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Transit-oriented developments and house prices

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Transit-oriented developments and residential property values: Evidence from the synthetic control method

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Abstract
As urbanization continues, congestion externalities are becoming more important due to an increasing utilization of the prevailing infrastructure. A growing number of cities have conducted transit-oriented developments to mitigate these congestion externalities. In this article, we analyze the effects of transit-oriented developments on residential property values. As an extension to the standard hedonic pricing method, we employ the synthetic control method to estimate the value-added of transit-oriented developments. Three quantitative case studies in the Netherlands indicate that the effects of transit-oriented developments are highly heterogeneous. One case shows strong positive results. The other two are either insignificant, or temporarily negative.

JEL classification: R38, R58

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1. Introduction

The ongoing trend of urbanization is accompanied with increasing concerns regarding the urban quality of life.[2] Although there is an abundance of theoretical (e.g., Duranton and Puga, 2004) and empirical (e.g., Puga, 2010) evidence for the existence of urban agglomeration externalities, it is also recognized that these positive agglomeration externalities are (partly) offset by congestion externalities (e.g., Glaeser, 1998; Brinkman, 2016). These negative externalities, which primarily appear in the form of traffic congestion, noise and air pollution, become increasingly important due to an expanding utilization of the prevailing infrastructure. For this reason, congestion externalities have acted as dispersion forces, inducing urbanization mainly to occur at the cities' edges, which leads to suboptimal internal structures of cities (OECD, 2017).

Transit-oriented developments have been increasingly referred to by policymakers as a potential solution to deal with these congestion externalities. Transit-oriented developments are meant to rejuvenate the area in and around a railway station, while maintaining or even improving accessibility. The principal objective of such developments is to create a compact, mixed-land use of real estate that by its design is accustomed to the needs of pedestrians and cyclists. This naturally discourages the car use in proximity of the railway station (Cervero, 2004). Furthermore, the design of the railway station intends to epitomize an urban symbol, enacting itself as a meeting place for both residents and businesses.

From a theoretical point of view, transit-oriented developments will lead to improved accessibility and an increase in urban amenities. As these help to strengthen agglomeration externalities and mitigate congestion externalities, transit-oriented developments are expected to capitalize into real estate prices. Establishing such a relationship empirically has been proven difficult however. While there is a large body of work establishing a positive relationship between real estate prices and living in proximity of a generic railway station (Debrezion et al., 2007), the literature in respect to transit-oriented developments remains sparse (Cervéro et al., 2002; Bartomolew and Ewing, 2011). Although recent studies have provided some insights in the value-added of transit-oriented developments (Duncan, 2011; Mathur and Ferrel, 2013; Kay et al., 2014), the literature remains plagued by a number of identification issues.

The most pressing issue relates to the fact that transit-oriented developments are generally conducted within the central business districts of city centers. As part of the urbanization wave, we show that these city centers have inherently become more attractive over time, as being mirrored by rising residential prices in proximity to city centers. Therefore, to establish causal inferences of transit-oriented developments, one cannot use residential property values at the cities' edges as a control group. Employing such a strategy would estimate the total effect as a combination of two components: the transit-oriented developments and the inherent city center trend. The empirical challenge is to separate the former effect from the latter.

The main contribution of this article is that we employ a novel strategy within the hedonic pricing literature to estimate the value-added of transit-oriented developments, by exploiting three case studies in the Netherlands. We make use of the insight that other cities have experienced an inherent city center trend as well. From an econometric point of view, a

[2] Projections indicate that 70 percent of the world population will live in urban areas in 2050 (United Nations, 2018).

differences-in-differences (DiD) strategy may be an adequate identification strategy. In such DiD estimates, one would compare the willingness to pay to live in proximity of a railway station in cities that did conduct transit-oriented developments to cities that did not. Yet, a few complications may undermine the application of such a conventional DiD strategy. The most prominent issue centers on the notion that characteristics of control cities may differ substantially from the characteristics of the treatment cities (George and Bennett, 2005). Moreover, it may be hard to control for unobserved confounding time-varying covariates that are affected by the transit-oriented developments. Differences-in-differences models assume these unobserved confounders to be constant over time. In these situations, the assumption of a parallel trend may not be plausible.

To deal with these issues, we employ the synthetic control method, which is originally coined by Abadie and Gardeazabal (2003) and further advanced by Abadie et al. (2010). Instead of just comparing the unit of interest with equally weighted control units, the synthetic control method provides a transparent data driven procedure to construct a counterfactual based on a convex combination of control units. The weights are designated in such a way that the synthetic control unit is able to replicate similar traits (outcome trends and relevant characteristics) as the treatment unit of interest during the pre-intervention period. In our case, the convex combination exhibits the counterfactual city, showing an estimate of what the willingness to pay to live in proximity of a railway station of the treatment city would have been in case no transit-oriented developments would have been conducted.

Our empirical findings are highly heterogeneous. One case (Tilburg) shows strong positive effects of the transit-oriented developments after two years of construction work. Another case (Arnhem) displays strong negative effects, albeit temporarily. The third case (Breda) exhibits no significant effect of the transit-oriented developments. We show that these results hold for a number of robustness exercises, including the usage of different compositions of potential control cities and in-time placebos.

When we further delve into the effects of transit-oriented developments, we find that there is a considerable variation in within-city effects as well. Our within-city results demonstrate a strong relationship between the willingness to pay effects and the intensity of the developments at both sides of the railway station and the railway line. Specifically, we find strong positive results at the northern-side of the railway station in Breda and Tilburg. We argue that these effects can be attributed to the removal of the barriers for inner city traffic and access to the railway station. This led to an increase of available amenities and improved accessibility for residents at the northern-side of these railway stations. Arnhem, on the other hand, experienced a substantial temporary negative effect at the southern side of the station. The most plausible explanation for this negative effect is intense nuisance due to unexpected delays in construction. Hence, there exist large differences in within-city effects. This insight could be used for new evaluations of transit-oriented developments.

The remainder of the article is structured as follows. In Section 2, we provide a description of the three case studies. Section 3 discusses our two-stage empirical approach to estimate the effects of transit-oriented developments, while Section 4 presents an overview of the employed datasets. Section 5 shows the main results, followed by a couple of robustness exercises and analyses of spatial heterogeneities. Section 6 wraps up with the conclusions.

2. Case descriptions

This section elaborates on the history of transit-oriented developments in the Netherlands (subsection 2.1), followed by an overview of the selection of the case studies (subsection 2.2). Then it provides a description of the common elements of the transit-oriented developments in Breda and Tilburg (subsection 2.3), and briefly discusses the unique characteristics of each of the three cases (subsection 2.4).

2.1. A brief history and the scope of transit-oriented developments in the Netherlands

The plans to conduct transit-oriented developments in the Netherlands were finalized in the 1990's. In the earlier decades, the Netherlands experienced a relatively long suburbanization wave. The relatively favorable economic situation during the 1990's helped to reverse this trend. Most prominently, businesses started to settle in the central business districts of city centers and residents eventually followed - a pattern that re-strengthened the position of Dutch cities (Van der Wouden et al., 2009).

The new urbanization wave proved to be a major challenge as well as an opportunity. The challenge for policymakers was to satisfy the increasing demand for commercial and residential space. At the same time, the urbanization wave proved to be an opportunity to transform the structure of cities. More specifically, municipalities started to consider integrating land-use policies with mobility policies. In doing so, policymakers proposed to conduct transit-oriented developments around outdated railway stations in proximity to city centers.

The scope of transit-oriented development effects

The Dutch transit-oriented developments follow a similar philosophy as put forward in the literature (Cervero et al., 2002; Cervero, 2004). This philosophy shares two interacting elements. The first element is that urban developments are planned in close proximity of a transit-station. The principal objective of such developments is to create a high-density land use of commercial and residential real estate. The second element – an enhanced transit system – is essential to exploit the developed real estate in an efficient manner.[3] That is, planned concentrations of development are connected with existing concentrations by an enhanced transit-system (Bertolini et al., 2009). In other words, the mixed-use developments and the public space around the transit-station are by its design accustomed to the needs of pedestrians, cyclists, and forms of public transport.

2.2 Selection of the case studies

During the 1990's, the Dutch government proposed to conduct transit-oriented developments in seven cities. We selected three out of these seven cities to evaluate the (causal) effects of transit-oriented developments. The selection was based on two main criteria. First, no other major

[3] Transit-oriented developments enhance the transit-system at two dimensions: within a city and between cities. The *within-city* enhancement of the transit-system occurs when a city (with transit-oriented developments) adapts its current infrastructure network, and or develops new infrastructure, in order to attain the new urban developments faster. Moreover, the *between-city* enhancement of the transit-system occurs when transit-oriented developments transform the railway station of the (treatment) city in order to handle trains more efficiently. This does not only enhance the level of service of the railway station of the treatment city, it also enhances the level of service of the railway stations of other cities (the entire network). We will show this formally later on.

public investments should have taken place in the city during the evaluation period. Second, the transformation of the railway station should be finalized at the end of our evaluation period. The cities of Amsterdam, Den Hague, Rotterdam and Utrecht do not adhere to either one or both of these criteria. For this reason, these cities are not analyzed in this article. In contrast, the cities Breda, Tilburg and Arnhem do comply with the selection criteria and are therefore evaluated in this article. These case studies are briefly discussed in the following paragraphs.

