*** |
| | | | | (0.00145) | (0.000945) |
| Park within 100m (>20ha) | | | | 0.0621*** | -0.0168*** |
| | | | | (0.00314) | (0.00194) |
| **Year fixed effect** | NO | YES | YES | YES | YES |
| **Postcode fixed effect** | NO | YES | YES | YES | YES |
| Constant | 11.83*** | 11.81*** | 11.16*** | 11.95*** | 11.17*** |
| | (0.00166) | (0.00245) | (0.0190) | (0.00319) | (0.0184) |
| Observations | 217,532 | 217,532 | 216,450 | 217,532 | 216,450 |
| R-squared | 0.218 | 0.489 | 0.584 | 0.514 | 0.861 |

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Dependent variable is the natural logarithm of house prices (Woz). The coefficients are the effect of being within 500 meters from the Gaasperdammertunnel and Brasapark within a specified time period compared to houses at 500 to 1500 meters away from the tunnel and park. Heteroskedasticity robust standard errors in parentheses.

# 7. Discussion

The research conducted with the main difference-in-difference (DiD) model to estimate the effect of the tunnelling of the Gaasperdammerweg and the creation of the Brasapark on house prices resulted in the same interaction term across all regressions. Houses within 500 meters of the tunnel and park increased approximately 5.12% less in price compared to house prices 500 to 1500 meters away, after 2016 relative to before 2016. The consistency of the interaction term across regressions is due to the nature of the DiD estimator, which controls for time-invariant differences between the treatment and control groups. Although the post-intervention effect is slightly negative, it is relatively small compared to the variation in other years or postal code areas (Appendix D). Therefore, it is crucial to avoid drawing overly definitive conclusions about the impact of the tunnel and park based on these results.

The inclusion of control variables increased the R-squared value. R-squared measures the proportion of variance in the dependent variable (house prices, in this case) explained by the independent variables in the model. An increase in R-squared indicates that the model with control variables explains more variability in house prices than the model without them. This improvement reflects the model's increased ability to isolate the effect of the treatment (Gaasperdammertunnel and Brasapark project) by controlling for confounding influences.

Despite the main model yielding a consistent negative coefficient for the interaction term, there is some variation in the sensitivity analysis. This suggests that different distances and treatment times result in varied responses of house prices to the Gaasperdammertunnel and Brasapark project. Over different intervals of the project, responses differ too.

The expanded study area analysis, as part of the sensitivity analysis, validates the findings from the main DiD model. In this new analysis, the interaction term (Treated*Post-effect year) remains consistently negative and significant, indicating that house prices within 500 meters of the Gaasperdammertunnel and Brasapark project increased approximately 0.83% to 0.85% less than house prices of houses located 500 to 1500 meters away, post-2016 relative to pre-2016. However, the small magnitude of this effect suggests a modest impact. Therefore, caution is necessary when drawing conclusions about the impact of the Gaasperdammertunnel and Brasapark on house prices. Furthermore, the practical or economic effect of such a small percentage change (0.83% to 0.85%) in house prices might be limited. Policymakers, stakeholders, and researchers should consider whether this effect size is substantial enough to influence decisions or perceptions about the project's impact on the housing market. Additionally, Housing prices are influenced by numerous factors, and isolating the effect of a single project within a complex market can be challenging. Thus, the effect of unobserved factors should be considered.

The results of all models predominantly suggest a negative effect, which has the most significant impact on the houses closest to the project (<500 meters). This negative interaction term contradicts the expectations formed in Chapter 1 and the findings from previous studies on infrastructure tunnelling (Tijm et al., 2018; Van Ruijven & Tijm, 2021). It also does not align with the literature on the effect of parks on houses (Crompton & Nicholls, 2022; Konijnendijk et al., 2013). However, several possible explanations exist.

