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The impact of tunnelling existing transport infrastructure on liveability and residential attractiveness: An analysis of property price effects in the Netherlands

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ABSTRACT

This study investigates the impact of tunnelling existing transportation infrastructure on liveability and residential attractiveness. As urban areas worldwide face increasing pressure on public spaces, underground infrastructure has emerged as a preferred solution to reshape urban environments, mitigate environmental challenges, and enhance the quality of life and public spaces. Utilising a difference-in-difference hedonic regression analysis, the study assesses property price effects around six tunnelling projects in the Netherlands: Gaasperdammertunnel, Koning Willem-Alexandertunnel, Salland-Twentetunnel, Limesaquaduct, Spoortunnel Best, and Kap van Barendrecht. The dataset includes 12,102 residential property transactions between April 1995 and January 2024. The findings indicate a significant positive effect on property prices within 600 metres of the tunnels post-construction, with prices increasing by approximately 16.77%. However, the positive effect diminishes with distance, highlighting the spatial attenuation of these benefits. During the construction phase, no significant anticipation effects were observed. The study further reveals a heterogeneous impact, with urban areas experiencing a more substantial positive effect post-construction compared to suburban and rural regions. This underscores the importance of context-specific planning and policy-making in urban development. The insights provided can guide future infrastructure projects and urban policy decisions, emphasising the value of tunnelling as a strategy for enhancing urban liveability.

Keywords: infrastructure tunnelling, external effects, residential real estate, property prices, transport, difference-in-difference

CONTENTS

1. INTRODUCTION

1.1 Motivation

Urban areas worldwide face increasing pressure on public space due to population growth, urbanisation, and the intensification of human activities. These persistent challenges necessitate an urgent shift towards more sustainable and efficient use of existing urban spaces (Cui et al., 2021). As the urban population grow and cities expand, the demand for high-quality, accessible public spaces becomes increasingly pressing, underscoring the need for sustainable urban planning and highlights the importance of improving residents' quality of life (Takano et al., 2023). Recognising the direct impact of public space on residents' well-being and overall satisfaction with urban life (Weijs-Perrée et al., 2019), urban planners and policymakers prioritise strategies that enhance the livability of cities (Mouratidis, 2021; Lin et al., 2022). Previous studies indicate that utilising underground space holds the potential to contribute to sustainable urban development (Sterling et al., 2012; Cui & Lin, 2016), enhancing city resiliency (Sterling & Nelson, 2013), creating livable cities (Hunt et al., 2016), and restoring natural landscape and ecology (Cui et al., 2021). As urban space becomes increasingly limited and costly, the use of underground spaces is emerging as a preferred solution for implementing infrastructure in (sub)urban settings, aimed at reshaping current urban environments, addressing environmental problems, and incorporating new functions into the existing urban landscape (Broere, 2016). The foundation of this innovative idea is rooted in the evolving perspectives on transportation infrastructure. There is a growing awareness that infrastructures act as physical barriers, fragmenting urban landscapes; it also raises environmental concerns like noise and air pollution and contributes to urban landscape degradation. This has amplified the demand for less intrusive infrastructure solutions, particularly among nearby residents (Chang et al., 2014; Cui & Nelson, 2019).

Traditionally, the primary aim of infrastructure was to reduce travel time. However, contemporary priorities have shifted towards mitigating negative externalities and optimising space usage (Badland et al., 2014). In recent years, many cities have undertaken projects to tunnel, lower, or cover existing infrastructure, thereby improving the quality of life and enhancing public spaces (Van Ruijven et al., 2018). Despite these efforts, there remains a lack of understanding regarding the value residents place on liveability improvements resulting from these tunnelling infrastructure projects. This study aims to empirically assess the value residents place on improved livability and residential attractiveness due to relocating transport infrastructure into tunnels.

Changes in residential property prices are utilised as a metric to capture the effects of liveability improvements. This approach is based on the premise that fluctuations in property prices reflect residents' valuation of enhanced liveability and the attractiveness of the area (see e.g. McDonald 2012; Liu, 2020). An increase in property prices signifies elevated demand, suggesting that these improvements have made the location more desirable to residents, thus providing a quantifiable measure of the area's improved liveability and overall appeal.

1.2 Literature review

The effects of negative externalities, such as noise and air pollution from transport infrastructure, on the prices of adjacent residential properties have been subject to comprehensive examination over the preceding years (Poon, 1978; Nelson, 1982; Al-Mosaind et al., 1993; Wilhelmsson, 2000; Theebe, 2004; Blanco & Flindell, 2011; Lowicki & Piotrowska, 2015; Walker, 2016). Also, the accessibility effects of transport infrastructure have been established well in the literature (Mikelbank, 2004; Debrezion et al., 2011; Tillema et al., 2012; Redding & Turner, 2015). However, little is known about the externality effects of infrastructure projects on a residential area's liveability and attractiveness. A clean identification of these externalities is challenging. Several studies have examined the spatial impact of new infrastructure developments on property prices (see e.g. Debrezion et al., 2007; Levkovich et al., 2016), but cannot disentangle accessibility and externality effects. Other studies have predominantly concentrated on noise and pollution or travel-savings data, to explain their effect on property prices (Day et al., 2007; Kim et al., 2007; Chang & Kim, 2013; Hoogendoorn et al., 2017). However, without quasi-experimental variation in the level of externalities, the results are likely to suffer from omitted variable bias as unobserved neighbourhood characteristics tend to be correlated with both, the property prices and other externalities (see e.g. Greenstone & Gayer, 2009; Boes & Nüesch, 2011; Zheng et al., 2020).

A limited number of studies have examined projects that simultaneously reposition existing infrastructure, enhance public space, and reduce negative traffic externalities with minimal changes in accessibility. Ossokina and Verweij (2015) provide valuable insights into the effect of traffic externalities on nearby property prices, based on the construction of a new ring-road in The Hague. Despite reduced traffic on former routes, local accessibility remains largely unchanged. Their findings indicate a negative relation between traffic intensity and property prices, particularly in areas with initially higher traffic density. Similarly, Ahlfeldt et al. (2016) investigate the effect of Berlin's metro line on nearby property prices by distinguishing between accessibility and nuisance. Elevated and underground metro stations confer identical accessibility benefits, but elevated sections exhibit higher noise levels. A 10 decibel (dB) noise increase correlates with a 1% decrease in property prices. Their study reveals underestimations in the effects of accessibility (40%) and nuisance (80%) when not considered together. While the above studies modelled the price effects of removing transport nuisances, they have not addressed the effects of improving public areas. The projects investigated lacked the objective of implementing new functions or adding green amenities, leaving a gap in understanding their effects.

The academic literature lacks comprehensive quantification of the externality effects of relocating existing infrastructure beyond noise and air pollution. Tajima (2003) assessed the value of proximity to parks and urban highways around the completion of the 'Big Dig' project in Boston, predicting the future economic effects of replacing the elevated highway with a tunnel and park before the project's completion. Her findings indicated an increase in property prices in the vicinity of parks (Tajima, 2003), but her cross-sectional approach struggled to account for unobserved location characteristics and cannot separate travel time and other externality effects (Tijm et al., 2019). Diao et al. (2016) investigated the impact of the cessation of the KTM railroad in Singapore, revealing a 13.7% increase in property prices within a 400-metre radius of the former railroad route. The study's primary focus was on evaluating how the reduction of traffic-related disadvantages influenced property prices. However, it did not explore the broader implications of redeveloping public green spaces on the former railroad route. Kang & Cervero (2008) look into the externality effects of dismantling the 'Cheong Gye Cheon' elevated highway in Seoul, replacing it with a urban stream and green park. Their study revealed land value increases within a 500-metre radius of the newly established urban stream and green park. However, it remains ambiguous whether these increases were attributable to the redevelopment of the public space or the alleviation of noise and other negative externalities. This ambiguity is further compounded by the study's short-term focus, as it only considered data from the first year following the project's completion (van Eldijk et al., 2022). Chang et al. (2014) further this discussion by quantifying the effects of relocating the 'Yongsan rail line' to a tunnel in Seoul. Their analysis leverages specific data to distinguish and individually estimate various society benefits. Specifically, their study assesses four externalities: noise pollution, grade separation, urban fragmentation, and landscape degradation. Notably, Chang et al. (2014) do not investigate the effect on property prices; instead, they focus on the number of individuals impacted by these externalities. The ex-post valuation of liveability improvements of such projects' public space redevelopment remains underexplored.

To the best of my knowledge, the only empirical study that has endeavored to quantify the value residents place on the externality effects of relocating existing infrastructure into a tunnel—and how these effects contribute to improving quality of life—is Tijm et al. (2019). This study employs the distance of a residence to the tunnel and property prices as proxies to measure these effects. They examined the relocation of the A2 highway in Maastricht, the Netherlands, which was moved underground to mitigate the negative effects of an open urban highway. While travel times remained largely unaffected, significant benefits were observed, notably an increase in property prices. Specifically, halving the distance to the tunnel correlated with a 3.4% rise in property prices. The study, however, was conducted merely nine months after the tunnel's completion, when the redevelopment of the public space above the tunnel was still under construction, leading to an incomplete assessment of the long-term impacts. As a result, their ex-post evaluation likely underestimated the actual benefits to the quality of life (Bos & de Swart, 2024), capturing primarily the anticipation effect rather than the full range of liveability benefits. Hence, a comprehensive ex-post assessment, particularly in terms of enhancing urban environment and liveability, remains pending and is yet to be thoroughly ascertained.

This study aims to fill this gap by empirically assessing the comprehensive ex-post valuation that residents place on improvements in the liveability and attractiveness of their residential areas resulting from the relocation of transport infrastructure into tunnels and the redevelopment of public green spaces.

1.3 Research problem statement

Existing literature indicates that there is an impact of infrastructure developments on socio-economic activities, land use, and residential attractiveness. Tunnelling existing infrastructure has emerged as a preferred solution to reshape urban environments, mitigate environmental challenges, and enhance the quality of life and public spaces. Despite this growing interest, limited academic literature explicitly examines the comprehensive ex-post valuation of such projects on residential property prices. A solitary case study delved into this topic, solely examining the short-term effects, casting doubt on the extent to which the results are applicable to broader contexts. The comprehensive ex-post effect of infrastructure tunnelling projects on liveability and residential attractiveness remains unclear, while research on this issue is of profound importance for various policy and market respects. The aim of this study is to investigate the full ex-post relationship between the relocation of infrastructure projects into tunnels and the attractiveness of residential areas. Property prices are used as a metric to measure these effects. Specifically, the study examines the effect of six tunnelling projects in the Netherlands—Gaasperdammertunnel, Koning Willem-Alexandertunnel, Salland- Twentetunnel, Limeaquaduct, Spoortunnel Best, and Kap van Barendrecht—on potential externalities across spatial and temporal dimensions. Transitioning from above-surface transport infrastructure configurations to tunnelling alternatives within the same location is complex and costly (Broere, 2016). Given the substantial public investments involved, for instance, ranging from €330 million in Nijverdal to €1,200 million in Maastricht, it is crucial for planners and investors to understand the quantitative effects of such projects on nearby property prices. This insight can substantiate decision-making processes and facilitate trade-offs in the planning stage of spatial initiatives. This study tries to answer the research question: *What value do residents attach to liveability improvement due to the relocation of existing transport infrastructure into a tunnel and the implementation of new green space?*

To adequately answer the research question, the following subjects need to be taken into account:

- *SQ1*: How do tunnelling infrastructure projects impact external factors such as noise reduction, air quality improvement, preservation of green spaces, and neighbourhood connectivity, and how do these changes affect liveability of residential areas and subsequently reflect in property prices?
- *SQ2*: To what extent are residential property prices influenced by infrastructure tunnelling projects?
- *SQ3*: What is the difference in effect in urban and suburban-rural regions?

1.4 Structure

The organisation of the paper is structured as follows. Section 2 offers insight into the externalities associated with tunnelling existing transport infrastructure and combines insights from Hedonic theory to provide a conceptual framework. Section 3 describes the data and presents the Difference-in-Difference (DID) empirical model used in the analysis. Subsequently, the results and sensitivity analysis are reported in Section 4. The discussion is provided in Section 5, and Section 6 concludes.

2. THEORICAL FRAMEWORK

This section explores the hypothetical external effects of relocating infrastructure into tunnels, focusing on noise reduction, improved air quality, preservation of green spaces, and enhanced neighborhood connectivity. It further examines how these factors influence liveability and their subsequent reflection on property prices.

2.1 Infrastructure tunnelling and liveability

Underground transportation infrastructure is widely acknowledged for its ability to mitigate noise pollution compared to surface-level infrastructure (Broere, 2016). Noise pollution poses a substantial concern, creating undesirable disturbances in people's daily lives, causing physiological and psychological harm to individuals (Welch et al., 2023). The physical barrier provided by underground structures serves as an effective sound and vibration insulation mechanism, reducing the propagation of traffic-generated noise and thereby minimising its direct impact on adjacent communities (Bosch et al., 2011). For instance, the tunnelling of the A2 highway in Maastricht has led to a notable noise reduction of between 5 and 20 dB (Atlas Living Environment, 2019), thereby improving the quality of life for nearby residents. Stansfeld et al. (2009) assert that a reduction in traffic noise levels by 4 dB or more is sufficient to positively impact mental health and diminish the annoyance of nearby residents. Furthermore, reduced traffic noise contributes to improving residents' overall quality of life (Botteldooren et al., 2011), and enhances human health and well-being by mitigating noise's adverse effects on physical and mental health (Hegewald et al., 2020; Khomenko et al., 2022). Thus, using infrastructure tunnels presents opportunities for communities to create a more pleasant and peaceful living environment.

With the increasing recognition of the adverse effects of vehicle-induced air pollution, tunnelling is likewise perceived as a potential solution to redress the health and environmental impacts associated with transport infrastructure (Cui & Nelson, 2019). For residents living near transportation infrastructure, tunnelling practice holds substantial implications for addressing air pollution and its attendant adverse health consequences, such as exacerbation of asthma, impairment of lung function, cardiovascular ailments, and respiratory mortality (Brauer et al., 2008; Manisalidis et al., 2020). Studies indicate that the removal of transportation infrastructure or the implementation of tunnelling techniques can substantially reduce the concentrations and distribution of traffic-related air pollution (Tuchschmid et al., 2011; Cowie et al., 2012; Zhou et al., 2014; Patterson & Harley, 2019). For instance, in Maastricht, the tunnel has led to a substantial reduction in the amount of nitrogen and particulate matter in the area (Atlas Living Environment, 2019). The improvement in air quality can contribute to the creation of a more liveable and healthier living environment (Nieuwenhuijsen, 2020).

In addition, tunnelling infrastructure presents opportunities to enhance urban functionality while preserving heritage or the surface environment. It enables long-term environmental improvements, more efficient use of space, and recourse in public space (Broere, 2016; Cui & Nelson, 2019). In fact, underground developments, such as tunnels, have been dubbed as "green roofs" due to their potential to restore the natural landscape and ecology (Cui et al., 2021). Parks and green spaces, repurposed from existing infrastructure, are recognised for their ability to stimulate the property markets in their vicinities. They serve as catalysts for revitalisation efforts, contributing to neighbourhood amenity improvement and enhancing liveability (Tyler et al., 2012). The proximity to newly developed green spaces has the potential to enhance the appeal of a neighbourhood to prospective buyers and tenants (Mokhtarian et al., 2008). Such proximity to green spaces confers a multitude of advantages, encompassing enhancements in physical and mental well-being (Bell et al., 2015), fostering social cohesion (Frumkin et al., 2004), and providing aesthetic satisfaction. Incorporating green spaces within a neighbourhood can improve the appearance and atmosphere of a neighbourhood, thereby rendering it a more attractive and appealing place to live (Chen et al., 2021). These externalities associated with the presence of new green spaces raise the overall quality of life, thereby augmenting the neighbourhood's attractiveness.