2.3 Common elements of transit-oriented developments Breda and Tilburg

The plans to conduct transit-oriented developments in Tilburg and Breda were rooted in the presence of large marshalling yards of the principal Dutch railway operator (Nationale Spoorwegen). These marshalling yards were located at the northern side of both railway stations and traditionally formed a physical barrier. For this reason, the railway stations in Tilburg and Breda were characterized by only one entrance: at the southern side. If north located residents wanted to travel by train, they were required to take a detour. The physical barrier could also be detected in the socio-economic domain. Traditionally, people with a relatively low socio-economic status resided north of the railway line, those with a (above) average socio-economic status at the south.

During 2004, the principal railway operator reconsidered its financial strategy and decided to sell their marshalling yards. This paved the way for the municipalities of Breda and Tilburg to purchase multiple hectares of land. Urban planners were invited by municipalities to come up with plans to revive the neighborhoods in and around the railway station. This eventually resulted in masterplans to conduct transit-oriented developments.

2.4 Unique characteristics of case studies

In the following, we provide a compressed overview of the unique characteristics of the three cities with transit-oriented developments. We provide detailed information about each of the three projects in Appendix A. The Appendix also includes timelines and figures specifying when and where the developments were carried out.[4]

A. Description Breda

In advance of the construction work on the railway station, space had to be freed up in Breda. This process started in 2008 with the demolishment of a few house blocks at the northern side of the station and took until 2012 – the year where the marshalling yards were demolished. The construction work on the new railway station began in 2012 as well. Next to the traditional amenity of being a transport hub of multiple public transport facilities, the new railway station includes space for residential- and commercial real estate. These amenities were gradually build during the period from 2012-2016. At the end of 2015, the two-way opening structure at both the southern and the northern side of the railway station was completed. This meant that residents at the northern side were finally able to easily attain the city center without having to take a detour.

[4] The information presented in the description of the cases is based upon interviews with the urban planners in-chief of the transit-oriented developments and the initial masterplans.

From 2015 onwards, the construction of real estate on the vacated space on mainly the northern side of the railway station took place. By the end of 2017, 132.000 m^2 of real estate was developed. The developments are planned to continue until the end of 2030 with another 300.000m^2 that are planned to be materialized, mainly at the north-eastern side of the railway station (see Appendix figure A1 for more details).

B. Description Tilburg

The developments in Tilburg started in 2012 with the demolishment of the marshalling yards. From 2013 onwards, the construction on the vacated space took place. The construction work on the railway station began with the widening of the travelers passage of the railway station to increase transit capacity and improve the quality of public space. The widening of the passage made it possible to create an opening at the northern side of the station. This two-way structure was finalized at the end of 2016. During these years, new shopping facilities were added to the passage. During the construction work, passengers were simply able to attain the platform of the railway station due to a temporary opening at the eastern side.

At the end of 2017, 135.000 m^2 of real estate had been developed. Two-thirds was for residential purposes. The remainder comprises mostly commercial real estate. The developments are planned to endure until the end of 2027, with another 200.000m^2 that are planned to be materialized at the north-eastern side of the railway station (see Appendix figure A2 for more details).

C. Description Arnhem

The main goal for Arnhem was to create a transport hub, where different modes of public transport allow easy transfers. The spatial developments outside the railway stations mainly consist of commercial buildings at the southern side of the railway station.

In contrast to the Breda and Tilburg cases, the presence of a marshalling yard was not a consideration to conduct the transit-oriented developments. The old railway station was located in the direct proximity of the city center. Short routes were already available to travel from the northern side of the rail way station to the southern site, and vice versa. Before the hub could be build, space had to be freed up to create enough room for bus and bicycle lanes. This process started in 1999. In 2003, the construction of two large commercial buildings started. These developments were followed by the demolishment of the former railway station in 2006.

The construction of an entirely new railway station began in 2008. At first, the municipality aimed to tender the construction of the entire railway station at once. This failed due to a very complicated rooftop construction of the station, which proved to be very costly. Finally, the construction phase was separated in two phases.

During the first phase, a transit platform was built under the railway station to allow easy bus-train transfers. After completion of this first phase, the project was delayed for over a year due to rooftop construction complications. The rooftop had to be redesigned due to the use of other materials (steel instead of concrete). Eventually, a contractor was willing to build the rooftop within the available budget. In 2015, the railway station was finally completed: 5 years later than initially projected. Meanwhile, 60.000 m2 of commercial real estate was built during a relatively long economic crisis in the Netherlands The developments are planned to continue until the end of 2025 with another 50.000 m^2 that are planned at the south-eastern side of the railway station (see Appendix figure A3 for more details).

3. Empirical framework

In this section we provide a description of our identification strategy. Subsection 3.1 starts with a description of the hedonic pricing method. In Subsection 3.2 we explain our process to find a proper counterfactual, which consist of two consecutive stages.

3.1 The hedonic pricing method and the willingness to pay for residential properties

The principal reason for cities to conduct transit-oriented developments is to enhance the urban quality of life in terms of accessibility, amenities, safety, quality of public space, while at the same time preventing urban sprawl (Cervero et al., 2002; Cervero, 2004). The key features of transit-oriented developments include a redesign of the existing transport infrastructure, mixed-use zones (of both commercial and residential properties) and the creation and redevelopment of public space such as squares and parks. We refer to these varied local benefits of transit-oriented developments as an improvement of the spatial quality of cities.[5]

An explicit market for spatial quality, however, does not exist. To this end, we use the hedonic pricing method to infer the economic value of the spatial quality of cities. The seminal contribution by Rosen (1974) provided the essential theoretical insights of the hedonic pricing method. Rosen conceived an individuals' willingness to pay for a differentiated good to be determined by the utility related to the specific characteristics of that good.

The utility from a residential property, for example, consists of utility derived from spatial quality as well as physical attributes such as floor space and maintenance status. A marginal change in these specific characteristics is expected to change its related experienced utility, and consequentially the price of the residence. Hence, everything else constant, we expect that an increase in spatial quality – initiated by the transit-oriented development – gives rise to an increase in the price of residential properties.

3.2. Finding a counterfactual

From a theoretical point of view, the effect of an improvement in spatial quality $\alpha_{i,t}$ can be described as follows:

$$\alpha_{i,t} = P_{i,t}^{I} - P_{i,t}^{N}$$

where $P_{i,t}^{I}$ and $P_{i,t}^{N}$ stand for the price level of residence *i* at year *t* with and without treatment, respectively. Note that we are able to observe residence prices in cities with treatment $P_{i,t}^{I}$. Therefore, in order to estimate $\alpha_{i,t}$, we need to be able to construct the counterfactual value $P_{i,t}^{N}$.

Two main approaches have been used to infer the counterfactual value $P_{i,t}^{N}$. The first strand of literature has compared dwelling prices in close proximity of a transit-oriented

[5] In other words, we argue that transit-oriented developments lead to a spatial quality improvement due to the strengthening of agglomeration externalities, while mitigating congestion externalities.

development (e.g., ½ mile) to dwelling prices at larger distances (beyond ½ mile).[6] In comparison, the second strand of literature has used either linear or logarithmic functions to determine whether closer distances to transit-oriented developments are associated with higher dwelling prices.[7]

This article argues that both approaches produce biased results of transit-oriented developments. To see why, note that transit-oriented developments are conducted in, or very near to, a central business district in a city center. These city centers are often characterized by an inherent increasing trend in its attractiveness and, as a consequence, they experience an increasing trend in residential prices.[8] This is formally illustrated in Figure 1 below. Using a traditional hedonic pricing model would therefore estimate two combined components: the effect of a transit-oriented development and the increasing trend in the willingness to pay to live in or near the city center. Our empirical identification strategy is designed to separate these two components.

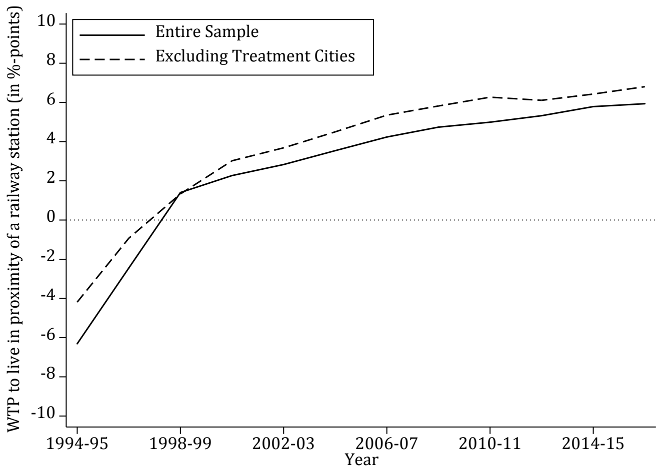

***Figure 1:** The Inherent Attractiveness Trend*

Notes: The Figure displays the results of hedonic pricing regressions relating the logarithmic residence price to the logarithmic distance to a railway station, while controlling for structural characteristics of the residence. For a full description see estimation function (1) in our empirical framework.

To this end, we exploit the fact that other cities have also experienced an inherent increasing trend in willingness to pay for residential properties in the city center. These cities however, did not conduct any transit oriented developments, and can therefore be used as potential counterfactuals. Since the cities' choice to conduct a transit-oriented development may be endogenous, we have to make sure our counterfactual is very similar to the treatment city. The synthetic control method, originally coined by Abadie and Gardeazabal (2003), provides a way to construct a counterfactual in a data-driven manner. This method ensures that the

[6] See Mathur and Ferrel (2013). These authors also estimate logarithmic functional forms.
[7] See Duncan (2011) and Kay et al. (2014). The latter deploy a linear distance form.
[8] Although there is an abundance of theoretical (Mills, 1967; Muth, 1969) and empirical evidence (e.g. Brueckner and Fansler, 1983) for the presence of an inverse relationship between property values and the distance (commuting cost) to a central business district, the literature has largely ignored the idea that this relationship may strengthen over time as well. We did not come across any articles that transformed the static monocentric city model into a dynamic one with time-varying relationships in the inverse relationship between property values and the distance to the central business district.

counterfactual is able to replicate similar traits as the treatment unit, both in terms of pre-intervention trends and relevant characteristics. In what follows, we elaborate on the two-stage approach that is used to execute the synthetic control method.