Firstly, in models like the one performed in this analysis, anticipation effects should be considered. These effects suggest that when a project is announced, the project starts to be capitalized in house prices. Residents anticipate an increase in utility from their homes due to the upcoming highway tunnelling project, driving up the present discounted values of these residences. Numerous studies suggest that anticipation effects are important in house price analysis (Levkovich et al., 2016; Van Ruijven & Tijm, 2021). In this analysis, the irrevocable announcement date of 2012 preceded the starting date of the used data (2014).

However, if the assumption is made that anticipation effects play a role, the negative coefficient can't be explained. If anticipation effects had played a role, an effect of around zero, meaning no difference between treatment and control group, would have been expected. A possible explanation for the negative coefficient could be a market overreaction. The market might have initially overreacted to the perceived benefits of the tunnel, driving up prices prematurely, followed by a correction when the actual benefits did not materialize as expected, which could explain the negative effect of the project in the tested years. Another explanation could be construction disruptions. The construction phase might have caused significant disruptions, leading to temporary or even long-term negative perceptions of the area. Including data points from the announcement date to the completion of the project could control for these anticipation effects, making a more comprehensive analysis.

While the Difference-in-Difference (DiD) methodology effectively controls for time-invariant differences between the treatment and control groups, it does not inherently control for time-variant factors that could influence the outcome variable (Levkovich et al., 2016). Hence, including time-variant variables, such as economic indicators (interest rates, unemployment rates, and average income levels), can improve the robustness of the model. For instance, changes in interest rates over the study period could affect housing prices by altering borrowing costs for homebuyers.

Furthermore, in the current analysis, the treatment area has been defined based on distance in meters from the Gaasperdammertunnel and Brasapark project. However, alternative approaches exist for defining the treatment area. For instance, one could define the treatment area based on environmental factors impacted by the project, such as air quality, noise levels, or visual impact. Alternative approaches may confirm the results or can provide new insights.

Lastly, the current analysis employs Ordinary Least Squares (OLS) regression, which assumes a linear relationship between the independent and dependent variables. However, the relationship between infrastructure projects and house prices may not necessarily be linear. Exploring non-linear relationships could provide a deeper understanding of the effect of the Gaasperdammertunnel and Brasapark on house prices.

# 8. Conclusion

This study found a significant coefficient between the Gaasperdammertunnel and Brasapark development and the nearby housing price in the Amsterdam-Zuidoost area. The study delivered a specific difference in difference model to estimate this effect. The estimated effect of the main model indicates a 5.12% smaller growth in house prices for houses no further than 500 meters away compared to 500 to 1500 meters away, after 2016 relative to before 2016. The study helps in understanding the effect of infrastructure projects over different time intervals on house prices, because of the use of different parameter settings of the DiD model. The sensitivity analysis validated the results by producing many significant negative outcomes for the DiD-estimator. However, the estimated coefficients are small relative to the variation in other model variables. Therefore, caution is necessary when drawing conclusions about the impact of the Gaasperdammertunnel and Brasapark on house prices. With data extending further back in time, the results can be improved or verified.

From an academic standpoint, employing a difference-in-differences model across various time spans and distances to analyse the influence of the Gaasperdammertunnel and Brasapark project on housing prices establishes a comprehensive framework for future research in the field of infrastructure valuation. This approach could also be applied to other research areas focused on the economic valuation of urban projects. Additionally, this study paves the way for further investigation into how different characteristics of infrastructure projects, such as tunnelling and park development, affect property values. Expanding this research could provide deeper insights into the economic impacts of urban development projects, thereby informing more effective urban planning and policy decisions.