Tunnelling transport infrastructure also establishes a physical connection between neighbourhoods that were previously separated by surface-level infrastructure (Lin et al., 2022). It fosters a sense of practical and conceptual continuity (Perini & Sabbion, 2017). As a connecting element, this infrastructure type contributes to broader urban connectivity and cohesion, creating a more integrated and accessible urban environment for residents (Stehlin, 2023). Cities such as Boston and Madrid, which tunnelled core sections of their transportation infrastructure that previously shadowed and divided neighbourhoods, have seen social improvement (Tajima, 2003; López-de Abajo, 2020).

The implementation of tunnelling infrastructure yields diverse improvements, encompassing noise reduction, improved air quality, preservation of surface green spaces, and facilitation of connectivity between neighbourhoods. These improvements, collectively termed positive externalities, contribute positively to residents' well-being and quality of life without a direct monetary transaction or market exchange. Despite their considerable contribution to neighbourhood liveability, these improvements are not subject to direct payment or explicit pricing within conventional market mechanisms – the beneficiary avails of these benefits without incurring any corresponding fee (Pigou, 1921).

2.2 Property prices and improved liveability

The absence of an explicit market delineating all the externalities associated with the tunnelling of transport infrastructure prohibits a direct assessment of the willingness to pay for an infrastructure tunnelling project. In order to estimate externalities, the literature traditionally leveraged the Hedonic Price Model within urban and real estate economics as a means to infer the value of non-market amenities. With this model, early studies have concentrated on the capitalisation of various environmental factors associated with alterations in current transportation infrastructures (e.g. McMillen, 2004; Boes & Nüesch, 2011; Ossokina & Verweij, 2015; Koemle et al., 2018). The Hedonic Price Model considers the price of a property to be described by a multidimensional vector of structural, spatial, and neighbourhood *n* characteristics (Rosen, 1974). The value assigned to a given property depends on location-specific qualities, ceteris paribus (Chesire & Sheppard, 1995). At its conceptual core, the marginal implicit price of each characteristic can be determined by taking the partial derivation of property price with respect to that specific characteristic, while keeping all else constant (Freeman, 1979). The price difference in properties with similar attributes can be attributed to non-market factors, such as noise and air pollution, as well as the level of location (green) amenities.

Given the absence of an explicit market for assessing the externalities associated with infrastructure tunnelling projects has led to literature relying upon the proximity of residential properties to such projects as a pragmatic substitute for assessing the magnitude of these externalities (e.g. Diao et al., 2016; Tijm et al., 2019). That is, assuming that the external effects of tunnelling projects are denoted as a specific *n* characteristic, the marginal price of these externalities implicitly affects the overall property value, ceteris paribus. Consumers' aversion to negative externalities, such as noise and air pollution, acceptance of nuisance levels hinges on proportional reductions in property prices as compensation (see for instance Theebe, 2004; Bateman et al., 2001).

Figure 1, line A, delineates this idea through the lens of the Hedonic model (Rosen, 1974). Each consumer selects a specific threshold of nuisance, which delineates their indifference curve to align with the marginal price associated with the intensity of nuisance. Proximate residents of transport infrastructure exhibit a willingness to endure diminished housing costs in exchange for tolerating the nuisance. In contrast, those residing farther away incur elevated housing expenditures commensurate with their remoteness from such nuisance, as posited by the Coase theorem (Coase, 1961). The resultant distance gradient represents the equilibrium premium accorded by consumers in tolerating said inconveniences, including the compromised liveability of the public space.

With the implementation of a “tunnel”, a new situation arises, capable of entirely eradicating all nuisances associated with transportation infrastructure while opening up spatial opportunities to establish a new public green space. Initially, this tunnelling project leads to a situation where the intensity of nuisances ceases to be contingent upon proximity to transportation infrastructure. Throughout the construction phase, noise and air pollution are mitigated, thereby improving the living conditions for nearby resident. As a result, the value of nearby property are anticipated to equalise, transitioning from line A to line B. However, the trajectory of line B may not follow a linear path during the construction due to potential nuisance caused by the construction activities. Secondly, the implementation of a tunneling project presents spatial opportunities for creating new green space. Prevailing homeowners, initially located along the hedonic pricing scheme with high nuisance intensity, experience an unexpected improvement in their overall living environment, as discussed in the previous Section 2.1. This, in turn, may stimulate greater interest in local residential properties within the immediate vicinity of a tunnel, increasing property prices and transitioning from line B to line C. Confronted with incongruence between the tangent of the hedonic price schedule and consumers' individual preferences, certain homeowners may elect to relocate to properties that offer optimal levels of preference and valuation.

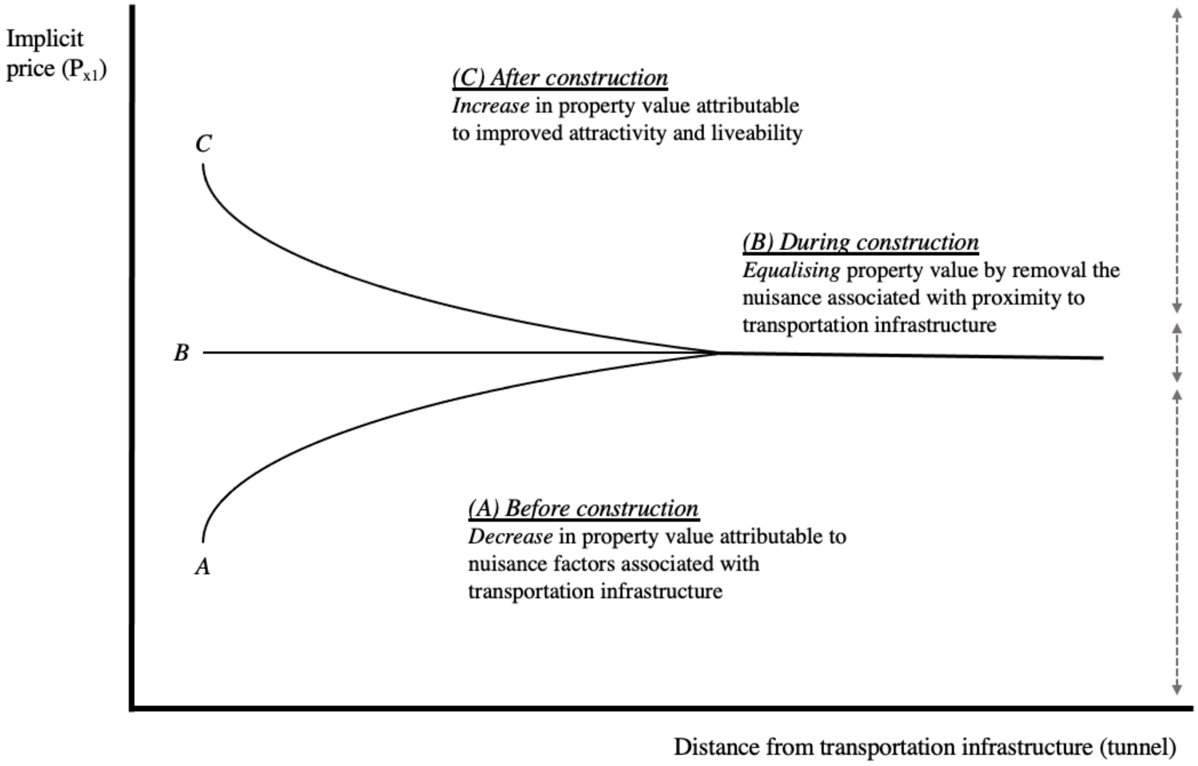

Figure 1. The hedonic price schedule for the external effects of transportation infrastructure

The simultaneous occurrence of the previously described capitalisation effects during the construction and opening of tunnelling projects is improbable. Instead, these effects are likely to manifest gradually over time. The precise timing of the potential capitalisation effect remains uncertain; it is plausible to consider multiple temporal points that could influence it (Schwarz et al., 2006). On the one hand, residents may anticipate the future liveability effects, leading to the capitalisation effect occurring during (anticipation effect) or even before (announcement effect) the commencement of construction work. In addition, the capitalisation effect might only occur post-construction, once the tunnel becomes visible and accessible to the public. On the other hand, the construction process may coincide with nuisance factors, including noise and disruption, potentially reducing the probability of a capitalisation effect until the completion of the tunnel project. Prior research suggests the presence of an anticipation effect in tunnelled infrastructure projects, wherein a large portion of the benefits of such projects capitalises into property prices during (Ahlfeldt et al., 2016; Diao et al., 2016; Hoogendoorn et al., 2017; van Ruijven & Tijm, 2021) and shortly after the completion (Levkovich et al., 2016).

2.3 Theoretical prediction

Reflecting on the existing theoretical framework, several key expectations emerge. Tunnelling of pre-existing transport infrastructure is anticipated to yield positive externalities that markedly enhance residents' quality of life and the overall attractiveness of the residential area, thereby influencing proximate residential property prices. Before construction, a positive relationship is expected between distance to the tunnel and residential property prices, as properties situated closer to the surface-level infrastructure are subjected to greater negative externalities, such as noise and pollution, compared to those located further away. Consequently, properties at a greater distance are presumed to command higher prices. As construction begins, anticipation effects will likely to emerge, with consumers capitalising expected benefits into property prices. Thus, it is expected that the relationship between distance and property prices will invert during and post-construction, becoming negative. This inversion indicates that properties closer to the new tunnel will become increasingly attractive over time due to the mitigation of negative externalities and the introduction of green amenities. Moreover, it is expected that residential property prices will experience an upward trajectory during the construction phase, reflecting residents' anticipation of future enhancements in livability and the overall attractiveness of the residential area. The most substantial increase in property prices is anticipated post-construction, once the tunnel becomes operational and the benefits of reduced noise, improved air quality, and enhanced green amenities are fully realised by residents. This hypothesis aligns with the anticipation and capitalisation effects observed in prior research, suggesting a nuanced temporal dynamic in how transport tunnelling infrastructure improvements impact surrounding residential property prices. The hypotheses are defined as follows:

H1: Tunnelling pre-existing transport infrastructure positively affect surrounding property prices

H2: The effect of tunnelling pre-existing transport infrastructure on property prices decrease with distance

H3: The most substantial effect in property prices is anticipated post-construction, once the tunnel becomes operational and the benefits are fully realized by residents, compared to the construction phase.

3. DATA & METHODOLOGY

3.1 Empirical model

This study aims to capture the external effects of relocating transport infrastructure into a tunnel, combined with the implementation of new green spaces. External effects are not subject to direct observation; hence, an indirect way of identification is required, as mentioned in Section 2. For this purpose, property prices are used near tunnelling projects. Property valuations are a nuanced amalgamation of intrinsic property features and extrinsic environmental effects, often analysed using the Hedonic Pricing Model (Can, 1992). This model deconstructs prices into implicit values for individual characteristics (Rosen, 1974), allowing the estimation of enhanced liveability near a tunnel project. However, its results might be questioned due to potential omitted variables bias, affecting its accuracy in capturing spatial variations (Von Graevenitz & Panduro, 2015; Brook & Tsolacos, 2010). In addition, the Hedonic model struggles to differentiate external effects over different time periods (Schwartz et al., 2006), potentially missing nuanced changes before, during, and after the construction phase of a tunnelling project. To address these limitations, a difference-in-difference approach is employed, controlling for unobserved heterogeneity across space and time. This quasi-experimental framework estimates the price change during and after a development in predefines target and control areas (Wooldrigde, 2013; Zhang et al., 2019). The complexity of the real estate market makes the difference-in-difference approach the most predominantly used non-market valuation methodology to capture the causal effect of external shock (Schwartz et al., 2006). By exploiting the relocation of infrastructure into a tunnel as an exogenous shock to the nearby housing market, this study employs the difference-in-difference approach to identify the value residents attach to improvements in liveability and residential attractiveness.

As Schwartz et al. (2006) argue, there exist three distinct temporal points during which a project could exert an influence on property prices: the announcement, the start and the completion of the project. However, the impact of the announcement effect will be disregarded, as infrastructural projects in the Netherlands typically entail extensive lead time for planning and decision-making processes, which often precludes immediate impacts from project announcements (Lim et al., 2023). Thus, the temporal variations in the study’s framework encompass the periods before, between and after the tunnelling projects. The *before* period can be construed as indicative of the (negative) external impact of transportation infrastructure prior to tunnel implementation. During the *between* period, it is pertinent to investigate reduced negative externalities resulting from these tunnel projects, notably reductions in air and noise pollution, removal of obstructed views, and improvement in physical safety. Nevertheless, it is plausible that such benefits might experience a transient downturn attributable to construction-related nuisances. The between period will provide some explanation for the anticipation effects. The *after* period presents a discernible opportunity to demonstrate the potential increase in amenity value, improved liveability, and enhanced public spaces in the target area post-construction. This includes the establishment of new public green spaces and the restoration of neighbourhood connections. Mathematically, the difference-in-difference hedonic multivariable regression in this study looks as follows:

$$\begin{aligned}\ln P_{ijt} = {} & \alpha + \beta_1 Target_i + \beta_2 Target_i * LnDistance_i + \beta_3 Target_i * Construction_t \\ & + \beta_4 Target_i * Construction_t * LnDistance_i + \beta_5 Target_i * After_t \\ & + \beta_6 Target_i * After_t * LnDistance_i + \theta_k \mathrm{X}_{kit} + \gamma_1 L_i + \gamma_2 I_{jt} + \varepsilon_{ijt}\end{aligned} \qquad (1)$$

Where $\ln P_{ijt}$ is the natural logarithm of the price of property *i* in a (small) geographical area *j* in sale year *t*; $Target_i$ is a dummy variable that takes the value of one if property *i* is located in the target area (0-600 metres), and zero otherwise (600-1200 metres). The criteria for defining the $Target_i$ and $Control_i$ dummies are delineated in Section 3.2; $\text{Ln}Distance_i$ is the log of distance between property *i* and its nearest tunnelled project in metres; $Construction_t$ is a dummy variable that equal one if property *i* is sold during the construction period of the nearest tunnelled project, and zero otherwise; $After_t$ is dummy variable that equal one if property *i* sold after the opening of all sections of the nearest tunnel project, and zero otherwise. The definition of the $Construction_i$ and $After_i$ dummies are provided in Section 3.3; *X* is a set of property characteristics *k* of property *i* sold in year *t*; L_j controls for spatial heterogeneity, by including the postal code level fixed effects (PC4 & PC6 level); I_{jt} control for project specific time fixed effect across the target and control areas, in a (small) geographical area *j* in sale year of property *t*; ε_{ijt} is an error term. The coefficients to be estimated are α, $\beta_{1\text{-}6}$, θ_k, and $\gamma_{1\text{-}2}$.

The difference-in-difference hedonic approach includes a variety of variables of interest, $Target_i$, $Target_i * Construction_t$ and $Target_i * After_t$. First, $Target_i$ captures the difference in property prices between the target and those in the control area before the development of infrastructure tunnelling projects. The variable $Target_i * After_t$ serves as a pivotal indicator for discerning the presence and magnitude of external effect or not. The coefficient measures the external effects of tunneling projects on property prices in the target area compared to the change of prices in the control area. By employing the spatial segmentation, the study seeks to discern and quantify any discernible difference in property prices attributable to proximity to a tunnelled project, while controlling for the problem of both spatial and property autocorrelation. Whereas, $Target_i * Construction_t$ serves as an indicator of the effect of tunnel projects on property prices during the construction period. This coefficient will provide insight into the anticipation effect associated with the tunnelling projects.