Stage 1: Traditional hedonic price model

For each transit-oriented development case (Tilburg, Breda, Arnhem) we have a dataset consisting of one treatment city and a number of J control cities, to which we refer as our donor pool. In the first stage, we estimate traditional hedonic pricing models for both the treatment city $j = 1$ and control cities $j = 2, \dots, J + 1$ separately. More specifically, for each control city and each dual year separately[9], we estimate the willingness to pay to live near the central railway station. A similar strategy will be employed for the treatment city up to year T – the year in which the transit-oriented developments start. From year T onwards, we estimate for each dual year separately the willingness to pay to live near a transit-oriented developed railway station. The following estimation function will be estimated in each city:[10]

$$\log P_{i,t} = \beta \mathrm{K}_{i,t} + \tau_t T_t + \gamma_r Z_{r(i,t)} + \delta_t \log Distance_i * T_{i,t} + \varepsilon_{i,} \quad (1)$$

where the logarithmic function of the price of dwelling object i at year t is described by a vector of structural residential characteristics ($K_{i,t}$), a vector of year fixed effects (T_t), and a vector of postal code fixed effects ($Z_{r(i,t)}$).[11] . β, τ_t and γ_r are parameters to be estimated.

The variable of interest is $\log Distance_i * T_{i,t}$. For the control and treatment cities, this variable refers to the minus of the logarithmic distance of dwelling i at year t to the (generic) central railway station and the transit-oriented developed station, respectively. We interact this variable with year dummies T_t to identify parameter δ_t. This variable captures the price elasticity with respect to distance: a percentage change in distance to the station to the power of the elasticity is associated with an estimated percentage point change in residence prices.

In order to ensure comparability among cities, we only consider residential objects that are sold within a distance of three kilometer of the railway station. This boundary of three kilometer safeguards us from exploiting residential objects that are actually located outside the city. That is, beyond this boundary, residences are no longer dependent on the quality of this railway station and its surrounding spatial quality.

Stage 2: The synthetic control method

The estimated parameters $\hat{\delta}_{j,t}$ from stage 1 serve as input for our synthetic control method in stage 2. The synthetic control method is used to construct the counterfactual for our treatment city: the synthetic control city. In other words, it analyzes what the willingness to pay for living

[9] We cluster observations in dual years instead of single years because this gives us more accurate estimates of the willingness to pay to live near railway stations.

[10] Variables capturing the time-variant quality of local amenities are not included in the equation because they are considered to be 'bad controls' (Angrist and Pischke, 2009, p. 47). After all, our sole purpose is to estimate an improvement in spatial quality, which may be generated by improvements in the quality of local amenities. When including these time-varying amenities in the equation, we would essentially control for the mechanism that we aim to identify. The postal code fixed effects are included to capture the time-invariant quality of local amenities.

[11] The vector of used structural residential property characteristics ($X_{j,t}$) is outlined in Appendix Table A3.

near a railway station in a treatment city would have been in case no transit-oriented developments were carried out.

The synthetic control method constructs the missing counterfactual city by using a formal data driven method. It assigns weights to members of the control group dependent on how 'similar' they are relative to the treatment city. The similarity is approximated in two elements. The first element is similar to the central differences-in-differences ('dif-in-dif') idea, in which the control group should follow the pre-intervention trend of the treatment group for the central parameter of interest (i.e. the willingness to pay near a railway station $\hat{\delta}_{j,t}$).[12] In addition to this traditional dif-in-dif element, the method is designed such that it produces similar relevant pre-intervention characteristics for the synthetic control city. In our application, these characteristics include, among others, the number of jobs and the stock of cultural heritage. The synthetic control method operates as follows.

The synthetic control method makes use of an iterative strategy. The core of the method revolves around the minimization of the distance between the pre-intervention characteristics of the treatment city (X_1) and the pre-intervention characteristics of the synthetic control ($X_0 W$).[13] The distance is minimized dependent on the extent to which these pre-intervention characteristics have a predictive power on the outcome. This determines the relative importance of the characteristics – captured by the nonnegative V-matrix ($v_m \geq 0$) that sums up to one ($\sum_1^k v_m = 1$).[14] Correspondingly, dependent on the relative importance of each characteristic the method assigns weights (W) to the control cities to minimize to the following function:

$$W^*(V) = arg \min(X_1 - X_0 W)' V (X_1 - X_0 W) \tag{2}$$

where W satisfies ($w_j \geq 0 \; \forall \; j \; \in \{2, \ldots, J+1\}$ and ($\sum_{j=2}^{J+1} w_j = 1$).

The iterative strategy of selecting V matrices and sets of w-weights can be implemented in such a way that the V–matrix minimizes the pre-treatment differences between the outcome variables of the treatment city and the weighted control city (the pre-intervention $\hat{\delta}_{j,t}$.vectors of stage 1). Abadie and Gardeazabal (2003) refer to this as the '*root mean squared prediction error (RMSPE)*'.[15] In practice, the method employs loops of iterations by using different sets of w-weights and V-matrices and eventually selects the combination that has the lowest RMSPE.

Our identifying assumption is that, as long as the synthetic counterfactual follows a good approximation of the actual treatment city during the pre-intervention period, any subsequent

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[12] Abadie et al. (2010) assume the unobserved outcome $P_{i,t}^N$ of the synthetic control to be defined by a factor model that generalizes to the usual differences-in-differences model. In contrast to the differences-in-differences model however, the synthetic control method allows for the confounding unobserved characteristics to vary over time. Taking time differences does therefore not eliminate the unobserved confounders.

[13] To be specific, X_1 represents a $1 * k$ vector of k pre-transit-oriented development characteristics of the treatment city. Within this vector $m = 1, \ldots k$ captures the value of the m-th variable. X_0 denotes a $k * J$ matrix of pre-transit-oriented development characteristics of J cities in the donor pool depicting the values of k variables. Moreover, W is a $1 * J$ vector of the (designated) weights to the cities in the donor pool.

[14] V represents a $(k * k)$ symmetric and positive semidefinite matrix, where values on the diagonal express the (relative) predictive power of pre-intervention characteristic k.

[15] The RMSPE is computed using the following function: $RMSPE = \left(\frac{1}{T_0} \sum_{t=1}^{T} \left(Y_{1t} - \sum_2^{J+1} w_j * Y_{jt}\right)^2\right)^{1/2}$, where T_0 and T refer to the entire pre-intervention period and the last pre-intervention period, respectively.

differences between them should then resemble the actual effects of the transit-oriented developments.[16]

Our identification strategy is not suited to identify the full scope of the transit-oriented development effects (see p. 4). This is due to the fact that transit-oriented developments also enhance the accessibility of other railway stations (level of service). We will later show that the enhanced between-city accessibility is largely similar in our treatment cities and their respective synthetic counterfactuals. Since this enhanced between-city accessibility is likely to positively affect the willingness to pay to live in proximity of a railway station, and assuming that this capitalizes similarly in both treatment cities and the synthetic control, we can conclude that our estimates do not capture any effects related to between-city accessibility. Instead, our estimates reflect transit-oriented development-induced improvements with respect to within-city accessibility, amenities, safety, and quality of the public space.

4. Data

This section provides an overview of the datasets that are used to execute the identification strategy. We start by a discussion of the residential property transaction data, used in the first stage of the estimation procedure. Then, we consider the city-specific characteristics that are used for the second stage.

Stage 1: Residential property transaction data

The first stage of our empirical strategy is conducted while employing micro transaction data of the Dutch Association of Real Estate Brokers and Experts (NVM). This dataset comprises about 80 percent of all residential properties sold in the Netherlands. The original dataset runs from 1985 to the end of 2017 and contains more than 3.6 million observations. A number of data cleaning steps is performed before we estimate Equation (1).

First, we exclude missing values and recreational residences in order to ensure that all transactions are related to residences used for living purposes. Second, we only consider transactions that are sold within a concentric ring of three kilometer around the railway station in the treatment and control cities. This leaves us with a dataset comprising 619,800 residential property transactions, distributed among both the treatment and the control cities. A more thorough description of the data cleaning process is provided in Table A1 of Appendix A. The descriptive statistics of the final dataset are shown in Table 1.

Stage 2: Predictors synthetic control method

The synthetic control method is executed using a set of ten pre-treatment city-specific characteristics. The literature provides evidence that each of these characteristics embodies factors that have either a positive or negative effect on the willingness to pay for residences. The predictors used in this article are listed in Table 2 – the notes showing an overview of the studies. Mirroring the first stage of our empirical strategy, the values of these predictors are computed by drawing a concentric ring of three kilometer around the railway station in city j.

[16] That is, we are able to identify the causal effect of transit-oriented developments if the weighted control city successfully reproduces the pre-intervention trend $(i)\ \hat{\delta}_{1,t}. \approx \sum_{2}^{J+1} w_j * \hat{\delta}_{j,t}$.and the relevant predictors (ii): $X_{1m} \approx \sum_{j=2}^{J+1} w_j^* X_{jm}$. Technical details are outlined in Appendix B of the article by Abadie, Diamond and Hainmuller (2010).