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# Appendix A

**Pairwise correlations table 1. Continuous and dichotomous variables**

| Variables | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| (1) size | 1.000 | | | |
| (2) near railroad | -0.089*** | 1.000 | | |
| | (0.000) | | | |
| (3) near largepark | 0.164*** | -0.150*** | 1.000 | |
| | (0.000) | (0.000) | | |
| (4) distance primaryroad | -0.084*** | 0.273*** | 0.165*** | 1.000 |
| | (0.000) | (0.000) | (0.000) | |

*** *p<0.01, ** p<0.05, * p<0.1*

**Cramer's V table 1. Construction year cat, housing type**

| | Housing type | | | | | |
|---|---|---|---|---|---|---|
| Construction year cat | Apartmnt | Semidet. | Corner | Terraced | Detached | Total |
| < 1950 | 1746 | 18 | 0 | 0 | 9 | 1773 |
| 1950 - 1970 | 25677 | 0 | 0 | 0 | 9 | 25686 |
| 1971 - 1990 | 48978 | 207 | 3213 | 10764 | 36 | 63198 |
| 1991 - 2010 | 20025 | 117 | 3078 | 13770 | 63 | 37053 |
| > 2010 | 2394 | 9 | 18 | 162 | 36 | 2619 |
| Total | 98820 | 351 | 6309 | 24696 | 153 | 130329 |

Cramér's V = 0.1931 , Pr = 0.000

**Cramer's V table 2. Construction year cat, near railroad**

| | Near railroad | | |
|---|---|---|---|
| Construction year cat | NO | YES | Total |
| < 1950 | 1773 | 0 | 1773 |
| 1950 - 1970 | 15831 | 9855 | 25686 |
| 1971 - 1990 | 39213 | 23985 | 63198 |
| 1991 - 2010 | 24138 | 12915 | 37053 |
| > 2010 | 819 | 1800 | 2619 |
| Total | 81774 | 48555 | 130329 |

Cramér's V = 0.1323 , Pr = 0.000

**Cramer's V table 3. Construction year cat, near largepark**

| | Large park within 100m | | |
|---|---|---|---|
| Construction year cat | NO | YES | Total |
| < 1950 | 1728 | 45 | 1773 |
| 1950 - 1970 | 23337 | 2349 | 25686 |
| 1971 - 1990 | 57186 | 6012 | 63198 |
| 1991 - 2010 | 34092 | 2961 | 37053 |
| > 2010 | 2583 | 36 | 2619 |
| Total | 118926 | 11403 | 130329 |

Cramér's V = 0.0512 , Pr = 0.000

**Cramer's V table 4. Housing type, near railroad**

| Housing type | Railroad within 300m NO | YES | Total |
|---|---|---|---|
| Apartment | 54864 | 43956 | 98820 |
| Semidetached | 333 | 18 | 351 |
| Corner | 5328 | 981 | 6309 |
| Terraced | 21096 | 3600 | 24696 |
| Detached | 153 | 0 | 153 |
| Total | 81774 | 48555 | 130329 |

Cramér's V = 0.2651 , Pr = 0.000

**Cramer's V table 5. Housing type, near largepark**

| Housing type | Large park within 100m NO | YES | Total |
|---|---|---|---|
| Apartment | 94725 | 4095 | 98820 |
| Semidetached | 171 | 180 | 351 |
| Corner | 4752 | 1557 | 6309 |
| Terraced | 19233 | 5463 | 24696 |
| Detached | 45 | 108 | 153 |
| Total | 118926 | 11403 | 130329 |