In this study, three variables are interacted with $LnDistance_i$ to observe how these effects vary with distance. A 'log-log' specification is chosen because the effects of air and noise pollution diminish with distance at a rate greater than linear (Tijm et al. 2019). This approach allows for a more accurate representation of the relationship between distance and the observed externalities. The distance variable in metres is measured by the Euclidean distance between property *i* and the polygon's edge of the nearest tunnelled infrastructure project, using Geographic Information System (QGIS) techniques. The polygons for tunnelled project are dawn in QGIS based on their actual locations, shapes, and sizes, and they reduce measurement error in the distance from properties to tunnelled project. This approach enables a more accurate assessment of the impact of distance on the observed effects. QGIS is commonly used for spatial data analysing or editing.

To control for unobserved neighbourhood characteristics, the study employs PC4 fixed effects, corresponding to neighbourhood sized areas, as the preferred specification. For sensitivity analysis, PC6 fixed effects, representing individual street sides, are also utilised. These finer fixed effects capture detailed, time-invariant differences in neighbourhood attractiveness but limit estimation to within-block variations near tunnels.

Furthermore, recent studies have shown that staggered difference-in-difference design might give inaccurate estimates of average treatment effect estimates due to negative weights (De Chaisemartin & D'Haultfœuille, 2020; Callaway & Sant'Anna, 2021). To address this issue, project-specific time-fixed effects are utilised, comparing price changes between treated and nearby untreated properties. Koster and van Ommeren (2022) argue that this approach effectively mitigates negative weights and has broader applicability.

To verify is the effect of the initial model stem from the log-log functional form, the study utilises a second model using distance band dummies instead of a continuous variable. This approach simplifies aggregating total gains of all properties in the area. The distances dummies interact with construction and post-construction periods as in the initial model, measuring the average property price increase within a specified range relative to properties 600 to 1,200 metres from the tunnel. This model is otherwise identical and specified as follows:

$$\begin{aligned} \ln P_{ijt} = {} & \alpha + \beta_1 Target_i + \beta_2 Target_i * DistanceDummie_i + \beta_4 Target_i * Construction_t \\ & * DistanceDummie_i + \beta_6 Target_i * After_t * DistanceDummie_i \\ & + \theta_k \mathrm{X}_{kit} + \gamma_1 L_i + \gamma_2 I_{jt} + \varepsilon_{ijt} \end{aligned} \qquad (2)$$

3.2 Target & Control area

An important issue in employing the difference-in-difference framework within the realm of spatial analyses pertains to the delineation of target and control area. As per the baseline specification, residential properties situated within 0 to 600-metres radius of the nearest project constitute the target groups, while the control area comprise those situated between 600 and 1,200 metres. The selected delineations diverge from those delineated by Tijm et al. (2019), where target areas around the Koning Willem-Alexander Tunnel were delineated at 500 metres, 500 to 1,000 metres, and 1,000 to 2,000 metres. These delineated domains of treatment do not wholly lend themselves to the comprehensive analysis of the evaluative metrics ascribed by residents to improve liveability resulting from the mitigation of negative externalities and the establishment of new green spaces. Literature concerning the valuation of air and noise pollution underscores a consensus regarding the spatial limitations of their effect in (sub)urban settings. Eliasson (2005) and Nelson (1982) elucidates that the external effects diminish beyond 300 to 600 metres from roads and railways. Complementarily, Wilhelmsson (2000) provides empirical evidence indicating that traffic noise substantially contributes to noise pollution within a proximity radius of less than 300-metres from roads situated in suburban areas. Concurrently, Mikelbank (2004) asserts that properties situated within a 400-metre radius (0.25 mile) of a highway, devoid of adjacent on- and off-ramps, incur a depreciation, attributable to the highway's negative external effects. Diao et al. (2016) present evidence derived from a railway tunnelling project, indicating that railways' air and noise pollution impacts properties prices within the initial 400 metres of the track. The target spatial demarcation aligns with established studies, which contends that a 300 to 500-metre radius usually represents the maximum threshold for residents' walkable access to urban green spaces (Barker, 1997; Toftager et al., 2011; Ben et al., 2023). Moreover, extant studies substantiate that increasing the cover of urban green space in a residential area within a radius of 300 to 500 metres exerts a positive impact on property prices (Kong et al., 2007; Melichar & Kaprová, 2013; Czembrowski & Kronenberg, 2016; Chen et al., 2023).

In addition to the accessibility of (urban) green spaces, the visible aesthetic structure play a substantial role in property prices (Jayasekare et al., 2019; Wu et al., 2022). As elucidated by Dai et al. (2023), quantifying visibility value within the urban landscape poses a formidable challenge, with the extant literature providing no clear consensus on the potential visibility radius. Nonetheless, it can be posited that the positive impact on visibility resulting from a tunnelled project is confined within a commensurate radius, mirroring the spatial extent of reduction other negative externalities, as air and noise pollution.

Based on the premise that noise and air pollution are negatively correlated with the distance of properties from transport infrastructure, juxtaposed against a positive correlation with the distance to urban green space, this study delineates key cutoff distance of 0 to 600 metres. This delineation specifies the threshold beyond which the relationship between property prices and distance shifts from negative to positive regarding pollution effects from transport infrastructure. Simultaneously, it signifies the threshold distance at which the presence of (sub-)urban green spaces exerts a discernible and substantive impact on property prices. This delineation provides a nuanced analysis of the spatial extent to which the effects are manifested, facilitating a better understanding of their implications. The reason for delineating the control group within distance has to do with the influence of physical residential environmental characteristics and, with a possible change in the impact of functional residential environmental characteristics. By setting the control area to span from 600 to 1,200 metres, the chance that the control area is affected by a tunnelled project is minimised. Appendix A presents the distribution of the target and control areas for each project, encompassing all transactions.

3.3 Project phases

The treatment period, denoted as 'after construction', spans three and a half years after the completion of the entire project. The latest tunnel project lacks data beyond a period of three and a half years post-completion. However, prior studies suggest the presence of an anticipation effect in tunnelled projects, wherein a large portion of the benefits are capitalised into property prices during (Ahlfeldt et al., 2016) and shortly after the completion (Hoogendoorn et al., 2017; Levkovich et al., 2016). Furthermore, several studies examine the externalities of infrastructure relocation projects for only a short timeframe following project completion, ranging from one to three years. This restricted time frame is because the most substantial price effects occur shortly after the completion (Kang & Cervero, 2008; Diao et al., 2016). Hence, it is expected that a period of three and a half year post-completion will be sufficient for assessing these effects. One could choose to exclude the most recent project and extend the observation period to seven years, partially mitigating the reduction in observations. However, this would necessitate the exclusion of the largest project in terms of road tunnel length and total creation of new green space (refer to Table 1). This would not only substantially diminish the dataset but also limit the generalisability of the findings to a broader geographical area.

To ensure consistent reporting, the preferred approach is to use the commencement month of construction and the completion month of the tunnelling project, given the absence of specific project dates. Additionally, considering that some projects are completed in phases, the decision has been made to denote the month when the final section opened, alongside the accessibility to the new green space. This approach acknowledges that the project's positive externalities can be realised from that point onwards, enabling a comprehensive assessment of the development's positive impacts, including quality of life improvements. By using the project’s completion month, when the new green spaces are accessible, the study accounts for the holistic benefits and mitigates any remaining anticipation effects.

3.4 Case selection

A selection of tunnelled transport infrastructure projects in the Netherlands will be analysed as a case study to differentiate instances where alterations to the infrastructure between pre- and post-measurement phases may have reduced or eliminated negative external effects while concurrently introducing new positive external effects. This study undertakes an examination of Dutch cases wherein extant infrastructure tunnelled projects, with the primary aim of reducing the negative effects associated with open transport infrastructure. The study area consists six infrastructure relocation projects, where construction activities occurred between 1998 and 2020. To ensure a comprehensive analysis, a deliberate effort has been made to incorporate as many infrastructure relocation projects as possible, thereby expanding the sample size. These projects have been sourced from various regions within the Netherlands, contributing to the generation of results that possess broader applicability and are not confined to specific cases. Factors including the geographical positioning, length, construction period, the presence of pre-existing infrastructure, and the integration of "green roof" parks determined the criteria for selecting infrastructure relocation projects. It is pertinent to note that this study excludes tunnelled projects that incorporate integrated area development atop the tunnel roof. In part due to the latter criterion, one large tunnelling project, Willem van Oranjetunnel in Delft, is excluded from the study. This underground structures are crucial components of large-scale urban development initiatives aimed at fostering new housing and employment opportunities. Table 1 presents an overview of the six infrastructure relocation projects included. The infrastructure sections encompass both roads and railways, spanning five Dutch provinces. In aggregate, they constitute roughly 9,600 kilometres of infrastructure and an estimated 39 hectares of green space have been established.

Table 1
Selection of tunnelled (sub-)urban infrastructure relocation projects in the Netherlands

#	Project	Type	Period	Description
1	Gaasperdammertunnel *Amsterdam*	Road	2015-2020 *Aug. July*	Widening of A9 highway from 2x2 to 2x5 lanes, construction of 3 km tunnel with 19 ha park on top
2	Koning Willem-Alexander *Maastricht*	Road	2011-2016 *Sep. Dec.*	Widening of A2 highway from 2x2 to 4x2 lanes, construction of 2.3 km tunnel with 8 ha park on top
3	Kap van Barendrecht *Barendrecht*	Railway	2000-2007 *Mar. July*	Widening of Rotterdam-Dordrecht rail track from 4 to 9 tracks, construction of 1.5 km tunnel with 9 ha park on top
4	Limesaquaduct *Leiderdorp*	Road	2009-2014 *Sep. Oct.*	Widening of A4 highway from 2x2 to 2x3 lanes, construction of 1.4 km tunnel with approx. 1.1 ha green space on top
5	Spoortunnel Best *Best*	Railway	1998-2002 *April Sep.*	Widening of the Boxtel-Eindhoven rail track from 1x2 to 2x2 tracks, construction of 935 m tunnel with approx. 1.3 ha of green space on top
6	Salland-Twentetunnel *Nijverdal*	Road/ Railway	2008-2013 *Feb. April*	Tunneling of 493 metre of two road lanes and two rail tracks, creation of approx. 1 ha of park on top

3.5 Data

The analysis combines data from multiple sources. First, the data on residential transactions and house characteristics are retrieved from the Association of Dutch Real Estate Agents (NVM). The NVM is the largest agents association in the Netherlands that gathers data on transactions of properties around the Netherlands. The NVM comprises 4,400 real estate agents, giving them a market share of almost 70 percent of all sold residential properties in the Netherlands (NVM, 2023). The data of the NVM reaches from April 1995 to January 2024 and consists transaction prices and characteristics of the different residential properties, which are utilised as control variables, such as square metres, property type, and building year. The dataset also contains address information, including home addresses, house numbers and zip codes. The total dataset includes 14.720 properties in the selected target and control areas. Second, the infrastructural tunnelled projects considered in this research are based on data from planning approval decision reports from the Ministry of Infrastructure and Water Management (2024) and ProRail (2024), supplemented by archival and contemporary satellite imagery of the Netherlands.

3.6 Descriptive statistics

The dataset encompasses a total of 12,102 observations from six selected cities and towns, following a thorough data cleansing process. In addition to the standard data cleaning procedures, several variables have been transformed. For a detailed description of the data cleaning process and the specific variable transformations applied, please refer to Appendix B & C. This approach ensures the reliability and robustness of the dataset for subsequent analysis. The summary statistics presented in Table 2 offer a comprehensive overview of the variables examined in this research study, providing a detailed overview of the dataset's characteristics, including mean, standard deviations, minimum, and maximum values across all variables.

The analysis encompasses a comprehensive dataset of property transaction prices ranging from €71,238 to €699,300, with a mean transaction price of €245,439.50 and a standard deviation of €113,431.60. This price variation reflects the diversity of the residential properties and their locations. A closer examination of transaction prices reveals a slight disparity between target and control areas. The mean transaction price in the target area is €242,403.30, whereas it is slightly higher at €272,210.90 in the control area. This discrepancy can likely be attributed to locational factors, prompting the inclusion of local spatial fixed effects in the analysis to account for these variations. Figure 2 illustrates the trend in average transaction prices for all municipalities, as well as for the target and control groups. From 1993 to 2024, the trend in average transaction prices for both the study and control groups follows a similar pattern, suggesting comparable market dynamics in both areas. Regarding the physical characteristics of the properties, the average living area is 111.02 square metres, with a standard deviation of 41.00 square metres, indicating a varied range of property sizes. The dataset predominantly features single-family houses, constituting nearly 55% of the total properties, while the remaining 45% are apartments.