The data are drawn from various sources, which are listed in Table A3 of Appendix B. The Appendix also includes a detailed description of predictors.

***Table 1:** Residence-Specific Descriptive Statistics*

	Mean	Standard deviation	Description
Transaction price	227,626	126,648	Transaction price of the residence, deflated in 2017 euros
Structural characteristics			
Floor space (m^2)	109.660	40.433	The number of square meters floor space of the residence
Living space (m^3)	324.439	134.292	The number of cubic meters living space of the residence
Number of rooms	4.172	1.414	The number of rooms in the residence
Number of floors	2.186	0.921	The number of floors in the residence
Dwelling quality			
Maintenance quality inside (1-9)	6.950	1.124	Quality of maintenance inside the dwelling, ranging from bad, bad (1) to excellent (9)
Maintenance quality outside (1-9)	7.000	0.950	Quality of maintenance at the exterior of the dwelling, ranging from bad (1) to excellent (9)
Maintenance of garden (1-5)	3.300	0.715	Quality of maintenance of the garden, ranging from no garden existent (1) to very-well-kept (5)
Parking space	0.227	0.419	Dummy variable indicating whether the residence has a parking space
Residence type			
i) Apartment			Dummy variable that equals one if the residence is an apartment and…
Downstairs	0.060	0.238	located downstairs of a building
Upstairs	0.081	0.273	located upstairs of a building
Porch	0.150	0.357	located in a porch flat
Gallery	0.094	0.292	located in a gallery flat
Other	0.033	0.177	either located in a maisonette, or comprising both the upper and lower floor
ii) House			Dummy variable that equals one if the residence is a house and…
Intermediate	0.349	0.477	located in between other houses
Corner	0.120	0.324	located at a corner
Semi-detached	0.074	0.261	semi- detached from other houses
Detached	0.040	0.195	completely detached from other houses

Notes: The total number of observations is 619,800. Only the most relevant variables of Equation (1) are reported in the table. The non-reported variables include: the quality of the insulation of the dwelling, whether the dwelling is located next to a park or open water, whether the dwelling has a central heating system, and the building period of the dwelling (in unequally distributed time-periods. A full description of all variables is provided in Table A2 of Appendix B.

Our set of predictors is based on the period before the construction plans were presented to the public. For Arnhem, this implies that the predictors are averaged for the 1996-1998 period. For Tilburg and Breda, the predictors are averaged for the 2002-2004 period. These periods are selected because the synthetic control method would be rendered invalid if the predictors reflect some of the effects of the intervention.[17]

Two main restrictions are imposed on the control cities that are included in the donor pool. First, we only consider cities that did not conduct any extraordinary measures to rejuvenate the railway station and its surrounding area (no transit-oriented developments).[18] Second, we choose to restrict the donor pool to cities with at least 50,000 inhabitants during the

[17] Even though we conservatively average the current set of predictors over the time periods noted above, we use the cross-validation methodology developed by Abadie et al. (2015) as a robustness test. In this method, the pre-intervention sample is divided in a training and a validation period, where the set of v_m weights of the training period are used to minimize the out-of sample errors in the validation period. We average the predictors of the training period during the years of 1994-1996. This applies for all three treatment cities.

[18] More specific, we excluded cities from the donor pool in case they presented explicit plans (a masterplan) to conduct the two interacting elements of transit-oriented developments: i) urban developments are planned in close proximity to a railway station, and ii) the transit-system (within a city) is enhanced to connect planned concentrations of urban developments with existing concentrations. Hence, this restriction does not exclude cities that planned (or conducted) urban developments in close proximity of the railway station. To observe whether this biased our results, we ran additional test with the restriction that excluded cities with such urban developments. Our results were robust to this additional restriction.

pre-intervention period. One obvious advantage of this restriction is that it ensures that the treatment city and the weighted control city are reasonably similar in terms of city size. The additional benefit is that other characteristics such as the percentages 15-24 years old, non-Western immigrants and the socio-economic status also becomes more similar as well. Using both restrictions leaves us with a set of 22 cities in the donor pool of potential controls.[19]

Table 2 lists the predictor means in the treatment cities and the donor pool sample. Despite the restrictions on the donor pool sample, we still observe some notable differences in the predictor means. For instance, Breda and Arnhem possess about twice as much cultural heritage as the average of the donor pool. The percentage inhabitants with lower education is also very different. These discrepancies make clear that the synthetic control method is necessary in order to construct a credible counterfactual.

Table 2: *Predictor means in donor pool relative to treatment cities*

	Breda	Tilburg	Donor pool Breda and Tilburg	Arnhem	Donor pool sample Arnhem
Density (natural logarithm of number of jobs) (a)	11.20	11.17	10.68	10.79	10.65
Culture (number of km² cultural heritage) (b)	2.95	1.57	1.40	2.60	1.40
Percentage inhabitants between 15-24 years old (c)	12.62	17.31	12.54	14.43	13.11
Percentage inhabitants with lower education (d)	17.68	34.60	25.79	21.87	26.49
Percentage inhabitants with Non-Western background(e)	11.95	13.58	12.08	17.49	11.68
Socio-economic status (−2, 5) (f)	−0.52	−1.07	−0.48	−1.20	−0.81
Satisfaction residents about quality of schools (1-10) (g)	6.81	5.24	6.14	5.78	6.05
Satisfaction residents about green-amenities (1-10) (h)	5.54	5.07	5.60	5.58	5.68
Future expectations neighborhood (1-3) (i)	1.82	1.83	1.79	1.75	1.82
Satisfaction quality of surrounding buildings (1-5) (j)	2.48	2.61	2.41	2.42	2.55

Notes: The predictors are computed by drawing a concentric ring of 3 kilometer around a railway station, both in the treatment cities and in the donor pool. The following articles provide empirical evidence that the predictors influence the willingness to pay for residential properties (a) density (Rappaport, 2010), (b) culture/ satisfaction surrounding buildings (Koster, van Ommeren, and Rietveld, 2016), (c) percentage 15-24 year olds (Glaeser, 2005), (d) percentage lower-educated (Glaeser and Saiz, 2004), (e) percentage non-Western immigrants (Saiz, 2003), (f) socio-economic status (Bayer, Ferreira, and McMillan, (2007), (g) satisfaction about schooling (Gibbons and Machin, 2003) (h) satisfaction about green amenities (Klaiber and Phaneuf, 2010), (i) future expectations neighborhood (Guerrieri, Hartley, and Hurst, 2013).

5. Results

In this section we provide a discussion of the estimation results. We start by showing the main results (subsection 5.1), followed by a number of sensitivity analyses (subsection 5.2). Subsection 5.3 analyzes whether the results are subject to spatial heterogeneities.

5.1 Main results

Panel A, B and C of Figure 2 plot the trends in willingness to pay to live near the railway station of respectively Breda, Tilburg and Arnhem and its synthetic counterparts over the period 1994-2017. The solid lines present the actual evolutions in the price elasticity with respect to the distance towards the transit station of the treatment city, while the dashed lines display the weighted combinations in price elasticities (hereafter: willingness to pay) of the synthetic control. The treatment lines are set on the last pre-intervention period – two years before the construction work starts on the railway station. Our estimates of transit-oriented developments

[19] As part of our robustness analyses, we check whether our results hold for various subsamples of the donor pool.

are presented by the difference between the solid lines and the dashed counterfactuals. Panel D demonstrates these estimates in terms of effect sizes.

Panels A-C show that the synthetic counterparts are adequately able to reproduce the actual trends in willingness to pay of the treatment cities before the transit-oriented developments were conducted. In combination with a strong resemblance in willingness to pay predictors this suggests that the post-intervention trajectories of the synthetic units serve as sound counterfactuals.

Table 3 demonstrates the similarity quantitatively, showing the predictor means of the treatment cities and their synthetic counterparts. The table suggests that the synthetic versions are much more appropriate comparisons units than the mean sample of the entire donor pool (see Table 2). The V_m-weights selected by the synthetic control method reveal that especially the density and percentage inhabitants between 15-24 years old variables are important predictors. The predictive power of those two variables combined ranges from 0.52 in Tilburg to 0.67 in Arnhem.[20]

Table 3: *Predictor means*

	Breda	Synthetic Breda	Tilburg	Synthetic Tilburg	Arnhem	Synthetic Arnhem
Density (natural logarithm of number of jobs)	11.20	11.09	11.17	11.11	10.79	10.77
Culture (number of km² cultural heritage)	2.95	2.23	1.57	1.55	2.60	0.77
Percentage inhabitants between 15-24 years old	12.62	12.68	17.31	17.28	14.43	14.43
Percentage inhabitants with lower education	18.68	18.94	34.60	24.32	21.87	22.04
Percentage inhabitants with Non-Western background	11.95	11.34	13.58	13.52	17.49	17.28
Socio-economic status (−2, 5)	−0.52	−0.37	−1.07	−1.03	−1.20	−0.98
Satisfaction residents about quality of schools (1-10)	6.81	6.12	5.24	5.41	5.78	5.57
Satisfaction residents about green-amenities (1-10)	5.54	5.67	5.07	5.34	5.58	6.04
Future expectations neighborhood (1-3)	1.82	1.85	1.83	1.82	1.75	1.88
Satisfaction quality of surrounding buildings (1-5)	2.48	2.41	2.61	2.37	2.42	2.42

Notes: The table presents the predictor variable similarity between the treatment city and its respective synthetic version. The sets of V weights are reported in Table A4 of Appendix B. A description of the variables is provided in Table A2 of Appendix B. All values in the table respond to the average of a concentric ring of 3km around the railway station. The exception being the Density and Culture variable which respond to the sum.