Cramér's V = 0.2995 , Pr = 0.000

**Pairwise correlations**

| Variables | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) | (16) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) size | 1.000 | | | | | | | | | | | | | | | |
| (2) near_railroad | -0.089*** | 1.000 | | | | | | | | | | | | | | |
| | (0.000) | | | | | | | | | | | | | | | |
| (3) near_largepark | 0.164*** | -0.150*** | 1.000 | | | | | | | | | | | | | |
| | (0.000) | (0.000) | | | | | | | | | | | | | | |
| (4) distance_prima~d | -0.084*** | 0.273*** | 0.165*** | 1.000 | | | | | | | | | | | | |
| | (0.000) | (0.000) | (0.000) | | | | | | | | | | | | | |
| (5) housing_type_d~1 | -0.467*** | 0.265*** | -0.289*** | 0.216*** | 1.000 | | | | | | | | | | | |
| | (0.000) | (0.000) | (0.000) | (0.000) | | | | | | | | | | | | |
| (6) housing_type_d~2 | 0.088*** | -0.035*** | 0.078*** | 0.047*** | -0.092*** | 1.000 | | | | | | | | | | |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | | | | | | | | | | | |
| (7) housing_type_d~3 | 0.203*** | -0.101*** | 0.127*** | -0.073*** | -0.399*** | -0.012*** | 1.000 | | | | | | | | | |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | | | | | | | | | | |
| (8) housing_type_d~4 | 0.380*** | -0.227*** | 0.229*** | -0.204*** | -0.856*** | -0.025*** | -0.109*** | 1.000 | | | | | | | | |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | | | | | | | | | |
| (9) housing_type_d~5 | 0.087*** | -0.026*** | 0.075*** | 0.011*** | -0.061*** | -0.002 | -0.008*** | -0.017*** | 1.000 | | | | | | | |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.520) | (0.005) | (0.000) | | | | | | | | |
| (10) constr_year_d~1 | -0.079*** | -0.090*** | -0.026*** | 0.014*** | 0.062*** | 0.017*** | -0.026*** | -0.057*** | 0.013*** | 1.000 | | | | | | |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | | | | | | | |
| (11) constr_year_d~2 | -0.041*** | 0.011*** | 0.007** | 0.173*** | 0.279*** | -0.026*** | -0.112*** | -0.240*** | -0.012*** | -0.058*** | 1.000 | | | | | |
| | (0.000) | (0.000) | (0.012) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | | | | | | |
| (12) constr_year_d~3 | -0.303*** | 0.014*** | 0.026*** | 0.045*** | 0.038*** | 0.011*** | 0.011*** | -0.047*** | -0.017*** | -0.114*** | -0.481*** | 1.000 | | | | |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | | | | | |
| (13) constr_year_d~4 | 0.376*** | -0.031*** | -0.017*** | -0.175*** | -0.321*** | 0.006** | 0.102*** | 0.293*** | 0.010*** | -0.074*** | -0.312*** | -0.612*** | 1.000 | | | |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.041) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | | | | |
| (14) constr_year_d~5 | 0.053*** | 0.093*** | -0.037*** | -0.101*** | 0.052*** | 0.002 | -0.028*** | -0.047*** | 0.053*** | -0.017*** | -0.071*** | -0.139*** | -0.090*** | 1.000 | | |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.458) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | | | |
| (15) treated | 0.037*** | 0.123*** | -0.097*** | -0.381*** | -0.146*** | 0.023*** | 0.086*** | 0.110*** | -0.001 | -0.067*** | -0.281*** | 0.300*** | -0.084*** | 0.057*** | 1.000 | |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.806) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | | |
| (16) control | -0.037*** | -0.123*** | 0.097*** | 0.381*** | 0.146*** | -0.023*** | -0.086*** | -0.110*** | 0.001 | 0.067*** | 0.281*** | -0.300*** | 0.084*** | -0.057*** | -1.000 | 1.000 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.806) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (1.000) | |

**** $p<0.01$, ** $p<0.05$, * $p<0.1$*

## Appendix B

***Appendix B table 1**. Sensitivity analysis using effect year 2016*

| Model<br>VARIABLES | (1)<br>Ln of Woz | (2)<br>Ln of Woz | (3)<br>Ln of Woz | (4)<br>Ln of Woz | (5)<br>Ln of Woz |
|---|---|---|---|---|---|
| Treated | -0.0504*** | 0.208*** | -0.128*** | 0.0471*** | 0.124*** |
| | (0.00410) | (0.00451) | (0.00325) | (0.00324) | (0.00384) |
| Post-effect year | 0.507*** | 0.524*** | 0.508*** | 0.524*** | 0.554*** |
| | (0.00346) | (0.00440) | (0.00345) | (0.00341) | (0.00291) |
| Interaction (Treated*post-effect year) | -0.0282*** | -0.0450*** | 0.0165*** | 0.000267 | -0.0755*** |
| | (0.00535) | (0.00601) | (0.00422) | (0.00418) | (0.00502) |
| Constant | 11.91*** | 11.65*** | 11.91*** | 11.74*** | 11.74*** |
| | (0.00266) | (0.00325) | (0.00266) | (0.00265) | (0.00222) |
| Observations | 83,277 | 63,675 | 130,329 | 146,232 | 79,182 |
| R-squared | 0.279 | 0.303 | 0.328 | 0.292 | 0.356 |