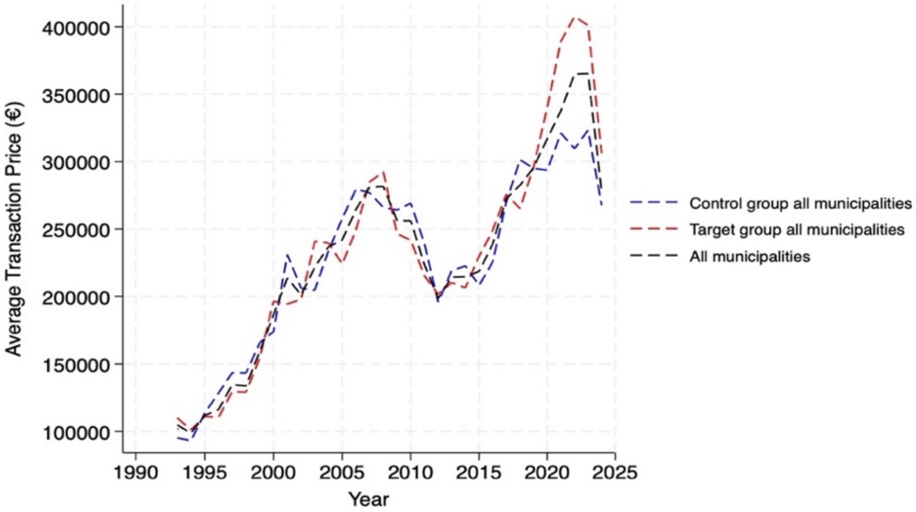

Figure 2. The average transaction price in the selected locations over time

Table 2. Descriptive statistics

Group	Variable	Mean	Std.Dev.	Min	Max
Total	Transaction price (in €)	245,439.5	113,431.6	71,238	699,300
	Ln Transaction price (in €)	12.3091	0.4537	11.1737	13.4578
	Distance to infrastructure tunnel project	608.52	330.57	12.44	1199.42
	Transaction year	2011.336	7.404179	1993	2024
	Living area (m^2)	111.0172	41.0016	26	617
	Building Category – Semi-detached (1 = yes)	0.0674	0.2508	0	1
	Building Category – Corner house (1 = yes)	0.1390	0.3459	0	1
	Building Category – Terraced house (1 = yes)	0.3133	0.4638	0	1
	Building Category – Detached (1 = yes)	0.0317	0.1752	0	1
	Building Category – Apartment (1 = yes)	0.4484	0.4973	0	1
	Building Period – 1500-1905 (1 = yes)	0.0166	0.1278	0	1
	Building Period – 1906-1930 (1 = yes)	0.0643	0.2454	0	1
	Building Period – 1931-1944 (1 = yes)	0.0750	0.2634	0	1
	Building Period – 1945-1959 (1 = yes)	0.0536	0.2252	0	1
	Building Period – 1960-1970 (1 = yes)	0.2026	0.4019	0	1
	Building Period – 1971-1980 (1 = yes)	0.2386	0.4263	0	1
	Building Period – 1981-1990 (1 = yes)	0.1501	0.3572	0	1
	Building Period – 1991-2000 (1 = yes)	0.0763	0.2655	0	1
	Building Period – 2001-2010 (1 = yes)	0.0968	0.2957	0	1
	Building Period – 2011-2020 (1 = yes)	0.0256	0.1582	0	1
	Target area	0.5105	0.4999	0	1
	Number of observations	12,102			
Target	Transaction price (in €)	242,403.3	116,083.6	71,238	699,300
	Ln Transaction price (in €)	12.2907	0.4651	11.1737	13.4578
	Distance to infrastructure tunnel project	327.7161	154.7202	12.44	599.95
	Transaction year	2010.698	7.6015	1993	2024
	Living area (m^2)	113.3566	42.22077	33	617
	Building Category – Semi-detached (1 = yes)	0.0844	0.2780	0	1
	Building Category – Corner house (1 = yes)	0.1516	0.3587	0	1
	Building Category – Terraced house (1 = yes)	0.3145	0.4643	0	1
	Building Category – Detached (1 = yes)	0.0362	0.1868	0	1
	Building Category – Apartment (1 = yes)	0.4131	0.4924	0	1
	Building Period – 1500-1905 (1 = yes)	0.0082	0.0922	0	1
	Building Period – 1906-1930 (1 = yes)	0.0529	0.2239	0	1
	Building Period – 1931-1944 (1 = yes)	0.0895	0.2855	0	1
	Building Period – 1945-1959 (1 = yes)	0.0683	0.2523	0	1
	Building Period – 1960-1970 (1 = yes)	0.1805	0.3846	0	1
	Building Period – 1971-1980 (1 = yes)	0.2953	0.4562	0	1
	Building Period – 1981-1990 (1 = yes)	0.1314	0.3379	0	1
	Building Period – 1991-2000 (1 = yes)	0.0557	0.2293	0	1
	Building Period – 2001-2010 (1 = yes)	0.1080	0.3104	0	1
	Building Period – 2011-2020 (1 = yes)	0.0091	0.0964	0	1
	Target area	1	0	1	1
	Number of observations	6,175			
Control	Transaction price (in €)	248,606.2	110,518.6	71,243	695,000
	Ln Transaction price (in €)	12.3284	0.4407	11.1738	13.4516
	Distance to infrastructure tunnel project	901.4063	173.9515	600.06	1199.42
	Transaction year	2012.001	7.132648	1993	2024
	Living area (m^2)	108.5772	39.54648	26	362
	Building Category – Semi-detached (1 = yes)	0.0497	0.2174	0	1
	Building Category – Corner house (1 = yes)	0.1258	0.3316	0	1
	Building Category – Terraced house (1 = yes)	0.3121	0.4634	0	1
	Building Category – Detached (1 = yes)	0.0269	0.1620	0	1
	Building Category – Apartment (1 = yes)	0.4852	0.4998	0	1
	Building Period – 1500-1905 (1 = yes)	0.0249	0.1560	0	1
	Building Period – 1906-1930 (1 = yes)	0.0762	0.2654	0	1
	Building Period – 1931-1944 (1 = yes)	0.0598	0.2373	0	1
	Building Period – 1945-1959 (1 = yes)	0.0382	0.1919	0	1
	Building Period – 1960-1970 (1 = yes)	0.2255	0.4179	0	1
	Building Period – 1971-1980 (1 = yes)	0.1796	0.3839	0	1
	Building Period – 1981-1990 (1 = yes)	0.1695	0.3752	0	1
	Building Period – 1991-2000 (1 = yes)	0.0978	0.2971	0	1
	Building Period – 2001-2010 (1 = yes)	0.0852	0.2792	0	1
	Building Period – 2011-2020 (1 = yes)	0.0426	0.2021	0	1
	Target area	0	0	0	0
	Number of observations	5,927			

4. RESULTS

4.1 Baseline results

Table 3 reports the results of the difference-in-difference hedonic multivariable regression analysis. The first Model (1) serves as the baseline specification, incorporating project-specific time-fixed effects to control for temporal project-specific variations. This model demonstrates an R-squared of 0.4688, indicating a modest explanatory power. Building upon the baseline specification, Model (2) includes additional control variables for the building period and property characteristics. By accounting for these structural and intrinsic property differences, the robustness of the findings is substantially enhanced, resulting in an improved R-squared of 0.8489. Models (3) and (4) offer more refined analyses, integrating restrictive location-fixed effects, which are crucial for accurately interpreting the spatial impact of the infrastructure relocation. These models provide a nuanced understanding of how proximity to the tunnel affects residential property prices by controlling for localised factors that could influence property values. Specifically, Model 3 incorporates postal code levels of 4 digits, resulting in an R-squared of 0.8825, while Model 4 sensitivity analysis further refines this approach by using 6-digit postal code levels, achieving an R-squared of 0.9372. The preferred regression specification, Model 3, with an R-squared of 0.8825, indicates that approximately 88.25% of the variation in the natural log of transaction prices is explained by the model. The incremental inclusion of control variables and restrictive location-fixed effects ensures a more precise and comprehensive analysis, progressively refining the model to account for a broader range of factors affecting residential property prices. Furthermore, the results of the OLS assumption test can be found in Appendix D.

In the preferred specification, which employs PC4 fixed effect, the interaction term *Target x After* coefficient is positive and statistically significant at a 1% level. This finding indicates that, on average, properties situated within 600 metres of the tunnelled segments sell at approximately 16.77%[1] higher prices after the completion of the tunnelling projects, at a distance of zero from the tunnel, compared to the control area, ceteris paribus. On this basis, infrastructure tunnelling projects have a positive and sizable effect on nearby residential property prices. Conversely, the interaction term *Target x Construction* is not statistically significant. The coefficient indicates a non-significant negative correlation, suggesting a negative price effect of 3,12%[2] for residential properties closer to the tunnelled segment during the construction phase. This coefficient suggest that there is no anticipation effect during the construction period, while remaining statistically insignificant. Based on these results, Hypothesis 1, which posited that *tunnelling pre-existing transport infrastructure positively affect surrounding property prices during and after the construction phase,* is rejected. The findings suggest a more nuanced effect: while there are negative effects during the construction and positive effect post-construction.

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[1] $(= (\exp^{(0.1550)}-1)*100)$ [2] $(= (\exp^{(-0.0317)}-1)*100)$

Moreover, the significant negative interaction effect at the 1% level of the term *Target x After x ln(Distance)* elucidates that the positive effect of tunnelling existing infrastructure on nearby property prices diminishes as the distance from the tunnel increases. Specifically, the coefficient indicates that a 10% increase in distance from the tunnel, the positive effect on transaction price decreases by approximately 0.6375%. This interaction term highlights the substantial influence of proximity to a tunnelling project on the magnitude of the price impact. For instance, halving the distance to the tunnel (e.g., from 600 metres to 300 metres) is associated with an approximately 4.42%[3] appreciation in residential property prices. This suggests that properties situated at greater distances from the tunnel experience lower transaction prices compared to those in closer proximity. Figure 3 represents the non-linear price effect as a function of distance, characterised by an exponential decay pattern. To further examine the influence of distance, a distance-band specification is utilised in subsequent analyses. The interaction term *Target x Construction x ln(Distance)*, however, does not yield statistically significant price effects. The estimate is similar in magnitude when location-fixed effects for PC6-levels are considered. Model 2, accounting for temporal project variations, structural differences, and property traits, reveals a significant negative interaction at the 10% level during the tunnel construction phase. However, the estimates lack control for unobserved neighbourhood characteristics, limiting their robustness.

Table 3. Difference-in-difference regression results

	(1) Base	(2) Extent	(3) *PC4*	(4) *PC6*
Sample	< 1,200 m	< 1,200 m	< 1,200 m	< 1,200 m
Target Area	0-600 m	0-600 m	0-600 m	0-600 m
Control Area	600-1,200 m	600-1,200 m	600-1,200 m	600-1,200 m
Target	-0.0581739**	-0.0673334***	-0.0573364***	-0.0587436***
	(0.1003752)	(0.0225672)	(0.0211465)	(0.02003882)
Target x Ln Distance	0.0064007**	0.0134756***	0.0166328***	0.0505112***
	(0.0174796)	(0.0071673)	(0.0071673)	(0.0157744)
Target x Construction	-0.0487223	-0.0597152	-0.0317152	-0.03705405
	(0.1289329)	(0.053545)	(0.0547296)	(0.0457027)
Target x Construction x Ln Distance	0.006118	0.001322*	-0.003208	-0.0048219
	(0.095041)	(0.0957357)	(0.0093983)	(0.0079641)
Target x After	0.1058243**	0.1182975***	0.1550675***	0.1422396***
	(0.1152078)	(0.0353661)	(0.0410476)	(0.0383501)
Target x After x Ln Distance	-0.0752613**	-0.0436147***	-0.0637563***	-0.0657625***
	(0.0217533)	(0.0094195)	(0.0097888)	(0.0090794)
Year * Project fixed effects	Yes	Yes	Yes	Yes
Building period property	No	Yes	Yes	Yes
Property characteristics	No	Yes	Yes	Yes
Location-fixed effects	No	No	Yes	Yes
Observations	12,102	12,102	12,102	12,102
R^2	0.4683	0.8489	0.8825	0.9373

Note: Dependent variable is the natural logarithm of transaction price. Robust standard errors in parentheses
$^{***}p<0.001$, $^{**}P<0.05$, $^{*}P<0.1$

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[3] $-0.0637563 \times \ln(0.5) \approx 0.0442$.

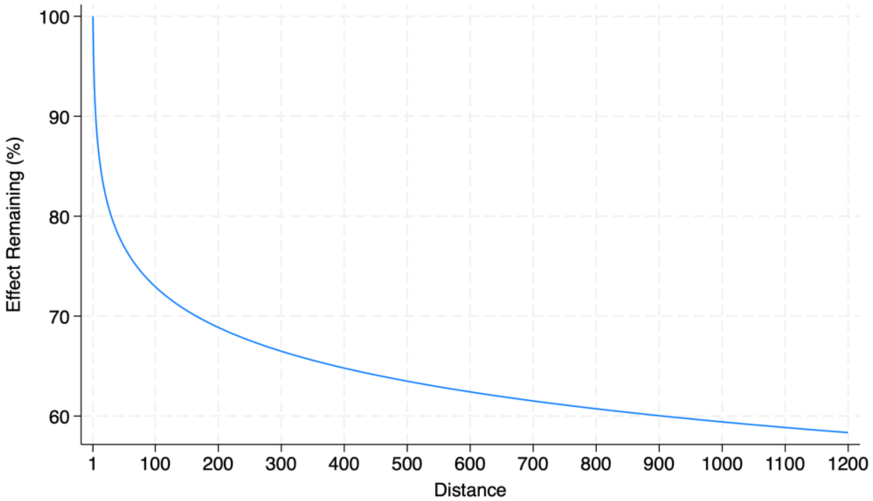

Figure 3. Reduction of price effect with increasing distance, normalised to 100% at 1 metre

4.2 Alternative specification

The results presented in Table 4 provide compelling evidence for Hypothesis 2, which posited that *the impact of tunnelling pre-existing transport infrastructure on property prices diminishes with increasing distance*. This is corroborated by an alternative specification, which confirms that tunnelling infrastructure increases property prices in close proximity, with the magnitude of this effect attenuating as the distance increases. In Model 3, the coefficients for all distance-band interaction terms *Target x After* are positive and statistically significant at the 1% level. The interaction terms, divided into four distance bands, reveal a discernible pattern: the most substantial price appreciation is observed closest to the tunnel, with a gradual decline as distance increases. Specifically, properties situated within 0-150 metres of the tunnel experience an average price increase of 8.5%[4], those within 150-300 metres see a 5.3%[5] increase, properties within 300-450 metres observe a 3.4%[6] increase, and those within 450-600 metres have a 2.0%[7] appreciation. Figure 4 shows these findings on a map around the Gaasperdammertunnel in Amsterdam. These results are consistent with those in Model 4 (PC6-level). This gradient in property price appreciation highlights the non-linear nature of the positive externalities by tunnelling infrastructure, where the price effects are most pronounced in the immediate vicinity of the tunnel and gradually taper off with increasing distance, reflecting a clear spatial attenuation effect. Consequently, based on both the baseline and alternative specification results, Hypothesis 2 is not rejected.

Furthermore, the interaction terms *Target x Construction* utilising distance bands reveal a nuanced pattern. The significant negative price effect is most pronounced for properties closest to the tunnelled segment (0-150 metres), potentially attributable due to construction-related disruptions. This negative effect diminishes with distance, showing no significant change within the 150-300 metre range. Interestingly, the effect turns

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[4] (= (exp$^{(0.0813)}$-1)*100) [5] (= (exp$^{(0.0512)}$-1)*100) [6] (= (exp$^{(0.0333)}$-1)*100) [7] (= (exp$^{(0.0204)}$-1)*100)

slightly significant negative within 300-450 metres and becomes significant positive in the 450-600 metres range, suggesting potential anticipation of future benefits from the tunnel project.

The abovementioned results derived from both baseline and alternative specification models do not reject Hypothesis 3, which asserts that *the most significant impact on property prices manifests post-construction, once the tunnel is operational and residents fully benefit, rather than during the construction phase*. The negative coefficient for the *Construction* terms indicates the persistence of negative externalities during the construction phase, resulting in observed negative effects. Conversely, the positive coefficient for the *After* terms signifies a potential increase in amenity value, improved liveability, and enhanced public spaces due to the tunnel project. This post-construction effect is notably more pronounced than the construction phase effect, suggesting that the benefits of the tunnel projects were not fully anticipated prior to their completion.

Table 4. Difference-in-difference regression results alternative specification with distance rings

	(1) Base	(2) Extent	(3) *PC4*	(4) *PC6*
Sample	< 1,200 m	< 1,200 m	< 1,200 m	< 1,200 m
Target Area	0-600 m	0-600 m	0-600 m	0-600 m
Control Area	600-1,200 m	600-1,200 m	600-1,200 m	600-1,200 m
Target (0-150 m)	-0.0529014**	-0.0210609**	-0.0134265**	-0.0819219**
	(0.0194959)	(0.0087889)	(0.0072723)	(0.026614)
Target (150-300 m)	-0.049332**	-0.0173789**	-0.0072074**	-0.0478795**
	(0.0155781)	(0.0083637)	(0.0033786)	(0.0228196)
Target (300-450 m)	-0.0102238**	0.0058632	0.0117347	0.005279
	(0.00149364)	(0.0082055)	(0.0085723)	(0.0179846)
Target (450-600 m)	0.0008639	0.0461726***	0.0343568***	0.0399935***
	(0.0206536)	(0.0098228)	(0.0097218)	0.0047937
Target x Construction (0-150 m)	-0.0253385	-0.0251324***	-0.023087***	-0.0211341***
	(0.0376939)	(0.0016753)	(0.0016826)	(0.0013223)
Target x Construction (150-300 m)	-0.0168437	-0.0451402	-0.0442515	-0.0404547***
	(0.0196911)	(0.040666)	(0.0103886)	(0.0064942)
Target x Construction (300-450 m)	-0.0096396	-0.0125002	-0.0030744**	-0.0032462***
	(0.0204019)	(0.0108384)	(0.0105327)	(0.0013715)
Target x Construction (450-600 m)	0.0267747	0.0396025**	0.0236219**	-0.0254361***
	(0.02667)	(0.0096156)	(0.0121685)	(0.0098823)
Target x After (0-150 m)	0.0355227**	0.0637906***	0.0813372***	0.0803764***
	(0.015068)	(0.0180503)	(0.018203)	(0.0166302)
Target x After (150-300 m)	0.0997904***	0.0572299***	0.0512201***	0.051815**
	(0.0218788)	(0.0120933)	(0.0117696)	(0.0205574)
Target x After (300-450 m)	0.0555508**	0.0428048***	0.0333954***	0.0388226***
	(0.0208785)	(0.0119092)	(0.0115789)	(0.0102291)
Target x After (450-600 m)	0.0403498**	0.0134791	0.019445***	0.0219541***
	(0.0161282)	(0.0130044)	(0.0126553)	(0.0110363)
Year + Project fixed effects	Yes	Yes	Yes	Yes
Building period property	No	Yes	Yes	Yes
Property characteristics	No	Yes	Yes	Yes
Location-fixed effects	No	No	Yes	Yes
Observations	12,102	12,102	12,102	12,102
R^2	0.4720	0.8489	0.8626	0.9374