Table 4 reports the w_j-weights of each donor pool city in the synthetic counterfactuals. For each of the three treatment cities, about five cities constitute the synthetic control. Eleven out of the 22 donor pool cities are never assigned a positive weight. These cities generally differ in terms of relevant characteristics relative to the treatment cities.

The three cities exhibit a peculiar difference in treatment effects. For Breda, the transit-oriented developments did not have much of an effect. This outcome is in sharp contrast with the estimates for Tilburg and Arnhem. For Tilburg, the solid and dashed line start to diverge after two years of developments. While the willingness to pay for synthetic Tilburg levels off, the willingness to pay in actual Tilburg keeps increasing at an even faster pace than before the developments started. Our estimates for Tilburg suggest a positive effect of transit oriented developments. We find that the price elasticity with respect to the distance would have been five percent points lower in case no developments were executed.

[20] The entire sets of V- weights on the diagonals of the matrices are reported in Appendix B Table A4.

Table 4: *Designated w- weights to cities in the donor pool*

Donor Pool City	Weights Breda	Weights Tilburg	Weights Arnhem	Donor Pool City	Weights Breda	Weights Tilburg	Weights Arnhem
Alkmaar	0	0	0	Gouda	0	0	0
Almelo	0	0	0	Groningen	0	0.461	0.116
Almere	0	0	0.203	Haarlem	0.044	0	0
Amersfoort	0.169	0	0	Helmond	0	0	0
Apeldoorn	0	0	0	Hilversum	0.161	0	0
Beverwijk	0	0.065	0	Leeuwarden	0	0	0
Deventer	0	0	0.050	Nijmegen	0.355	0	0.212
Dordrecht	0	0	0	Purmerend	0	0	0
Ede	0	0	0	Zaandam	0	0.375	0.419
Eindhoven	0.035	0.087	0	Zoetermeer	0.235	0	0
Enschede	0	0.011	0	Zwolle	0	0	0

Contrary to the positive effect of Tilburg, we obtain a negative estimate of transit-oriented developments in Arnhem. After four years of developments, the willingness to pay in actual Arnhem drops substantially, while the synthetic Arnhem largely flattens out. The peak of the negative effect is largest after 8 years of construction work, reaching over seven percent points in the price elasticity with respect to the distance towards the railway station. Following a U-shaped pattern, the effect does thereafter recover. Still, the recovery remains insufficient to fully offset the decline in willingness to pay.

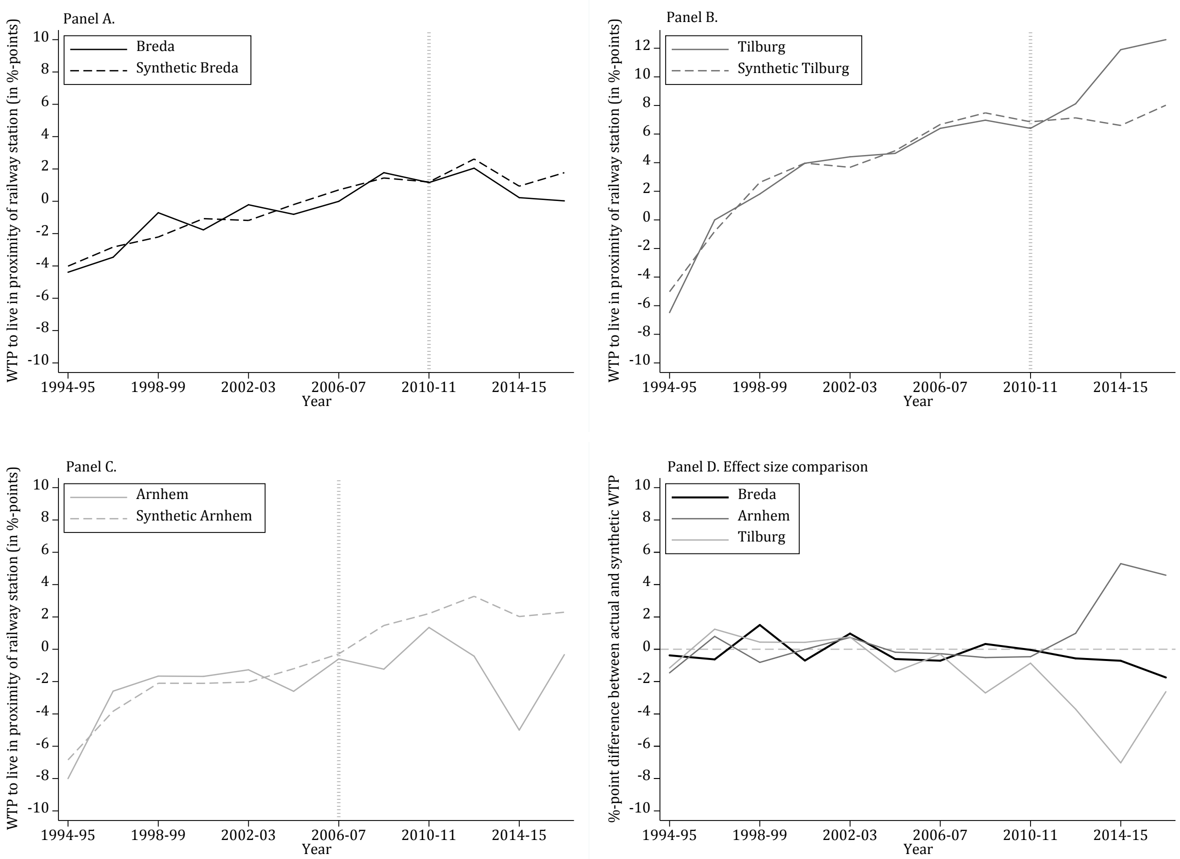

Figure 2: *The effects of transit-oriented developments* – Actual versus synthetic trends in the price elasticity with respect to the distance towards a railway station

5.2 Placebo results

In this section, we probe the credibility of our obtained results. Following Abadie et al. (2010), we perform inference using a falsification exercise. In this case, we iteratively apply the synthetic control method on each of the 22 control cities in the donor pool, while using the other 21 control cities as the relevant donor pool. Correspondingly, we compare the distribution of 'placebo' effects to the actual effects obtained for the treatment city. It must be noted that a large post-intervention effect (post-RMSPE) does not necessarily indicate a credible causal effect if the pre-intervention fit (pre-RMSPE) between the placebo city and its synthetic control is large as well. We therefore divide the post-intervention RMSPE by the pre-intervention RMSPE for each of the estimated placebo effects. The distribution of the placebo and actual treatment effects provides insight in the probability that our results are obtained by chance.

Figure 3 demonstrates the RMSPE ratios. Tilburg and Breda are both shown in Panel A. due to their identical pre-intervention matching window. Panel A conveys a clear pattern. Tilburg stands out as a city with a distinctively high RMSPE ratio. The post-intervention gap is more than three times as large as the lack of fit during the pre-intervention period. No other city reaches such a ratio. Put in terms of random chances, if one were to assign the treatment to another city in the donor pool, the portion or chance it would reach a ratio as high is $1/23(\approx 0.043)$. The ratio achieved by Breda does clearly not stand out relative to the ratios of the other donor pool cities. The random chance of achieving a ratio as high as Breda is $(11/23 \approx)$ 0.48.

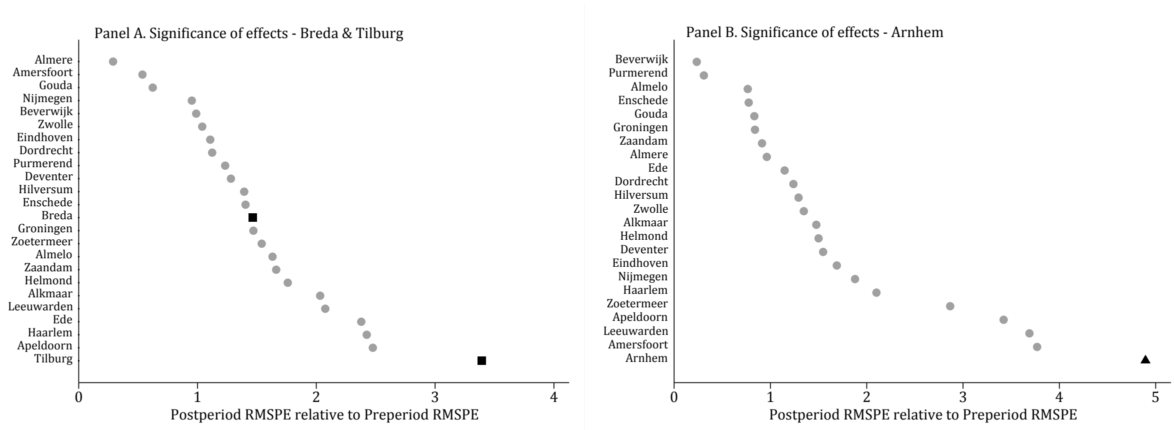

Figure 3: *To what extent are the results achieved by chance?*

Notes: Both panels display the RMSPE ratio of the treatment city rank relative to the placebo ranks of the cities in the donor pool (22). Breda and Tilburg reported in the same panel due to their identical matching window and donor pool.