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Dependent variable is the natural logarithm of house prices (Woz). The coefficients are the effect of being within a certain amount of meters from the Gaasperdammertunnel and Brasapark within a specified time period compared to houses at a certain amount of meters away from the tunnel. Heteroskedasticity robust standard errors in parentheses.

In appendix table 1 the following scenario's were used:

Model 1: Treatment group includes houses within 500 meters of the Gaasperdammerweg, and the control group includes houses situated between 1000-1500 meters.

Model 2: Treatment group includes houses within 500 meters of the Gaasperdammerweg, and the control group includes houses situated between 2000-2500 meters.

Model 3: Treatment group includes houses within 1000 meters of the Gaasperdammerweg, and the control group includes houses situated between 1000-1500 meters.

Model 4: Treatment group includes houses within 1000 meters of the Gaasperdammerweg, and the control group includes houses situated between 1500-2500 meters.

Model 5: Treatment group includes houses within 500 meters of the Gaasperdammerweg, and the control group includes houses situated between 500-1000 meters.

***Appendix B table 2.*** *Sensitivity analysis using effect year 2017*

| VARIABLES | (1)<br>Ln of Price | (2)<br>Ln of Woz | (3)<br>Ln of Woz | (4)<br>Ln of Woz | (5)<br>Ln of Woz |
|---|---|---|---|---|---|
| Treated | 0.0298*** | -0.0489*** | 0.206*** | -0.122*** | 0.0497*** |
| | (0.00322) | (0.00365) | (0.00408) | (0.00289) | (0.00289) |
| Post-effect year | 0.542*** | 0.522*** | 0.535*** | 0.522*** | 0.536*** |
| | (0.00222) | (0.00331) | (0.00432) | (0.00330) | (0.00326) |
| Interaction | -0.0569*** | -0.0365*** | -0.0497*** | 0.00979** | -0.00427 |
| (Treated*Post-effect year) | (0.00453) | (0.00515) | (0.00585) | (0.00403) | (0.00400) |
| Constant | 11.88*** | 11.96*** | 11.71*** | 11.96*** | 11.79*** |
| | (0.00161) | (0.00236) | (0.00298) | (0.00236) | (0.00236) |
| Observations | 130,329 | 83,277 | 63,675 | 130,329 | 146,232 |
| R-squared | 0.360 | 0.324 | 0.343 | 0.376 | 0.337 |

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Dependent variable is the natural logarithm of house prices (Woz). The coefficients are the effect of being within a certain amount of meters from the Gaasperdammertunnel and Brasapark within a specified time period compared to houses at a certain amount of meters away from the tunnel. Heteroskedasticity robust standard errors in parentheses.

In appendix table 2 the following scenario's were used:

Model 1: Treatment group includes houses within 500 meters of the Gaasperdammerweg, and the control group includes houses situated between 500-1500 meters.

Model 2: Treatment group includes houses within 500 meters of the Gaasperdammerweg, and the control group includes houses situated between 1000-1500 meters.

Model 3: Treatment group includes houses within 500 meters of the Gaasperdammerweg, and the control group includes houses situated between 2000-2500 meters.

Model 4: Treatment group includes houses within 1000 meters of the Gaasperdammerweg, and the control group includes houses situated between 1000-1500 meters.

Model 5: Treatment group includes houses within 1000 meters of the Gaasperdammerweg, and the control group includes houses situated between 1500-2500 meters.