Note: Dependent variable is the natural logarithm of transaction price. Robust standard errors in parentheses ***p<0.001, **P<0.05, *P<0.1

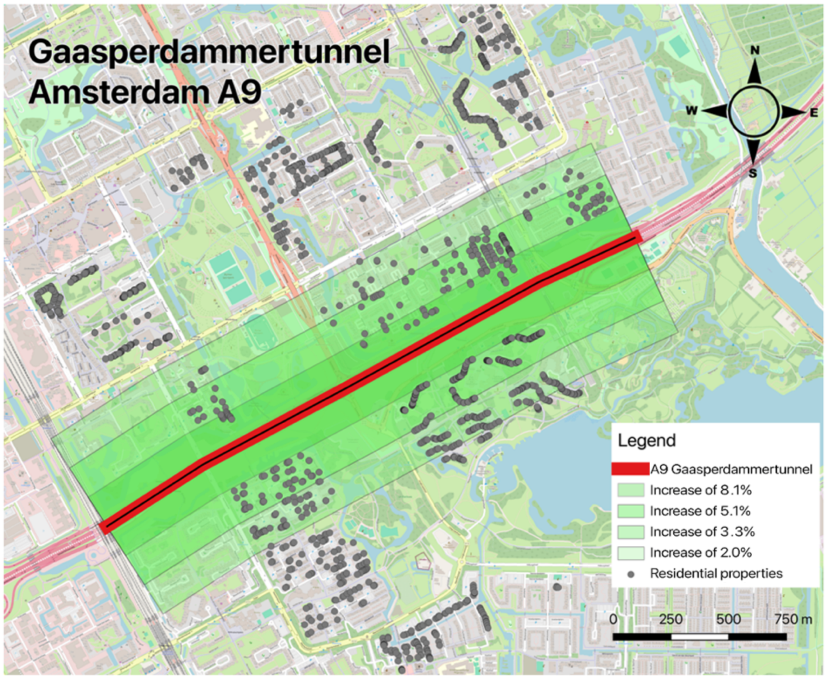

Figure 4. Map of Gaasperdammertunnel in Amsterdam showing appreciation in four distance bands

4.3 Heterogeneity

In Table 5, a comparative analysis between Model (5) and Model (6) is conducted to explore the differential effect of tunnelling infrastructure on property prices in urban versus suburban and rural residential regions. The heterogeneity of property prices in urban and rural settings, as posited by DiPasquale and Wheaton (1996), suggests a potential divergence in the valuation of such infrastructure projects by residents of these different areas. Intuitively, one would expect tunnelling projects that create new public spaces and green amenities to have a more pronounced effect in urban regions, characterised by limited green spaces and high population density. These urbanised regions would substantially benefit from such projects, providing recreational and environmental externalities. Conversely, suburban/rural areas, which typically have more abundant natural surroundings, may experience a lesser effect from such projects, as the implementation of additional public spaces and green amenities does not alter the pre-existing landscape or provide as substantial an incremental externalities to residents. To test this heterogeneity, the analysis employs model specifications that divide the preferred model into two groups: urban and suburban-rural located tunnelling infrastructure projects.

The heterogeneity regression analysis reveals distinct geographical pattern in the trajectories of the effects. In suburban and rural regions, properties located within 0-600 metres of the tunnel directly start to experience a significant positive price effect of 5% during the construction phase. This contrasts with urban regions, where properties in the same proximity initially suffer a significant negative price effect of 9,5%. The estimate for the latter indicates a direct capitalisation effect in suburban and rural regions, where the anticipation of improved liveability outweighs the temporary disruptions of construction. Interestingly, following the completion of the tunnelling projects, properties in urban regions experienced a more pronounced significant positive price effect of 21.9%[8], compared to a 12.4%[9] increase in suburban/rural regions. In both geographical contexts, the positive effect diminished with increasing distance from the tunnel. Specifically, the coefficient indicates that for every 10% increase in distance from the tunnel, the positive effect on transaction price decreases by approx. 0.632519% in urban regions and approx. 0.310177% in suburban and rural regions.

These findings align with the intuitive expectation that the valuation of tunnelling infrastructure projects varies according to the urban-suburban and rural contexts. The results indicate that urban residents place a higher premium on living close to these tunnelling projects due to the increased amenity value, improved liveability, and enhanced public (green) spaces post-construction. Several factors could explain these results. Firstly, the scarcity effect plays a role. The limited availability of public spaces and green amenities in urban regions enhances their value and desirability among residents. As noted by Sehnert et al. (2014), the value of a resource generally increases when its availability is limited. The presence of a few public green spaces in urban areas substantially impacts the perceived desirability and value of properties (Bockarjova et al., 2020). Another possibility has to do with the removal of negative externalities. Sørensen and Thorsen (2010) highlighted that urban residents place a higher premium on highly quiet environments due to their exposure to elevated baseline noise levels. Consequently, noise abatement measures such as tunnelling infrastructure, impact property values in urban areas compared to suburban or rural regions.

Table 5. Regression results for urban and rural comparison

	(5) Urban	(6) Suburban/rural
Sample	< 1,200 m	< 1,200 m
Target Area	0-600 m	0-600 m
Control Area	600-1,200 m	600-1,200 m
Target	-0.1033305**	-0.1172837***
	(0.0479697)	(0.0188412)
Target x Ln Distance	0.0293856**	0.0343545***
	(0.012668)	(0.00592425)
Target x Construction	-0.0953349**	0.0503781**
	(0.0325107)	(0.0243008)
Target x Construction x Ln Distance	0.0383298**	-0.0189659**
	(0.0153584)	(0.0087898)
Target x After	0.1979967***	0.1171862***
	(0.0301423)	(0.0108542)
Target x After x Ln Distance	-0.0632519***	-0.0310177***
	(0.0108884)	(0.003554)
Year * Project fixed effects	Yes	Yes
Building period property	Yes	Yes
Property characteristics	Yes	Yes
Location-fixed effects	Yes	Yes
Observations	5,306	6,796
R^2	0.8834	0.8852

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[8] (= (exp$^{(0.1979)}$-1)*100)

[9] (= (exp$^{(0.1171)}$-1)*100)

5. DISCUSSION

Overall, the findings of this analysis indicate that the tunnelling of pre-existing transport infrastructure exerts a positive effect on nearby property prices upon the project's completion. Notably, the magnitude of this positive effect diminishes as the distance from the newly tunnelled section increases. These findings are in line with the previous literature on the price effects associated with the relocation of existing transport infrastructure (Tajima, 2003; Kang & Cervero, 2008; Ossokina & Verweij, 2015; Ahlfeldt et al., 2016; Diao et al., 2016; Tijm et al., 2019). However, it should be acknowledged that a direct comparison of these findings is not feasible due to differences in the type of relocating infrastructure projects, the geographical area of the studies, and the modelling approach. Given the unique externalities associated with infrastructure tunnelling projects, it is imperative to compare the findings with literature focusing on similar projects. To ascertain whether the price effect is in line with existing literature, a comparison has been made with the paper by Tijm et al. (2019).

A key distinction between the findings lies in the magnitude of the observed price effects. Tijm et al. (2019) reported a 7.1% increase nine months post-completion within 500 metres of the tunnel, with new public space and green amenities still under construction. In contrast, the present study, spanning 3.5 years after completing both the tunnelling projects and the associated public green spaces and amenities, reveals a 16.7% increase within 600 metres of the tunnels. A plausible explanation for this rise over time is the improved liveability and residential attractiveness resulting from the completion and accessibility of (new) public spaces and green amenities. The extended period allowed the market to absorb and reflect the value of these improvements. Moreover, as residents acclimated to newly introduced green amenities and recognised the enhanced quality of life, the cumulative effect likely intensified, potentially explaining the increased positive effect over time. This explanation aligns with existing literature, which indicates that residents exhibit a higher willingness to pay for residential properties located in proximity to established green and public spaces that have replaced former transport infrastructure after project completion compared to during the construction phase (Kang & Cervero, 2008; Cervero et al., 2009). As anticipated by Bos & de Swart (2024), the study of Tijm et al. (2019) appears to underestimate the long-term benefits of their interventions on improved quality of life. This study underscores the necessity for policymakers to consider the long-term benefits in cost-benefit analyses, as short-term evaluations may underestimate these benefits, potentially leading to undervalued decisions.

The discrepancy in the price effect observed between this study and the findings of Tijm et al. (2019) possibly suggests that a portion of the willingness to pay for such tunnelling projects is already capitalised in property prices before the project's full completion, including redevelopment of public green spaces. This observation is consistent with the literature, which provides evidence that a large part of infrastructure projects' benefits are capitalised into property prices shortly after their opening (Ahlfeldt et al., 2016; Diao et al., 2016;

Levkovich et al., 2016). However, one caveat of this study is its failure to consider the overall pattern of the price effect over time post-completion. This omission raises questions about how property prices evolve immediately after the tunnel's opening and to what extent the effect is already capitalised at that point. For future research, giving more prominence to the evaluated effect over time is recommended.

Another topic for discussion is the finding of an (insignificant) negative effect during the construction phase. These results contrast with the conclusions of previous studies, which identified a positive (anticipation) effect during the construction period (Kang & Cervero, 2008; Diao et al., 2019; van Ruijven & Tijm, 2021). However, The heterogeneity test has yielded intriguing results, indicating a significant positive effect in suburban-rural regions, contrasted by a significant negative effect in urban regions. There are two ways to look at these differences. Firstly, suburban-rural residents might already anticipate improvement in utility and liveability from such projects, while the benefits for urban residents remain unclear. Secondly, the higher density and more complex urban environments may lead to greater disruptions from construction activities. In suburban-rural regions, however, the anticipated benefits might outweigh any temporary inconveniences caused by the construction. Further research is necessary to elucidate the underlying reasons for these differences.

The analysis of the effect following the completion of construction projects reveals a divergent outcome. Contrary to the perceptions held by rural inhabitants, urban residents attribute greater value to the proximity of completed tunnelled projects, as evidenced by a more substantial positive effect and increased sensitivity to distance observed in urban regions. Considering these findings, the willingness to pay for such projects may vary depending on the urban-suburban-rural context. These results emphasise the complex dynamics between the relocation of infrastructure into tunnels and property prices, highlighting the need for context-specific approaches to effectively inform decision-making and project planning.

This study has several (data) limitations that need to be considered. First, the analysis is constrained by the absence of data on actual liveability and residential attractiveness improvements, limiting the study to perceived benefits reflected in property prices. Including other variables that capture "liveability", such as proximity to green spaces and public amenities, air quality, and noise levels, could provide a more direct measure of these factors and enhance the robustness of the findings. Second, the available transaction data offered limited availability of structure property characteristics. The third limitation is that this study did not consider the specific project-related characteristics. The chosen project cases exhibit variation across several dimensions, including size, type of infrastructure, nature of public space redevelopment, size of new green spaces, and negative externalities. These differences may influence the results; however, examining multiple cases was intended to enhance the generalisability of the results. Finally, the exclusion of qualitative methods limited deeper insights into residents' perspectives on tunnelling infrastructure projects.

6. CONCLUSION

The main purpose of this study is to investigate the value residents place on improved liveability and residential attractiveness resulting from the relocation of transportation infrastructure into tunnels and the associated redevelopment of public green spaces. Tunnelling existing infrastructure is being considered more frequently to mitigate the negative impact of infrastructure in densely populated areas. Despite this growing interest, there is limited academic literature explicitly examining the comprehensive ex-post valuation of such projects on property prices. This study aims to address this gap by examining multiple projects involving various types of infrastructure rather than focusing on a single project case, as previous studies have done. This broader understanding can inform policy decisions and facilitate trade-offs associated with these large public investments. A dataset of 12,102 property transactions distributed across six projects in the Netherlands was examined to assess the value residents place on improved liveability and residential attractiveness resulting from these projects. The study employed difference-in-difference hedonic regression analysis to compare property prices between target and control areas during and after the construction of the projects.

The findings indicate that the relocation of pre-existing transportation infrastructure into tunnels, coupled with the subsequent redevelopment of public green spaces, exerts a significant influence on the prices of nearby residential properties. The findings revealed that residential properties situated within 600 metres of the tunnel sections sell at approximately 16.77% higher prices after the completion of the projects compared to the control area (600-1,200 metres), ceteris paribus. The magnitude of the positive effect diminishes with increasing distance from the tunnel section, quantifying that a 10% increase in distance corresponds to a 0.6375% decrease in price appreciation. However, the positive price effect is not uniform, displaying nuanced spatial dynamics. There is significant heterogeneity in the willingness-to-pay effects, indicating that residents in urban areas attribute a higher value to the proximity of completed tunnelled projects compared to their suburban-rural counterparts. Conversely, in suburban and rural settings, a positive effect is observed during the construction phase, suggesting that the anticipation of future benefits potentially outweighs the temporary disruptions caused by construction activities. The differential effect on property prices in urban and suburban-rural regions underscores the necessity for context-specific strategies in urban planning and infrastructure development.

Based on the findings, it can be concluded that residents are willing to pay a price premium for properties located in close proximity to infrastructure tunnelling projects. It can, therefore, be suggested that residents attribute significant value to the improved liveability and residential attractiveness resulting from such infrastructural developments. This information is crucial for urban planning, policymaking, and real estate investment to balance such projects' development costs and community benefits.

Future research should incorporate comprehensive direct measures of liveability and residential attractiveness improvements, utilising quantitative and qualitative data to validate and extend the study findings. Expanding the scope of research to include the proposal or announcement periods and more extended post-construction periods would provide more robust data. Moreover, examining a broader range of infrastructure tunnelling projects, varying the target and control areas, and including projects outside of the Netherlands would enhance the generalisability of the results. Incorporating transaction data of commercial properties is crucial for creating a more nuanced understanding. Furthermore, investigating the specific project-related characteristics that lead to potential variations in the effect between different tunnel types, particularly with regard to large and small-scale projects, as well as road and railroad projects, is essential.

Overall, this study enriches the academic literature on the economic valuation of infrastructure tunnelling projects, providing empirical evidence of their positive effect on property prices. By elucidating the value residents place on improved liveability and residential attractiveness, this study also offers critical guidance for policymakers and urban planners aiming to foster sustainable residential environments through strategic infrastructure investments.