Panel B reports the RMSPE ratio for Arnhem. The figure illustrates that no other city achieves a higher RMSPE ratio than Arnhem – in random chance terms $(1/23 \approx)$0.04. The significance level for Arnhem does vary considerably over time. Table 5 presents the RMSPE ratio's per post-intervention period. The overall significance is primarily driven by the effect sizes of the first, third and fourth post-intervention period, where no other cities achieve a higher RMSPE ratio as Arnhem. During the last post-intervention period, the random chance rises to 25%. This suggests that the negative effect of the transit-oriented developments has been temporarily in Arnhem. The significance levels of Breda remains high although reduces considerably in the latest post-intervention period. The random chance in Tilburg reduces over time and obtains an absolute minimum value (i.e. 0.04) in the latest post-intervention period.

***Table 5:** Significance Levels in Post-Intervention Periods*

	Breda		*Tilburg*		*Arnhem*	
	Effect Size	*p*-value	Effect Size	*p*-value	Effect Size	*p*-value
2008-09					–0.027	0.043
2010-11					–0.009	0.391
2012-13	–0.006	0.696	0.010	0.174	–0.037	0.043
2014-15	–0.007	0.609	0.053	0.087	–0.070	0.043
2016-17	–0.017	0.304	0.046	0.043	–0.026	0.261

Notes: The table reports the percentage differences between the actual price elasticity with respect to the distance towards a railway station trajectories and their synthetic counterpart for each of the post-intervention periods. The *p*-values for each of the post-intervention periods were computed by dividing the post-intervention period RMSPE relative to the entire pre-intervention RMSPE, ranked in terms the treatment city relative to the control cities. The number of cities in the donor pool is 22.

5.3 Robustness

We perform a couple of sensitivity tests to show the robustness of the main results. First, we follow the subsampling method coined by Saia (2017) to assess whether our results are driven by the size and the composition of the donor pool. The idea of the subsampling method is that our results can be considered credible if we iteratively obtain similar results relative to the baseline using randomly drawn subsamples of the donor pool. We conduct the subsampling method by iteratively applying the synthetic control method 200 times on randomly drawn subsamples of two-third the size of the original donor pool.[21] The results are reported in Figure 4.

The average values of the 200 obtained synthetic counterfactuals are exhibited by the dashed lines. The 95% confidence intervals are drawn around the dashed lines. The panels display that, before the treatment cities start conducting transit-oriented developments, the actual treatment cities remain within the confidence interval of the synthetic counterfactuals. While this remains the case in Breda, it changes just after the transit-oriented developments begin in Tilburg and Arnhem. From the moment of treatment onwards, the actual willingness to pay in Tilburg and Arnhem starts to diverge significantly from the confidence intervals, following a similar pattern as shown in Table 5. The subsampling method thus illustrates that our main results are not driven by the composition or size of the donor pool.

Second, we explore whether the results are driven by our prediction procedure. Note that the original synthetic control method uses the pre-intervention characteristics to minimize the in-sample outcome differences of the pre-intervention period. We therefore do not know whether the predictors have sufficient power to predict out-of-sample. To this end, we follow Abadie et al. (2015) and divide our pre-intervention sample in a training period and validation period.

[21] The number of subsampling procedures (200) and the fraction of the donor pool (two-third) were artificially chosen. We have conducted a number of additional robustness exercises where we vary the number of subsampling procedures and the fraction of the donor pool. The results from this exercise are quantitatively very similar to the results reported in this article.

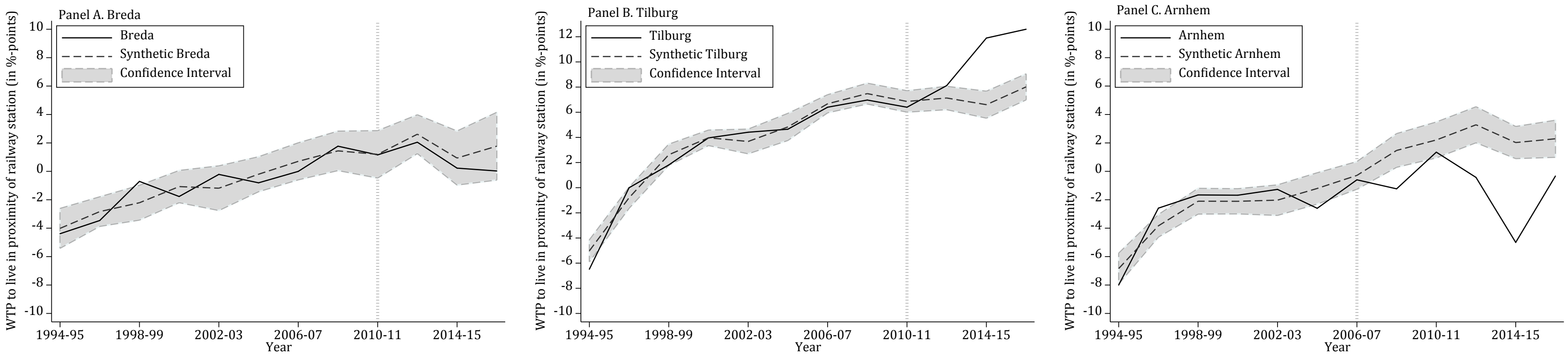

***Figure 4:** The Robustness to Sensitivity Tests*– Subsampling method

Notes: The Panels in Figure 4 illustrate the developments in the price elasticity with respect to the distance towards the railway station in the actual treatment city relative to its synthetic counterpart. The solid lines refer to the actual treatment city, the dashed lines to the average value of 200 synthetic counterfactuals, using randomly drawn subsamples of the donor pool at two-third of the original size. The grey areas refer around the synthetic counterparts indicate the 95% confidence interval.

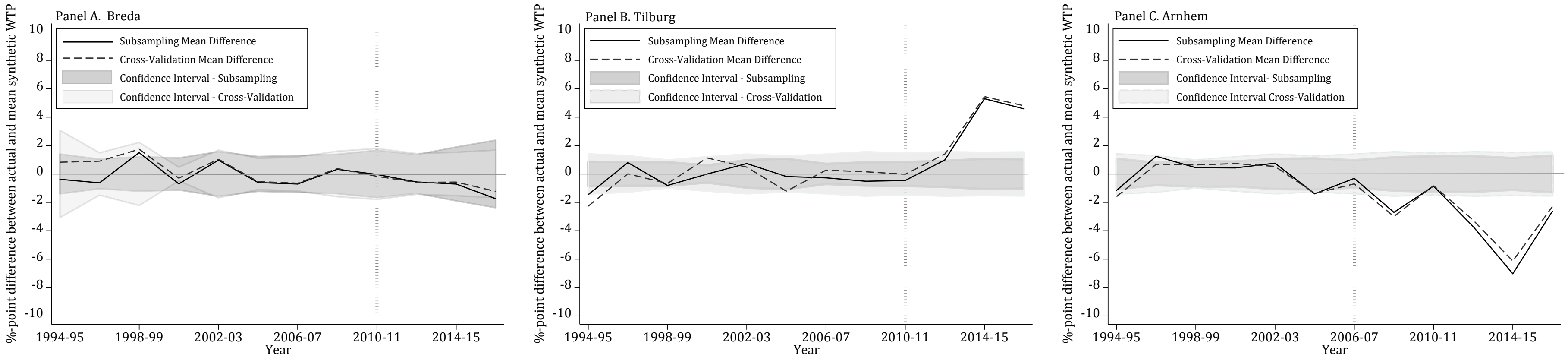

***Figure 5:** The Robustness to Sensitivity Tests*– Cross Validation

Notes: The Panels in Figure 5 display the percentage difference between the developments in the price elasticity in the actual treatment city relative to its synthetic counterpart. The solid lines report to the average value of the baseline subsampling method (Figure 4). The dashed lines present the average value of the cross-validation method, again using 200 randomly drawn subsamples of the donor pool at two-third of the original size. We implement the cross-validation technique using averaged predictors for the 1994-1996 (training) period for all three treatment cities. The corresponding parameter values W and V, are chosen to minimize the RMSPE of the validation period (remainder of the pre-intervention period). The grey areas around the synthetic counterparts indicate the 95% confidence interval.

To assess the out-of-sample prediction power, we use a cross-validation technique where the predictors of the training period, with corresponding parameter values W and V are chosen to minimize the RMSPE of the validation period.[22] To further validate the credibility of this method, we again exploit the subsampling method by iteratively applying the synthetic control method 200 times on randomly drawn subsamples of two-third the size of the original donor pool - this time using the cross-validation technique.

The results are presented by the dashed lines of Figure 5. Despite that the pre-intervention gaps become slightly worse during the training period, the corresponding gaps during the validation period are virtually unaltered. This suggests that the predictors can adequately predict out-of-sample. Moreover, the estimated effect sizes of the cross-validation method diverge significantly from the confidence intervals at the same years as the effect sizes of the baseline subsample method. Table 6 demonstrates the outcomes of both figures in a quantitative manner.