***Appendix B table 3.*** *Sensitivity analysis using effect year 2020*

| VARIABLES | (1)<br>Ln of Woz | (2)<br>Ln of Woz | (3)<br>Ln of Woz | (4)<br>Ln of Woz | (5)<br>Ln of Woz |
|---|---|---|---|---|---|
| Treated | 0.00540* | -0.0627*** | 0.188*** | -0.115*** | 0.0531*** |
| | (0.00290) | (0.00328) | (0.00370) | (0.00262) | (0.00255) |
| Post-effect year | 0.492*** | 0.489*** | 0.502*** | 0.489*** | 0.508*** |
| | (0.00268) | (0.00393) | (0.00546) | (0.00392) | (0.00394) |
| Interaction | -0.0327*** | -0.0293*** | -0.0424*** | -0.00750 | -0.0263*** |
| (Treated*Post-effect year) | (0.00554) | (0.00624) | (0.00731) | (0.00485) | (0.00486) |
| Constant | | | | | |
| | 12.07*** | 12.14*** | 11.89*** | 12.14*** | 11.98*** |
| | (0.00147) | (0.00212) | (0.00273) | (0.00212) | (0.00204) |
| Observations | | | | | |
| R-squared | 130,329 | 83,277 | 63,675 | 130,329 | 146,232 |

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

Dependent variable is the natural logarithm of house prices (Woz). The coefficients are the effect of being within a certain amount of meters from the Gaasperdammertunnel and Brasapark within a specified time period compared to houses at a certain amount of meters away from the tunnel. Heteroskedasticity robust standard errors in parentheses.

In appendix table 3 the following scenario's were used:

Model 1: Treatment group includes houses within 500 meters of the Gaasperdammerweg, and the control group includes houses situated between 500-1500 meters.

Model 2: Treatment group includes houses within 500 meters of the Gaasperdammerweg, and the control group includes houses situated between 1000-1500 meters.

Model 3: Treatment group includes houses within 500 meters of the Gaasperdammerweg, and the control group includes houses situated between 2000-2500 meters.

Model 4: Treatment group includes houses within 1000 meters of the Gaasperdammerweg, and the control group includes houses situated between 1000-1500 meters.

Model 5: Treatment group includes houses within 1000 meters of the Gaasperdammerweg, and the control group includes houses situated between 1500-2500 meters.

# Appendix C

The used Stata code is given in the following Stata 17 command prompt.

```
* i reshaped my old dataset to a new panel data one
reshape long woz, i(id) j(year)

* This is with the new dataset
import delimited "C:\Users\Tim\Documents\Jaar 3\Scriptie\Data-scriptie\Final-dataset-clipped1-wide-to-long-V3-gaasperdammerwegVersie.csv"

* Test on correlation between independent variables
* Command 'pwcorr' to calculate correlations between dichotomous or ordinal variables and continuous variables
pwcorr size near_railroad near_largepark distance_primaryroad, sig

* Nominal Variables
tabulate constr_year_cat housing_type, V
tabulate constr_year_cat near_railroad, V
tabulate constr_year_cat near_largepark, V
tabulate housing_type near_railroad, V
tabulate housing_type near_largepark, V


* Set the reference category for 'housing_type' to 'Apartment'
fvset base 1 housing_type
* Set the reference category for 'year' to '2014'
fvset base 2014 year
* Set the reference category for 'constr_year_cat' to 1971- 1990
fvset base 3 constr_year_cat

* Cut-off the control group for 1500 meters
keep if distance_gaasperdammerweg <= 1500
* Generate post effect year time variable
gen post_effectyear = 0
replace post_effectyear = 1 if year > 2017
* Define treatment area
gen treated = 0
replace treated = 1 if distance_gaasperdammerweg < 500

* Generate interaction term
gen interaction = treated * post_effectyear
* Generate log of price
gen ln_price = log(woz)
* Make dummys for postcode
destring postcode_numeric , generate(postcode_num2)
fvset base 1103 postcode_num2

* Make the regression model
regress ln_price treated post_effectyear interaction,r
outreg2 using table15.doc, replace
regress ln_price treated post_effectyear interaction i.year i.postcode_num2,r
outreg2 using table15.doc, append
regress ln_price treated post_effectyear interaction i.year i.postcode_num2 size i.housing_type i.constr_year_cat,r
outreg2 using table15.doc, append
regress ln_price treated post_effectyear interaction i.year i.postcode_num2 distance_primaryroad near_railroad near_largepark, r
outreg2 using table15.doc, append
regress ln_price treated post_effectyear interaction i.year i.postcode_num2 size i.housing_type i.constr_year_cat distance_primaryroad near_railroad near_largepark,r
outreg2 using table15.doc, append

* Same as
didregress (ln_price) (interaction), group(distance_gaasperdammerweg) time(year)
* Parallel trends graph
estat trendplots

*VIF test
vif
*Heteroskedasticity test.
hettest

* Make a descriptive statistics table
asdoc sum woz ln_price year housing_type size constr_year_cat distance_gaasperdammerweg distance_primaryroad near_largepark near_railroad postcode_num2

* Sensitivity analysis was done by changing keep if command (keep if (distance_gaasperdammerweg)), by changing treated variable, and by changing the post_effectyear variable
```