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APPENDICES

Appendix A – Maps with transactions

Appendix B – Data cleaning process

Appendix C – Descriptive statistics

Appendix D – OLS assumptions testing

Appendix E – Syntax STATA

APPENDIX A – MAPS WITH TRANSACTIONS

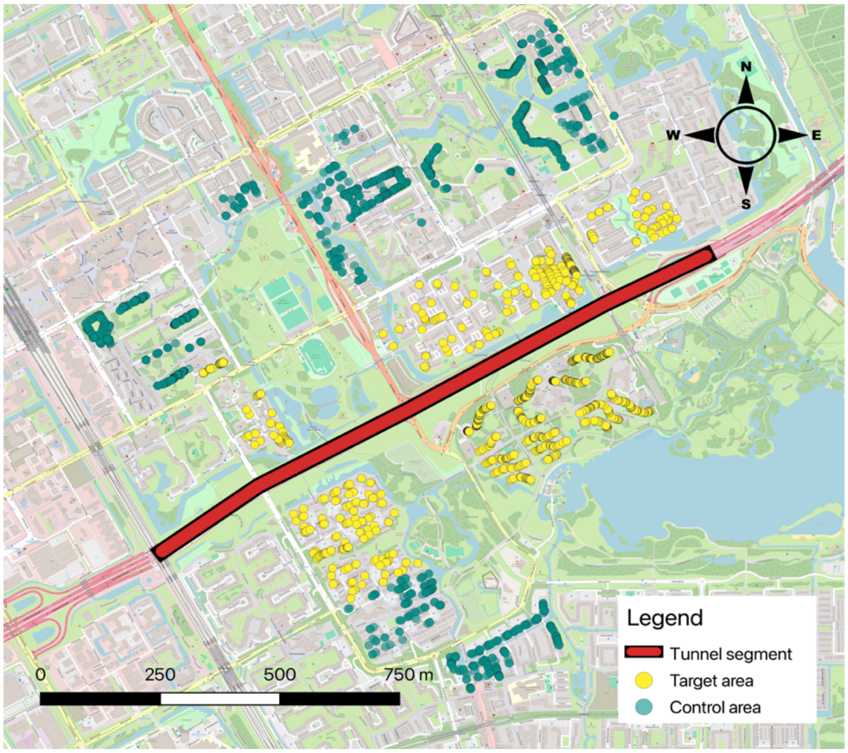

Figure A1. *Transactions around the Gaasperdammertunnel, Amsterdam.*

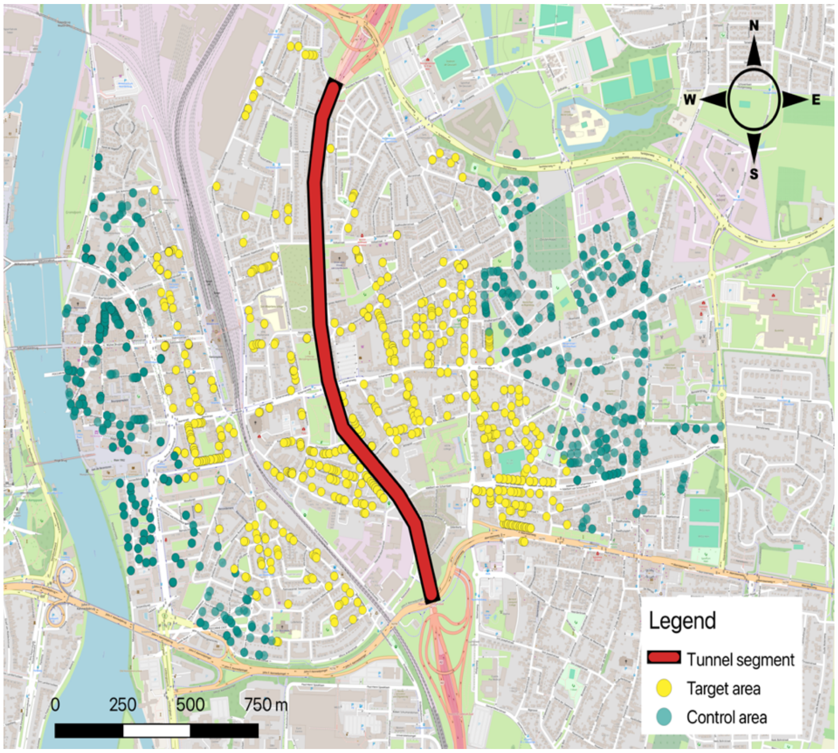

Figure A2. *Transactions around the Koning Willem-Alexander tunnel, Maastricht.*

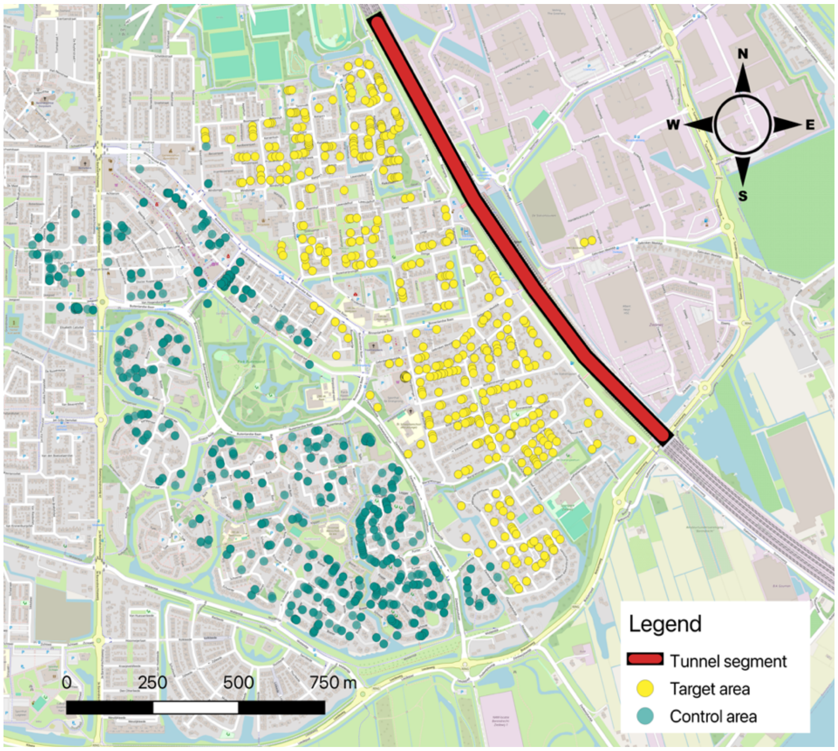

Figure A3*. Transactions around the Kap van Barendrecht, Barendrecht.*

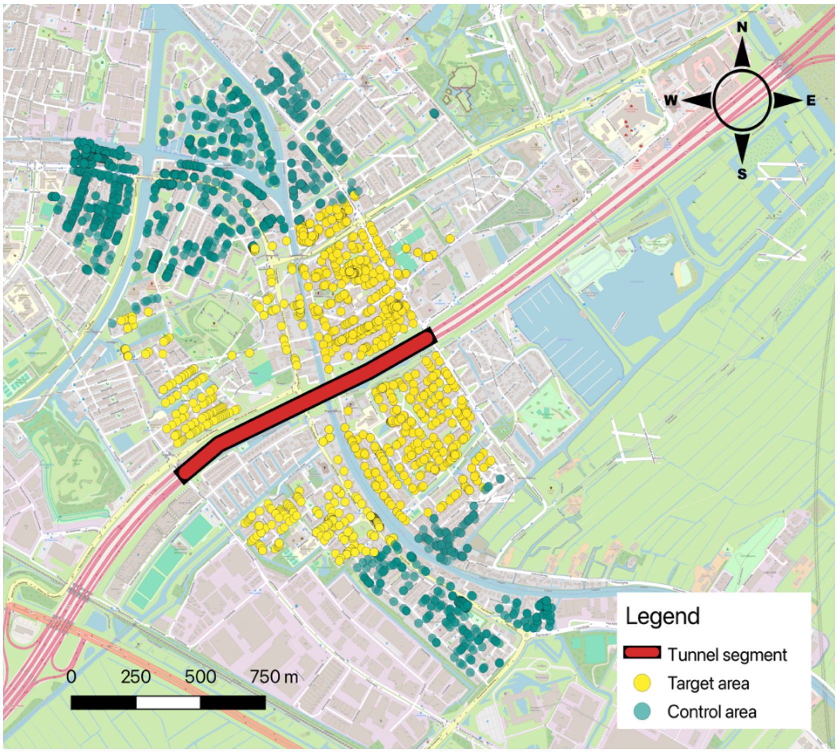

Figure A4*. Transactions around the Limeaquaduct, Leiderdorp, Leiden & Zoeterwoude-Rijndijk*

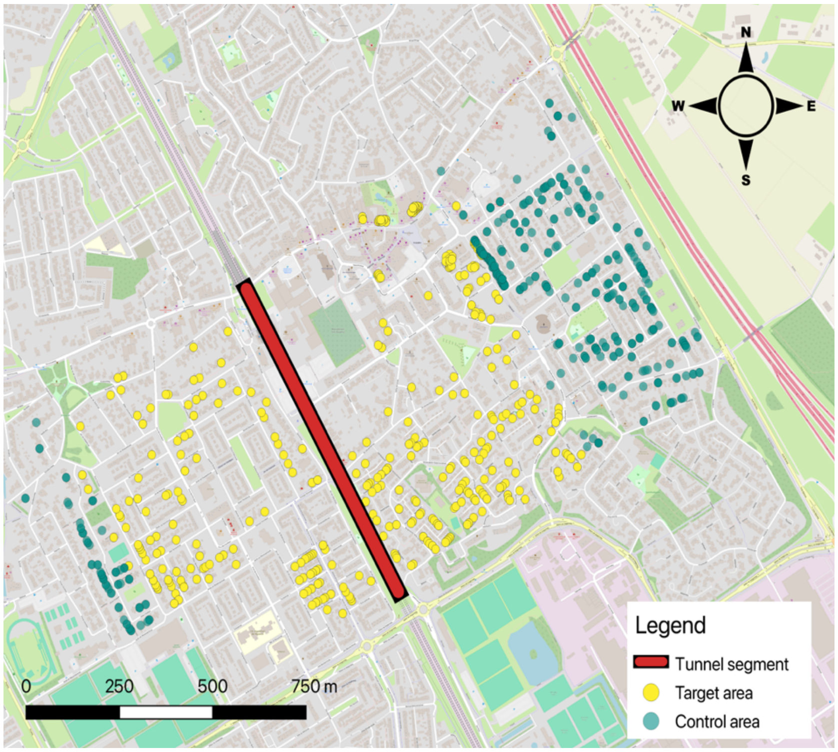

Figure A5. *Transactions around the spoortunnel Best, Best*

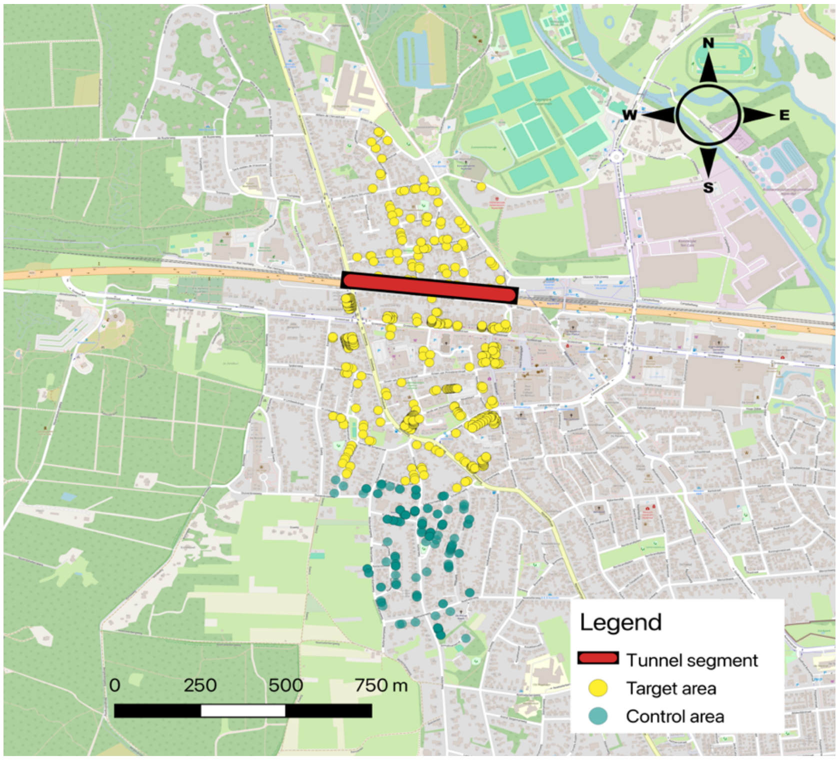

Figure A6. *Transactions around the Salland-Twentetunnel, Nijverdal*

APPENDIX B – DATA CLEANING PROCESS

The NVM provided data on 14,720 residential transaction cases across the six selected cities and towns. In preparation for geoprocessing and distance calculations, the residential properties were geocoded in GIS. Geocoding involves converting addresses into geographic coordinates, allowing them to accurately projected onto a map. Following the projection of properties onto a base map, redundant observations were omitted through the implementation of buffers around the projects. Transaction cases lying beyond the defined buffer zone, extending 1,200 metres around each tunnelled infrastructural project, were omitted from the dataset. This study focuses exclusively on transaction cases occurring within the designated time frame. Cases involving transactions conducted outside the specified analysis periods (before, construction, after) have been omitted. Furthermore, transactions falling below or above a predetermined threshold were considered outliers potentially skewing analysis results; thus, the first and last 1% of transactions were omitted to ensure robust statistical analysis less susceptible to outliers influence. In the context of handling missing data, transaction cases that have no information on the variables 'transaction_price', 'type_of_property', 'transaction_date', 'pc_4', 'pc_6', 'building_period', 'parcel_area', and 'living_area' are omitted. This decision for omitting those cases was motivated by the significance of these variables for subsequent comparisons between different property types and the effect of tunnelled infrastructural projects. Transaction cases containing values labeled as being unrealistic have also been omitted, such as living area of either 0 sqm or 9.999 sqm. Furthermore, the omission of duplicates was imperative due to the inherent limitations of the methods employed inn processing multiple occurrences of a singular transaction. This results in a dataset comprising. 12,102 unique cases. For a thorough representation of the do-file employed in the data cleaning procedure, please refer to Appendix E.

APPENDIX C – DESCRIPTIVE STATISTICS

In addition to data cleaning, several variables within the dataset underwent a transformation. Given the skewed distribution of 'transaction prices', the natural logarithm was applied to these transaction prices to achieve a distribution more closely resembling a normal distribution. This transformation facilitates the establishment of linearity between both the dependent and independent variables (Brooks & Tsolacos, 2010). Similarly, the variable 'living_area' wtransformed using the natural logarithm to address its initial skewness.

Table C1*. Observations per tunnelled infrastructure project*

Project	Frequency	Percent	Cumulative
Gaasperdammertunnel *(1)*	3,657	30.20	30.20
Koning Willem-Alexander *(2)*	1,650	13.63	43.83
Kap van Barendrecht *(3)*	1,886	15.59	59.42
Limesaquaduct *(4)*	3,088	25.50	84.92
Spoortunnel Best *(5)*	1,136	9.38	94.30
Salland-Twentetunnel *(6)*	691	5.70	100
Total	12,102	100	

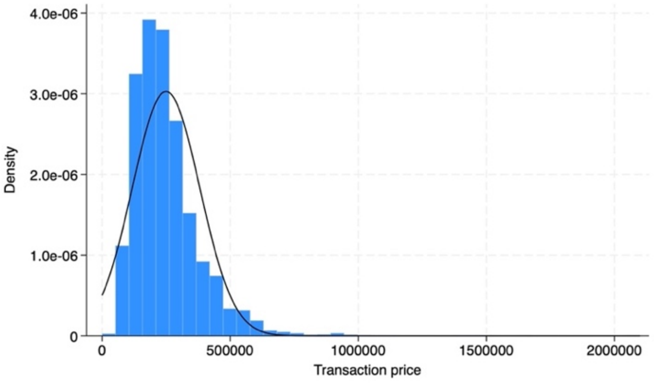

Figure C1. *Histogram Transaction price*

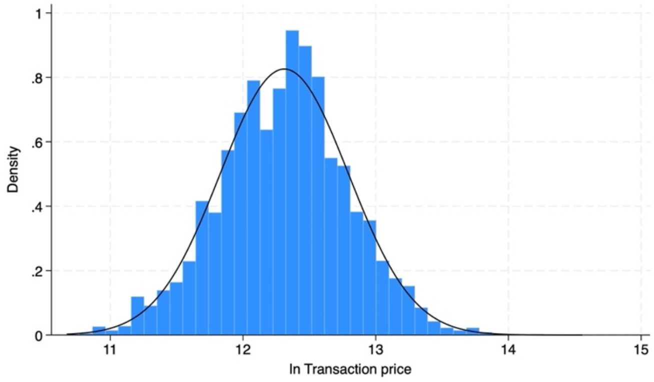

Figure C2. *Histogram Ln Transaction price*

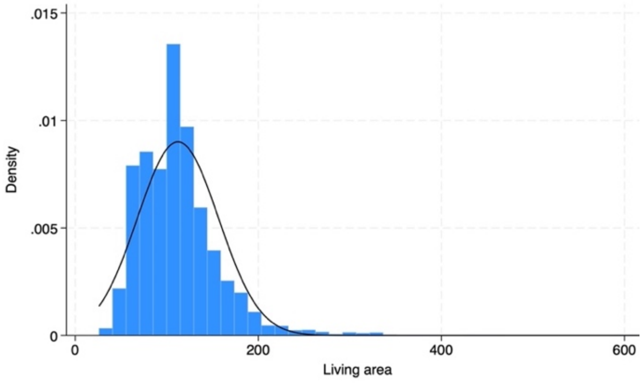

Figure C3. *Histogram Living area*

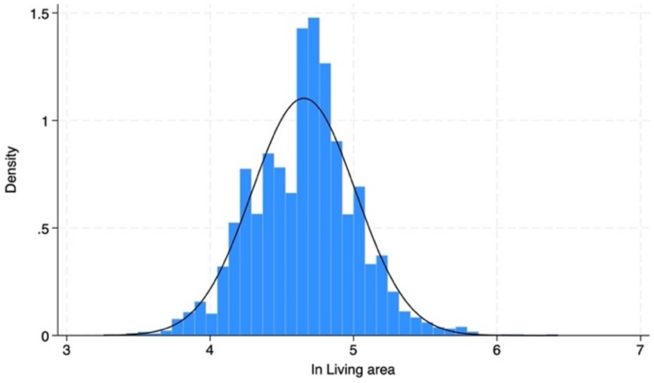

Figure C4. *Histogram Ln Living area*

APPENDIX D – OLS ASSUMPTIONS TESTING

To ensure the validity of coefficient estimates from difference-in-difference hedonic multivariable regression analysis and their associated standard errors, five assumptions must be tested. Meeting these assumptions confirm that the method employed is the Best Linear Unbiases Estimator (Blue), as described by Brooks and Tsolacos (2010). The five assumptions that must be satisfied are as follows:

Table D1. *OLS Asssumptions by Brooks & Tsolacos (2010)*

Assumption	**Technical Notation**	**Interpretation**
1: Linearity	$E(u_t) = 0$	The average value of the errors is zero
2: Homoscedasticity	$var(u_t) = \sigma^2 < \infty$	The variance of the errors is constant and finite
3: No autocorrelation	$cov(u_i, u_j) = 0\ for\ i$	The covariance between the error terms is zero, which means no autocorrelation
4: Independence	$cov(u_t,x_t) = 0$	The regressors are non-stochastic, they are not related to the error terms
5: Normality of errors	$u_t \sim N(0, \sigma^2)$	The error terms are normally distributed

Testing Assumption 1: *Linearity*

A histogram of the residuals, presented in Figure D1, reveals an approximately normal distribution with a mean close to zero. This observation suggests that the residuals are symmetrically distributed around the mean, fulfilling the first assumption of regression analysis. According to Brooks and Tsolacos (2010), this assumption is upheld when a constant term (α) is included in the regression. Given that STATA automatically incorporates a constant term in the regressions, this assumption is inherently satisfied in the analysis.

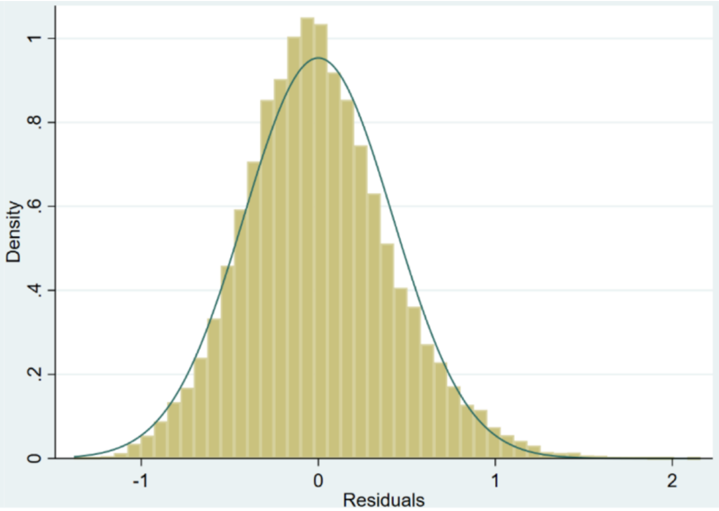

Figure D1. *Histogram of Residuals*

Testing Assumption 2: *Homoscedasticity*

Ensuring the assumption of homoscedasticity, which requires the errors to have a constant variance. This assumption is assessed using two methods. Firstly, a visual inspection of the residuals versus the fitted values is conducted, as illustrated in the residuals-versus-fitted plot in Figures D2. The presence of a discernible pattern in the data suggests heteroscedasticity, violating the assumption of homoscedasticity. Secondly, the Breusch-Pagan/Cook-Weisberg test for heteroscedasticity is employed. The results show highly significant p-values, rejecting the null hypothesis of constant variance. To address this, heteroscedasticity-consistent standard error estimates, or robust standard errors, are applied, ensuring the regression analysis's reliability despite heteroscedasticity (Brooks & Tsolacos, 2010).

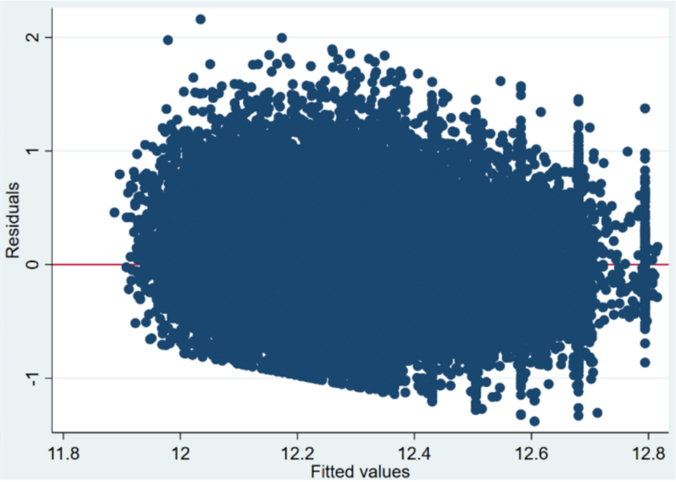

Figure D2. *RVplot*

Table D2. *Breusch Pagan/Cook-Weisberg test for heteroskedasticity.*

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity	
H0	Constant variable
Variables	Fitted values of lnTransaction
Chi2(1)	52392.43
Prob > chi2	0.0000

Testing Assumption 3: *No Autocorrelation*

The assumption of autocorrelation implies that errors are statistically independent and uncorrelated. According to Brooks & Tsolacos (2010), some degree of autocorrelation is common in real estate regressions. The Durbin-Watson test detects autocorrelation: a value of 2 indicates no autocorrelation, 0 indicates perfect positive autocorrelation, and 4 indicates perfect negative autocorrelation. The Durbin-Watson d-statistic for this analysis is 2.008315, suggesting that autocorrelation is nearly absent.

Testing Assumption 4: *Independence*

A correlation matrix (see Table D3) was generated to verify the independence between variables and between variables and the residuals in the preferred model specification. For variables to be considered independent, their correlation coefficients should remain below the threshold of 0.8. High correlations were observed among the interaction variables measuring the effects of the tunnelling infrastructure project, labeled as 'Target.' These high correlations are expected due to the repetitive nature of similar interactions among these variables and do not pose significant issues. No correlations exceeding the 0.8 threshold were detected among the other variables. Additionally, the Variance Inflation Factor (VIF) analysis, presented in Table D3, revealed that all VIF values were well below 10, indicating no multicollinearity concerns. Therefore, no variables were removed from the regression, and any potential issues were mitigated by including clustered standard errors in the regression analysis.

Table D3. *Matrix of correlation*

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1) lnTransaction	1.000												
(2) Target	-0.040	1.000											
(3) DistanceTunnel~t	-0.039	0.688	1.000										
(4) TargetxConstru~n	-0.080	0.476	0.464	1.000									
(5) DistanceTunnel~n	-0.081	0.472	0.472	0.893*	1.000								
(6) TargetxAfter	0.231	0.449	0.447	-0.222	-0.221	1.000							
(7) DistanceTunnel~r	0.230	0.446	0.455	-0.221	-0.219	0.893*	1.000						
(8) ProjectTimeFE	0.409	-0.078	-0.086	-0.055	-0.060	0.277	0.271	1.000					
(9) BuildingPeriod	0.097	-0.028	-0.021	-0.005	-0.005	0.029	0.036	0.202	1.000				
(10) BuildingType	0.134	0.045	0.032	0.026	0.021	-0.032	-0.037	-0.244	-0.235	1.000			
(11) Garden_Dummy	-0.213	-0.065	-0.052	-0.026	-0.020	0.024	0.030	0.364	0.285	-0.415	1.000		
(12) lnArea	0.494	0.066	0.061	0.037	0.033	-0.013	-0.012	-0.287	-0.083	0.478	-0.312	1.000	
(13) PC4	-0.125	0.222	0.210	0.107	0.102	0.127	0.119	-0.320	-0.176	0.212	-0.262	0.259	1.000

Note: Correlations between variables are shown in the table. High correlations (>0.8) are indicated with an asterisks (*).

Testing Assumption 5: *Normality of errors*

To ensure the normal distribution of error terms, Figure D1 indicates that the residuals follow a normal distribution. The Jarque-Bera test further assesses normality, with the null hypothesis stating that the variable is normally distributed. The test results indicate that the residuals are not normally distributed. However, with a sample size of 12,102 observations, this violation is negligible and inconsequential (Brooks & Tsolacos, 2010). Additionally, most variables in this study have been transformed into their natural logarithms to further aid normality. This approach ensures the robustness of the results despite the non-normality of the error terms.

Table D4. *VIF analysis*

	VIF	1/VIF
Target	179.377	.006
DistanceTunnelTarget	178.224	.006
TargetxConstruction	187.825	.005
DistanceTunnelCons~n	183.472	.005
TargetxAfter	176.641	.006
DistanceTunnelAfter	175.232	.006
2.ProjectTimeFE	1.158	.863
3.ProjectTimeFE	1.305	.767
4.ProjectTimeFE	1.237	.808
5.ProjectTimeFE	1.548	.646
6.ProjectTimeFE	1.309	.764
7.ProjectTimeFE	1.359	.736
8.ProjectTimeFE	1.326	.754
9.ProjectTimeFE	1.635	.612
10.ProjectTimeFE	1.516	.66
11.ProjectTimeFE	1.468	.681
12.ProjectTimeFE	1.455	.687
13.ProjectTimeFE	1.466	.682
14.ProjectTimeFE	1.311	.763
15.ProjectTimeFE	1.503	.665
16.ProjectTimeFE	1.309	.764
17.ProjectTimeFE	1.325	.755
18.ProjectTimeFE	1.321	.757
19.ProjectTimeFE	1.565	.639
20.ProjectTimeFE	1.239	.807
21.ProjectTimeFE	1.014	.986
22.ProjectTimeFE	1.355	.738
23.ProjectTimeFE	1.33	.752
24.ProjectTimeFE	1.287	.777
25.ProjectTimeFE	1.104	.906
26.ProjectTimeFE	1.504	.665
27.ProjectTimeFE	1.802	.555
28.ProjectTimeFE	1.358	.736
29.ProjectTimeFE	1.091	.916
30.ProjectTimeFE	1.138	.879
31.ProjectTimeFE	1.259	.794
32.ProjectTimeFE	1.812	.552
33.ProjectTimeFE	1.122	.892
34.ProjectTimeFE	1.056	.947
35.ProjectTimeFE	1.255	.797
36.ProjectTimeFE	1.216	.823
37.ProjectTimeFE	1.998	.5
38.ProjectTimeFE	1.2	.834
39.ProjectTimeFE	1.21	.826
40.ProjectTimeFE	1.172	.853
41.ProjectTimeFE	1.774	.564
42.ProjectTimeFE	1.141	.876
43.ProjectTimeFE	1.242	.805
44.ProjectTimeFE	1.271	.787
45.ProjectTimeFE	1.536	.651
46.ProjectTimeFE	1.102	.907
47.ProjectTimeFE	1.235	.81
48.ProjectTimeFE	1.374	.728
49.ProjectTimeFE	1.341	.746
50.ProjectTimeFE	1.637	.611
51.ProjectTimeFE	1.096	.913
52.ProjectTimeFE	1.446	.692
53.ProjectTimeFE	1.292	.774
54.ProjectTimeFE	1.371	.729
55.ProjectTimeFE	1.518	.659
56.ProjectTimeFE	1.636	.611
57.ProjectTimeFE	1.556	.643
58.ProjectTimeFE	1.305	.766
59.ProjectTimeFE	1.718	.582
60.ProjectTimeFE	1.141	.876
61.ProjectTimeFE	1.426	.701
62.ProjectTimeFE	1.401	.714
63.ProjectTimeFE	1.63	.613
64.ProjectTimeFE	1.157	.864
65.ProjectTimeFE	1.803	.555
66.ProjectTimeFE	1.55	.645
67.ProjectTimeFE	1.764	.567
68.ProjectTimeFE	1.216	.822
69.ProjectTimeFE	1.928	.519
70.ProjectTimeFE	1.353	.739
71.ProjectTimeFE	1.819	.55
72.ProjectTimeFE	1.293	.773
73.ProjectTimeFE	2.233	.448
74.ProjectTimeFE	1.569	.637
75.ProjectTimeFE	1.847	.541
77.ProjectTimeFE	1.979	.505
78.ProjectTimeFE	1.639	.61
79.ProjectTimeFE	1.872	.534
80.ProjectTimeFE	2.059	.486
81.ProjectTimeFE	1.491	.671
83.ProjectTimeFE	2.009	.498
84.ProjectTimeFE	1.493	.67
85.ProjectTimeFE	1.827	.547
87.ProjectTimeFE	3.033	.33
88.ProjectTimeFE	2.234	.448
89.ProjectTimeFE	1.699	.589
1.BuildingPeriod	4.712	.212
2.BuildingPeriod	5.354	.187
3.BuildingPeriod	4.226	.237
4.BuildingPeriod	7.338	.136
5.BuildingPeriod	6.318	.158
6.BuildingPeriod	8.531	.117
7.BuildingPeriod	5.539	.181
8.BuildingPeriod	6.625	.151
9.BuildingPeriod	2.794	.358
1.BuildingType	4.329	.231
2.BuildingType	7.922	.126
3.BuildingType	3.839	.26
4.BuildingType	6.481	.154
5.BuildingType	8.202	.122
Garden Dummy	7.939	.126
lnArea	2.14	.467
Mean VIF	12.769	.