***Table 6:** Inference estimates of robustness methods*

	Breda		Tilburg		Arnhem	
	(1)	(2)	(3)	(4)	(5)	(6)
Pre-intervention	−0.002	0.005	−0.006	−0.004	−0.006	−0.002
	(0.007)	(0.007)	(0.005)	(0.007)	(0.006)	(0.009)
2008-09					−0.028	−0.030
					(0.007)	(0.011)
2010-11					−0.004	−0.008
					(0.009)	(0.010)
2012-13	−0.006	−0.006	0.013	0.014	−0.027	−0.033
	(0.007)	(0.007)	(0.005)	(0.007)	(0.010)	(0.012)
2014-15	−0.010	−0.006	0.053	0.054	−0.069	−0.061
	(0.010)	(0.008)	(0.006)	(0.008)	(0.009)	(0.011)
2016-17	−0.018	−0.012	0.040	0.048	−0.026	−0.023
	(0.012)	(0.009)	(0.005)	(0.008)	(0.010)	(0.011)
Subsampling	Y	Y	Y	Y	Y	Y
Cross-Validation	N	Y	N	Y	N	Y

Notes: The reported values present to the average difference in price elasticities between the treatment unit and the synthetic control for each of the post-intervention periods shown on the left side of the table. The average is computed after operating 200 subsampling procedures of the synthetic control method, using randomly drawn subsamples of the donor pool at two-third of the original size. The cross-validation results are also estimated using the subsampling method. We implement the cross-validation technique using averaged predictors for the 1994-1996 training period for all three treatment cities. The standard errors are reported between parentheses.

Third, we determine the validity of the main estimates by reassigning the treatment date to respectively two, four, and six years before the actual intervention occurred. These in-time placebo exercises hinge on the notion that the results cannot be considered reliable if they depend on an artificial treatment date. To implement the in-time placebo test we again conduct the subsampling method.[23] The average values are displayed in Figure 6.

Panel A and B indicate that the results in Breda and Tilburg are not driven by the artificial treatment dates. The artificial effect size trajectories follow a similar pattern as the actual trajectory. Panel C shows that also in Arnhem the effect size does not depend on an

[22] In this methodology, the predictors of the training period are averaged for the 1994-1996 period for all treatment cities. For Breda and Tilburg, we divide the pre-intervention sample in a training period that ranges from 1994 to 2002, and the validation period that ranges from 2004 to 2010. For Arnhem, we divide the training and validation period in the 1994-1998 and 2000-2006 periods, respectively.

[23] We again operate the subsampling method using 200 synthetic control procedures from randomly drawn subsamples of two-third the original size of the donor pool.

artificial treatment date. However, for each of the four subsampling procedures, we find that the divergence starts 2 years before the treatment kicks in. This is due to the fact that before the building of the station, which we consider as the starting point of the treatment, demolition and redevelopment activities were conducted to enable the building of the station. The in-time placebo tests therefore provide strong support for the robustness of the main results.[24]

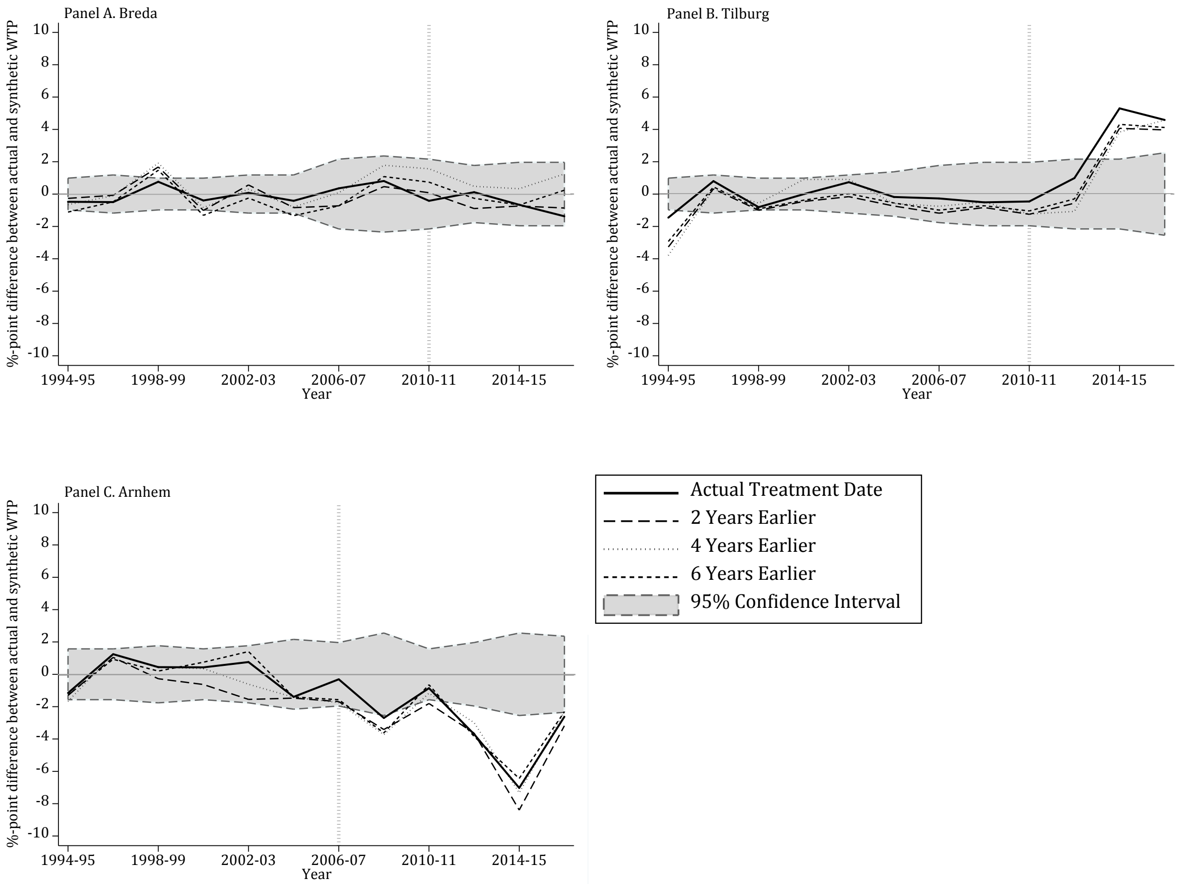

Figure 6: *The Robustness to Sensitivity Tests*– In-time placebos

Notes: The Panels in Figure 6 display the percentage difference between the developments in price elasticity with respect to the distance towards the railway station in the actual treatment city relative to its synthetic counterpart. The solid lines report to the average value of the subsampling method (Figure 4). The dashed lines report the average values of in-time placebo procedures, where the treatment date is reassigned to respectively two, four, and six years earlier. These average values respond to 200 synthetic control procedures using randomly drawn subsamples of the donor pool at two-third of the original size. The grey areas around the synthetic counterparts indicate the 95% confidence interval of the in-time placebo where the treatment date is reassigned six years earlier. The standard errors of the other in-time placebos are reported in Table A5 of Appendix B.

5.4 Heterogeneous treatment effects

As argued in subsection 2.3, there may be reasons to believe the spatial quality effects differ dependent on whether residents live at one of the either sides of the railway line (railway station). For instance, due to the removal of the marshalling yards and the corresponding restructuring of the surrounding neighborhoods, the developments have been much more intense at the northern side in Tilburg and Breda. Contrastingly, in Arnhem the developments have been much more intense for residents living at the southern side of railway station (see

[24] The results portrayed in Figure 6 are formalized in the Appendix Table A5. This Table also reports the standard errors of the subsampling procedures of the other in-time placebos.

Appendix A). To investigate whether these differences in spatial developments have a differential effect on the willingness to pay, we repeat our empirical strategy. For this analysis, we divide the treatment sample in residential property transactions conducted at i) the northern side of the railway line, and ii) those conducted at the southern side.

The results are depicted in Figure 7 and quantitatively reported in Table 7. Panel A of Figure 7 exhibits a peculiar difference in the results for Breda. Even though we observe a positive effect on the willingness to pay to live in proximity of the railway station at the northern side, this positive effect is offset by a negative willingness to pay effect at the southern side. Panel B shows that the northern side of the railway station in Tilburg experienced a substantial increase in the willingness to pay, while the southern side did not see any sizeable effect. Hence, the positive effect for Tilburg as a whole appears to be entirely driven by the positive willingness to pay effect at the northern side.

Interestingly, Panel C shows that the northern side of Arnhem experiences a temporary positive willingness to pay effect. The negative effect at the southern side, however, more than fully compensates for the positive effect at the north. The U-shaped pattern of the entire sample is thus driven by the negative effect at the south.

Table 7: *Heterogeneous effects* – Decomposition spatial effects over time

	Panel A. Breda					
	Total		*North*		*South*	
	Effect Size	p-value	Effect Size	p-value	Effect Size	p-value
Overall significance		0.565		0.130		0.087
2012-13	–0.006	0.696	0.037	0.130	–0.032	0.130
2014-15	–0.007	0.609	0.014	0.609	–0.035	0.130
2016-17	–0.017	0.304	0.080	0.043	–0.074	0.043
	Panel B. Tilburg					
	Total		*North*		*South*	
	Effect Size	p-value	Effect Size	p-value	Effect Size	p-value
Overall significance		0.087		0.043		0.565
2012-13	0.010	0.174	0.024	0.435	–0.007	0.739
2014-15	0.053	0.087	0.090	0.043	0.009	0.609
2016-17	0.046	0.043	0.061	0.087	–0.017	0.522
	Panel C. Arnhem					
	Total		*North*		*South*	
	Effect Size	p-value	Effect Size	p-value	Effect Size	p-value
Overall significance		0.043		0.217		0.043
2008-09	–0.027	0.043	0.017	0.522	–0.033	0.043
2010-11	–0.009	0.391	0.043	0.087	–0.014	0.130
2012-13	–0.037	0.043	0.052	0.087	–0.088	0.043
2014-15	–0.070	0.043	0.019	0.522	–0.115	0.043
2016-17	–0.026	0.261	–0.016	0.565	–0.032	0.130

Notes: The table reports the percentage differences between the price elasticity with respect to the distance towards the transit station trajectory of the treatment city and its synthetic counterpart for each of the post-intervention periods, decomposed into two spatial subgroups; North and South. The North and South decompositions respond to all residential property transactions for the half of a concentric ring of three kilometers from the railway station, only considering transactions that are sold at the north side of the railway line, and the south side of the railway line, respectively. The p-values demonstrate the extent to which our results are obtained by chance. The number of cities in the donor pool is 22.