# Appendix D

**Appendix D table 1.** Year and postal code effects of the base model.

| Model<br>VARIABLES | (2)<br>Ln of Woz | (3)<br>Ln of Woz | (4)<br>Ln of Woz | (5)<br>Ln of Woz |
|---|---|---|---|---|
| Post-effect year | 0.530*** | 0.872*** | 0.872*** | 0.872*** |
| | (0.00234) | (0.00391) | (0.00197) | (0.00365) |
| **Year dummies – Reference: 2014** | | | | |
| 2015 | 0.0287*** | 0.0287*** | 0.0287*** | 0.0287*** |
| | (0.00378) | (0.00172) | (0.00353) | (0.00171) |
| 2016 | 0.0891*** | 0.0891*** | 0.0891*** | 0.0891*** |
| | (0.00376) | (0.00178) | (0.00351) | (0.00176) |
| 2017 | -0.614*** | -0.614*** | -0.614*** | -0.614*** |
| | (0.00373) | (0.00191) | (0.00351) | (0.00188) |
| 2018 | -0.451*** | -0.451*** | -0.451*** | -0.451*** |
| | (0.00386) | (0.00208) | (0.00361) | (0.00203) |
| 2019 | -0.299*** | -0.299*** | -0.299*** | -0.299*** |
| | (0.00387) | (0.00205) | (0.00361) | (0.00201) |
| 2020 | -0.254*** | -0.254*** | -0.254*** | -0.254*** |
| | (0.00383) | (0.00198) | (0.00357) | (0.00194) |
| 2021 | -0.197*** | -0.197*** | -0.197*** | -0.197*** |
| | (0.00377) | (0.00193) | (0.00352) | (0.00190) |
| 2022 (omitted) | - | - | - | - |
| **Postal code dummies – Reference: 1103** | | | | |
| 1102 | -0.0319*** | 0.0553*** | -0.101*** | 0.0490*** |
| | (0.00238) | (0.00151) | (0.00205) | (0.00184) |
| 1104 | -0.0827*** | -0.0102*** | -0.172*** | -0.0157*** |
| | (0.00249) | (0.00193) | (0.00225) | (0.00149) |
| 1112 | 0.562*** | 0.142*** | 0.196*** | 0.0582 |
| | (0.0370) | (0.0447) | (0.0372) | (0.0432) |

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

**Note**: Due to a software issue, the 2022 dummy was omitted. Be cautious in interpreting the year coefficients because of this. The prices from 2017 and onward are now the combination of the post-treatment effect and the specific year effect. For 2017, this looks as follows: post-treatment effect: 0.872, minus year effect: -0.614, resulting in 0.258. The year dummies for 2015 and 2016 are correctly defined.