APPENDIX E – SYNTAX STATA

Additional install

```
ssc install outreg2
ssc install asdoc
ssc install winsor2
ssc install jb
ssc install regcheck
```

Destring (in)dependent variables

Transaction price

```
replace transaction_price = subinstr(transaction_price, ",", ".", .)
destring transaction_price, replace force
```

Distance to tunnel

```
replace distance = subinstr(distance, ",", ".", .)
destring distance, replace force
```

Living area

```
replace living_area = subinstr(living_area, ",", ".", .)
destring living_area, replace force
```

Drop oberservations

```
drop if missing(pc_4)
drop if length(pc_4)<4
drop if missing(pc_6)
drop if length(pc_6)<6
drop if missing(project)
drop if missing(transaction_price)
drop if missing(transaction_date)
drop if missing(days_on_the_market)
drop if missing(type_of_property)
drop if missing(parcel_area)
drop if missing(building_period)
drop if missing(living_area)
drop if living_area > 990
drop if missing(distance)
```

Drop transaction by transaction date

```
drop if project == 1 & date(transaction_date, "DMY") >= date("01/02/2024", "DMY")
drop if project == 1 & date(transaction_date, "DMY") < date("01/08/2010", "DMY")
drop if project == 2 & date(transaction_date, "DMY") >= date("01/10/2021", "DMY")
drop if project == 2 & date(transaction_date, "DMY") < date("31/08/2006", "DMY")
drop if project == 3 & date(transaction_date, "DMY") >= date("01/01/2014", "DMY")
drop if project == 3 & date(transaction_date, "DMY") < date("28/02/1995", "DMY")
drop if project == 4 & date(transaction_date, "DMY") >= date("01/04/2018", "DMY")
drop if project == 4 & date(transaction_date, "DMY") < date("31/08/2004", "DMY")
```

```
drop if project == 5 & date(transaction_date, "DMY") >= date("01/03/2006", "DMY")
drop if project == 5 & date(transaction_date, "DMY") < date("31/03/1993", "DMY")
drop if project == 6 & date(transaction_date, "DMY") >= date("01/10/2016", "DMY")
drop if project == 6 & date(transaction_date, "DMY") < date("31/01/2003", "DMY")
```

Drop distances

```
drop if distance < 0
drop if distance > 1200
```

Drop Transaction

```
sum transaction_price, detail
histogram transaction_price, normal
tab transaction_price
log using "table_output.txt", text replace
drop if transaction_price <= 71200   //*winsorizing:drop lowest 1%*
drop if transaction_price >= 700000 //*winsorizing: drop highest 1%*
histogram transaction_price, normal
sum transaction_price, detail
```

Recode building_period variable

```
capture label drop period_label
gen BuildingPeriod = .
replace BuildingPeriod = 0 if building_period == "1500-1905"
replace BuildingPeriod = 1 if building_period == "1906-1930"
replace BuildingPeriod = 2 if building_period == "1931-1944"
replace BuildingPeriod = 3 if building_period == "1945-1959"
replace BuildingPeriod = 4 if building_period == "1960-1970"
replace BuildingPeriod = 5 if building_period == "1971-1980"
replace BuildingPeriod = 6 if building_period == "1981-1990"
replace BuildingPeriod = 7 if building_period == "1991-2000"
replace BuildingPeriod = 8 if building_period == "2001-2010"
replace BuildingPeriod = 9 if building_period == "2011-2020"
replace BuildingPeriod = 10 if building_period == "unkown"
label define period_label 0 "<1906", replace
label define period_label 1 "1906-1930", add
label define period_label 2 "1931-1944", add
label define period_label 3 "1945-1959", add
label define period_label 4 "1960-1970", add
label define period_label 5 "1971-1980", add
label define period_label 6 "1981-1990", add
label define period_label 7 "1991-2000", add
label define period_label 8 "2001-2010", add
label define period_label 9 "2011-2020", add
label define period_label 10 "unkown", add
label values BuildingPeriod period_label
tabulate BuildingPeriod
```

Create dummy variable - 0 = House; 1 = Apartment

```
gen apartment_dummy = 0
replace apartment_dummy = 1 if type_of_property == "Apartment"
label define apartment_dummy 0 "House" 1 "Apartment"
label values apartment_dummy apartment_dummy
tabulate apartment_dummy
```

Create dummy variable - 0 = Garden; 1 = No Garden

```
gen Garden_Dummy = 1
replace Garden_Dummy = 0 if parcel_area >= 1
label define Garden_Dummy 1 "No Garden" 0 "Garden"
label values Garden_Dummy Garden_Dummy
tabulate Garden_Dummy
```

Recode buidling type

```
encode type_of_property, generate(BuildingType)
tabulate BuildingType
```

Create dummy variable for tunnelled road infrastructure

```
gen Road = 1
replace Road = 0 if project==3
replace Road = 0 if project==5
replace Road = 0 if project==6
label define Road 0 "Railroad" 1"Road"
label values Road Road
tabulate Road
```

Create dummy variable for tunnelled railroad infrastructure

```
gen Railroad = 0
replace Railroad = 1 if project==3
replace Railroad = 1 if project==5
replace Railroad = 1 if project==6
label define Railroad 0 "Road" 1 "Railroad"
label values Railroad Railroad
tabulate Railroad
```

Spatially Fixed Effects: Postcode

```
encode pc_4, generate(PC6)
gen PC_4 = substr(pc_4, 1, 4)
encode PC_4, generate(PC4)
```

Time Fixed Effects: Transaction Year

```
gen Tran = date(transaction_date, "DMY")
format Tran %td
gen TransactionYear = year(Tran)
tabulate TransactionYear
```

Project Time Fixed Effects: Year * Project F.E.

```
gen Project_Time_FE = string(TransactionYear) + "-" + string(project)
encode Project_Time_FE, generate(ProjectTimeFE)
```

Target and Control Area

```
gen Target = 1
replace Target = 0 if distance >600
label define Target 0 "Control" 1 "Target"
label values Target Target
tabulate Target
```

Create dummy variable for periods (Before, Construction or After)

```
gen transaction_date_stata = date(transaction_date, "DMY")
format transaction_date_stata %td
gen project_str = string(project)
```

Before Construction Dummy

```
gen Before = 0
replace Before = 1 if project_str == "1" & transaction_date_stata < mdy(8, 1, 2015)
replace Before = 1 if project_str == "2" & transaction_date_stata < mdy(9, 1, 2011)
replace Before = 1 if project_str == "3" & transaction_date_stata < mdy(3, 1, 2000)
replace Before = 1 if project_str == "4" & transaction_date_stata < mdy(9, 1, 2009)
replace Before = 1 if project_str == "5" & transaction_date_stata < mdy(4, 1, 1998)
replace Before = 1 if project_str == "6" & transaction_date_stata < mdy(2, 1, 2008)
label define Before 0 "Not Before" 1 "Before"
label values Before Before
tabulate Before
```

During Construction Dummy

```
gen Construction = 0
replace Construction = 1 if project_str == "1" & transaction_date_stata >= mdy(8, 1, 2015) &
transaction_date_stata < mdy(6, 1, 2020)
replace Construction = 1 if project_str == "2" & transaction_date_stata >= mdy(9, 1, 2011) &
transaction_date_stata < mdy(4, 1, 2018)
replace Construction = 1 if project_str == "3" & transaction_date_stata >= mdy(3, 1, 2000) &
transaction_date_stata < mdy(6, 1, 2007)
replace Construction = 1 if project_str == "4" & transaction_date_stata >= mdy(9, 1, 2009) &
transaction_date_stata < mdy(10, 1, 2014)
replace Construction = 1 if project_str == "5" & transaction_date_stata >= mdy(4, 1, 1998) &
transaction_date_stata < mdy(9, 1, 2002)
replace Construction = 1 if project_str == "6" & transaction_date_stata >= mdy(2, 1, 2008) &
transaction_date_stata < mdy(4, 1, 2013)
label define Construction 0 "Not Construction" 1 "Construction"
label values Construction Construction
tabulate Construction
```

After Construction Dummy

```
gen After = 0
replace After = 1 if project_str == "1" & transaction_date_stata >= mdy(6, 1, 2020)
replace After = 1 if project_str == "2" & transaction_date_stata >= mdy(4, 1, 2018)
replace After = 1 if project_str == "3" & transaction_date_stata >= mdy(6, 1, 2007)
replace After = 1 if project_str == "4" & transaction_date_stata >= mdy(10, 1, 2014)
replace After = 1 if project_str == "5" & transaction_date_stata >= mdy(9, 1, 2002)
replace After = 1 if project_str == "6" & transaction_date_stata >= mdy(4, 1, 2013)
label define After 0 "Not After" 1 "After"
label values After After
tabulate After
```

Create Dependent Variable

```
histogram transaction_price, normal
gen lnTransaction = ln(transaction_price)
histogram lnTransaction, normal
kdensity lnTransaction, normal
```

Variable transformation

```
histogram living_area, normal
sum living_area, detail
gen lnArea = ln(living_area)
histogram lnArea, normal
kdensity lnArea, normal
```

Functional form - Distance

```
histogram distance, normal
gen lndistance = ln(distance)
```

Difference-In-Difference Interactions

```
gen TargetxConstruction = Target*Construction
gen TargetxAfter = Target*After
```

Difference-In-Difference Interactions distances

```
gen DistanceTunnelTarget = Target*lndistance
gen DistanceTunnelConstruction = Target*Construction*lndistance
gen DistanceTunnelAfter = Target*After*lndistance
```

Regression analysis

1: Model 1 - Base

```
reg lnTransaction Target DistanceTunnelTarget TargetxConstruction DistanceTunnelConstruction
TargetxAfter DistanceTunnelAfter i.ProjectTimeFE, vce(robust)
```

2: Model 2 - Extent

```
reg lnTransaction Target DistanceTunnelTarget TargetxConstruction DistanceTunnelConstruction
TargetxAfter DistanceTunnelAfter i.ProjectTimeFE i.BuildingPeriod i.BuildingType
Garden_Dummy lnArea, vce(robust)
```

3: Model 3 - PC4

```
reg lnTransaction Target DistanceTunnelTarget TargetxConstruction DistanceTunnelConstruction
TargetxAfter DistanceTunnelAfter i.ProjectTimeFE i.BuildingPeriod i.BuildingType
Garden_Dummy lnArea, absorb (PC4) vce(robust)
```

4: Model 4 - PC6

```
reg lnTransaction Target DistanceTunnelTarget TargetxConstruction DistanceTunnelConstruction
TargetxAfter DistanceTunnelAfter i.ProjectTimeFE i.BuildingPeriod i.BuildingType
Garden_Dummy lnArea, absorb (PC6) vce(robust)
```

Alternative Specifications data preparation

Distance dummies Target

```
gen Target150 = 0
replace Target150 = 1 if distance <150
gen Target300 = 0
replace Target300 = 1 if distance >150 & distance <300
gen Target450 = 0
replace Target450 = 1 if distance >300 & distance <450
gen Target600 = 0
replace Target600 = 1 if distance >450 & distance <600
```

Distance dummies Target x Construction

```
gen Target150C = 0
replace Target150C = 1 if distance <150 & Construction
gen Target300C = 0
replace Target300C = 1 if distance >150 & distance <300 & Construction
gen Target450C = 0
replace Target450C = 1 if distance >300 & distance <450 & Construction
gen Target600C = 0
replace Target600C = 1 if distance >450 & distance <600 & Construction
```

Distance dummies Target x After

```
gen Target150A = 0
replace Target150A = 1 if distance <150 & After
gen Target300A = 0
replace Target300A = 1 if distance >150 & distance <300 & After
gen Target450A = 0
replace Target450A = 1 if distance >300 & distance <450 & After
gen Target600A = 0
replace Target600A = 1 if distance >450 & distance <600 & After
```

Alternative specification regression analysis

1: Model 1 - Base

```
reg lnTransaction Target150 Target300 Target450 Target600 Target150C Target300C Target450C Target600C Target150A Target300A Target450A Target600A i.ProjectTimeFE, vce(robust)
```

2: Model 2 - Extent

```
reg lnTransaction Target150 Target300 Target450 Target600 Target150C Target300C Target450C Target600C Target150A Target300A Target450A Target600A i.ProjectTimeFE i.BuildingPeriod i.BuildingType Garden_Dummy lnArea, vce(robust)
```

3: Model 3 - PC4

```
reg lnTransaction Target150 Target300 Target450 Target600 Target150C Target300C Target450C Target600C Target150A Target300A Target450A Target600A i.ProjectTimeFE i.BuildingPeriod i.BuildingType Garden_Dummy lnArea, absorb (PC4) vce(robust)
```

4: Model 4 - PC6

```
reg lnTransaction Target150 Target300 Target450 Target600 Target150C Target300C Target450C Target600C Target150A Target300A Target450A Target600A i.ProjectTimeFE i.BuildingPeriod i.BuildingType Garden_Dummy lnArea, absorb (PC6) vce(robust)
```

Create Urban versus Suburban/Rural Areas

```
gen Urban_dummy = 0
replace Urban_dummy = 1 if project == 1
replace Urban_dummy = 1 if project == 2
label define Urban_dummt 0 "Suburban/Rural" 1 "Urban"
label values Urban_dummy Urban_dummy
tab Urban_dummy
```

Urban versus Suburban/Rural Areas Specifications

```
reg lnTransaction Target DistanceTunnelTarget TargetxConstruction DistanceTunnelConstruction TargetxAfter DistanceTunnelAfter i.ProjectTimeFE i.BuildingPeriod i.BuildingType lnArea if Urban_dummy ==1, absorb (PC4) vce(robust)
```

```
reg lnTransaction Target DistanceTunnelTarget TargetxConstruction DistanceTunnelConstruction TargetxAfter DistanceTunnelAfter i.ProjectTimeFE i.BuildingPeriod i.BuildingType lnArea if Urban_dummy ==0, absorb (PC4) vce(robust)
```

OLS Assumptions

```
reg lnTransaction Target DistanceTunnelTarget TargetxConstruction DistanceTunnelConstruction TargetxAfter DistanceTunnelAfter i.ProjectTimeFE i.BuildingPeriod i.BuildingType Garden_Dummy lnArea, absorb (PC4) vce(robust)
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

```
reg lnTransaction Target DistanceTunnelTarget TargetxConstruction DistanceTunnelConstruction
TargetxAfter DistanceTunnelAfter i.ProjectTimeFE i.BuildingPeriod i.BuildingType
Garden_Dummy lnArea, absorb (PC4) robust
predict r1, resid
gen time=_n
tsset time
dwstat
```

Assumption 4: Independence

```
reg lnTransaction Target DistanceTunnelTarget TargetxConstruction DistanceTunnelConstruction
TargetxAfter DistanceTunnelAfter i.ProjectTimeFE i.BuildingPeriod i.BuildingType
Garden_Dummy lnArea, absorb (PC4) vce (robust)
vif

corr lnTransaction Target DistanceTunnelTarget TargetxConstruction DistanceTunnelConstruction
TargetxAfter DistanceTunnelAfter ProjectTimeFE BuildingPeriod BuildingType Garden_Dummy
lnArea PC4

reg lnTransaction Target DistanceTunnelTarget TargetxConstruction DistanceTunnelConstruction
TargetxAfter DistanceTunnelAfter i.ProjectTimeFE i.BuildingPeriod i.BuildingType
Garden_Dummy lnArea, absorb (PC4) vce (robust)
sktest
```

Assumption 5: Normality

```
histogram r,
normal histogram r1, normal
jb r
jb r1
```

Descriptive statistics

```
summarize transaction_price lnTransaction distance TransactionYear living_area lnArea
i.BuildingType i.BuildingPeriod apartment_dummy Target

summarize transaction_price lnTransaction distance TransactionYear living_area lnArea
i.BuildingType i.BuildingPeriod Target if distance <600

summarize transaction_price lnTransaction distance TransactionYear living_area lnArea
i.BuildingType i.BuildingPeriod Target if distance >600
```

Graph

Graph descriptive statistics

```
collapse (mean) avg_price=transaction_price, by(TransactionYear)
collapse (mean) avg_price=transaction_price, by(TransactionYear Target)
reshape wide avg_price, i(TransactionYear) j(Target)

twoway (line avg_price0 TransactionYear, lcolor(blue) lpattern(solid)) ///
        (line avg_price1 TransactionYear, lcolor(red) lpattern(dash)), ///
        title("Development of Property Prices Over the Years") ///
        ytitle("Average Transaction Price") ///
        xtitle("Year") ///
        legend(order(1 "Control Group" 2 "Target Group")) ///
        xlabel(, angle(45))

twoway (line avg_price TransactionYear), ///
    title("Development of Property Prices Over the Years") ///
    ytitle("Average Transaction Price") ///
    xtitle("Year") ///
    xlabel(, angle(45))
```

Graph distance effect

```
set obs 1200
gen distance = _n
gen ln_distance = ln(distance)
gen totaleffect_normalized_100=100+(-0.0587563 * ln_distance*100)
twoway line totaleffect_normalized_100 distance, ytitle("Effect Remaining (%)") xtitle("Distance")
legend(off) graphregion(color(white)) xlabel(1 100 200 300 400 500 600 700 800 900 1000 1100
1200)
```