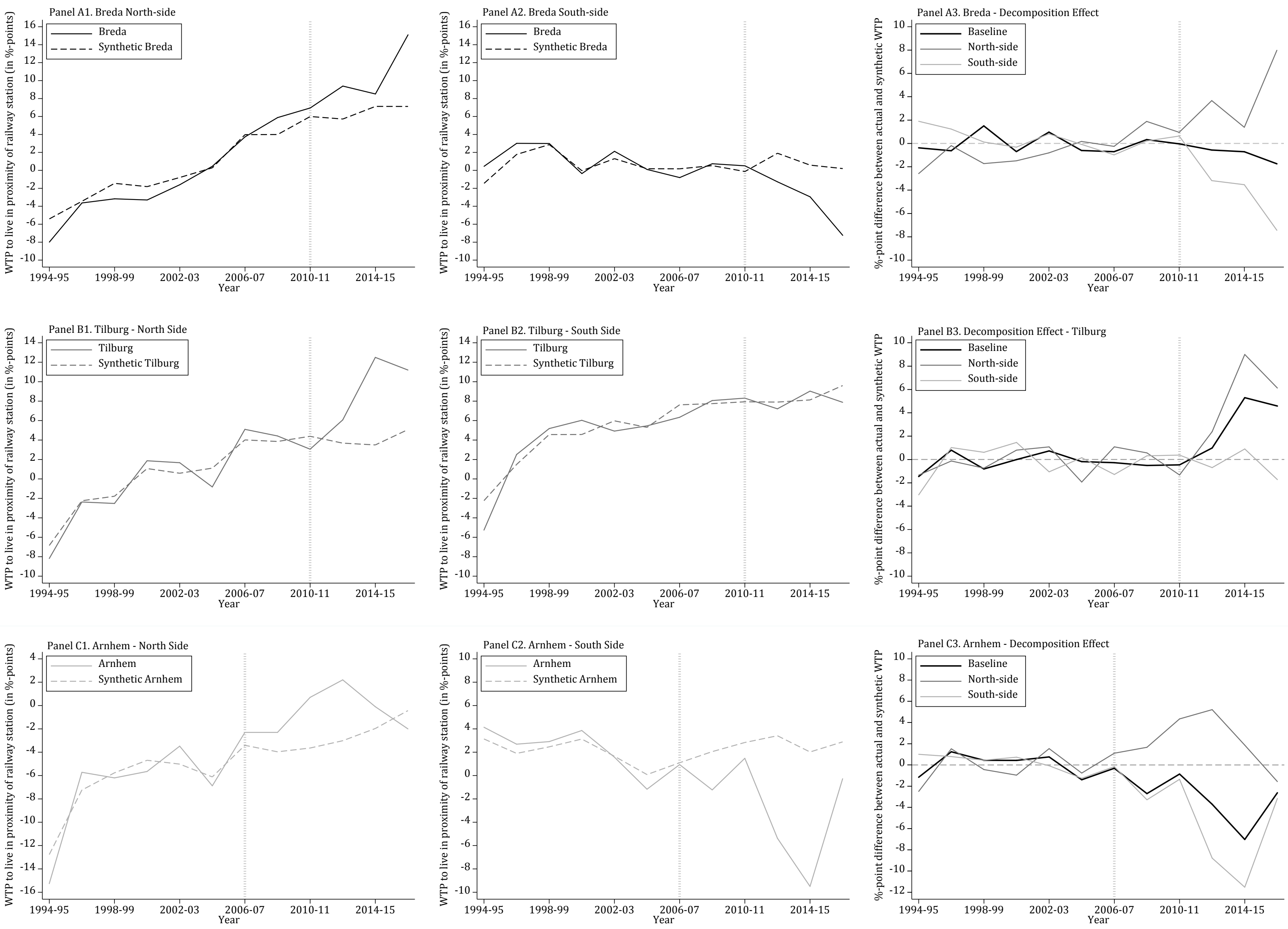

Figure 7: *The heterogeneous effects of transit oriented developments* – North versus South

Notes: The Panels in Figure 7 display to what extent the estimation procedures of the entire city can be attributed towards effects in the north relative to effects in the south. These decompositions respond to all residential property transactions for the half of a concentric ring of three kilometers from the railway station, only considering transactions that are sold at the north-side of the railway line, and the south-side of the railway line, respectively. The *p*-values that indicate the extent to which the results are obtained by chance are reported in Table 9.

5.5 Explanations for spatial differences in treatment effects

There are two plausible explanations for the spatial differences in treatment effects for Breda and Tilburg. The first explanation is the change in accessibility *within a city.*[25] The removal of the marshalling yards at the northern side of the station enabled residents to access the railway station and the city center (located at the southern side) much faster and pleasant than before. In particular residents close to the railway station at the northern-side experienced a large percentage reduction in travel time. Residents at the southern side of the station did not experience such a change in within-city accessibility (see Table A6 in the Appendix). The second explanation is the change in available amenities. In addition to the benefit of being able to access the railway station much faster, residents at the North can now enjoy many more amenities, which were primarily added at the northern side of the railway station (see Appendix A for details).

In Breda the positive effect at the North coincides with a negative effect in the South. We can only speculate what drives these differences. A possible explanation provided in the academic literature is a lack of demand for novel real estate (James, 2009; Janssen-Janssen et al., 2012), facilitating a waterbed effect. The increase in attractiveness in the North may have gone at the expense of the South, which became more attractive in absolute terms but less attractive compared to the North. The drop in relative attractiveness in the South may result in falling house prices if the city lacks sufficient demand for housing to fill this gap.

The temporary negative effect at the southern side of the station in Arnhem can also be explained. We find the largest negative effects during the time period where the project was delayed for over one year. During this period of delay, residents at the southern side of the railway station were left with a visual outlook on the public space resembling a building ruin.

There are two major explanations within the academic literature that can explain why delayed transit-oriented developments result in (temporary) negative effects. First, during the delay phase, residents were unsure whether the construction of the rooftop would even be finalized. This created considerable uncertainty among (future) residents and businesses. Communication from the municipality with the local community was subpar during the delay period. A lack in continuity of the construction phase can therefore pose a major threat for the local support of transit-oriented developments (Thomas and Bertolini, 2014).

Second, the lack of continuity explanation interacts with the second explanation provided in the literature: the lack of demand for novel real estate (James, 2009; Janssen-Janssen et al., 2012). In case there is no real demand for new estate, negative shocks are much more likely to capitalize in real estate prices. In Arnhem, there was even no new residential real estate developed, despite the fact that in the original masterplan of Arnhem, there were plans to do so. The results in the southern side of Arnhem suggest that such a lack of pressure on the

[25] In theory, transit-oriented developments could also induce a difference in the *between-city* accessibility for the railway station in the treatment city relative to its synthetic control. For example, by inducing an efficiency improvement in the network of the treatment city railway station, and not a similar efficiency improvement for the control cities. Even though this cannot account for the within-city variation in spatial effects, it could have an effect on the sign of the within-city effects. In Table A7 of the Appendix, we demonstrate that there is no difference in the between-city accessibility for the railway station of the treatment city versus its synthetic control. The sign therefore is not influenced by a change over time in between-city accessibility.

local housing market interacted with a negative shock leads to substantial direct negative effects on property prices.

Lastly, on a more speculative note, it is likely that the effect sizes will be more positive in the future. None of the surrounding areas of the railway stations are finalized yet. Especially Breda and Tilburg have plans to develop a large amount of novel real estate in the future.

6. Conclusions

This article examines the effects of transit-oriented developments on residential prices, by studying three cases in the Netherlands. Our findings are highly heterogeneous. One case (Tilburg) shows strong positive effects of the transit-oriented developments after two years of construction work. Another case (Arnhem) displays strong negative effects, albeit temporarily. The third case (Breda) exhibits no significant effect of the transit-oriented developments. Upon closer examination, we conclude that property values at the northern side of the railway station in both Tilburg and Breda experienced a positive effect.

We argue that these positive effects can be attributed to the removal of the marshalling yards and restructuring of the surrounding neighborhoods. This enabled municipalities to increase the available amenities at the northern-side of the railway station, while enabling residents to access the railway station considerably faster. Hence, the positive effect in the North of Tilburg and Breda appears to be the result of an increase in accessibility of amenities. Arnhem, on the other hand, experienced a substantial temporary negative effect at the southern side of the station. The most plausible explanation for this negative effect is intense nuisance due to unexpected delays in construction.

The relationship between residential prices and transit-oriented developments is confounded by endogeneity concerns. These problems of endogeneity arise because the developments are conducted near central business districts in city centers, which experience an inherent upward trend in attractiveness. To account for these issues, we exploit the idea that other cities – that did not conduct any transit-oriented developments – have experienced an inherent city center attractiveness trend as well. Hence, we use these other cities to construct a credible counterfactual, using the synthetic control method. The first stage of our approach uses micro data on residential property transactions to estimate hedonic pricing models, for both the treatment city and control cities separately. These estimation results serve as input for the synthetic control method that is executed in the second stage.

7. Appendix

***Appendix A**: Case descriptions*

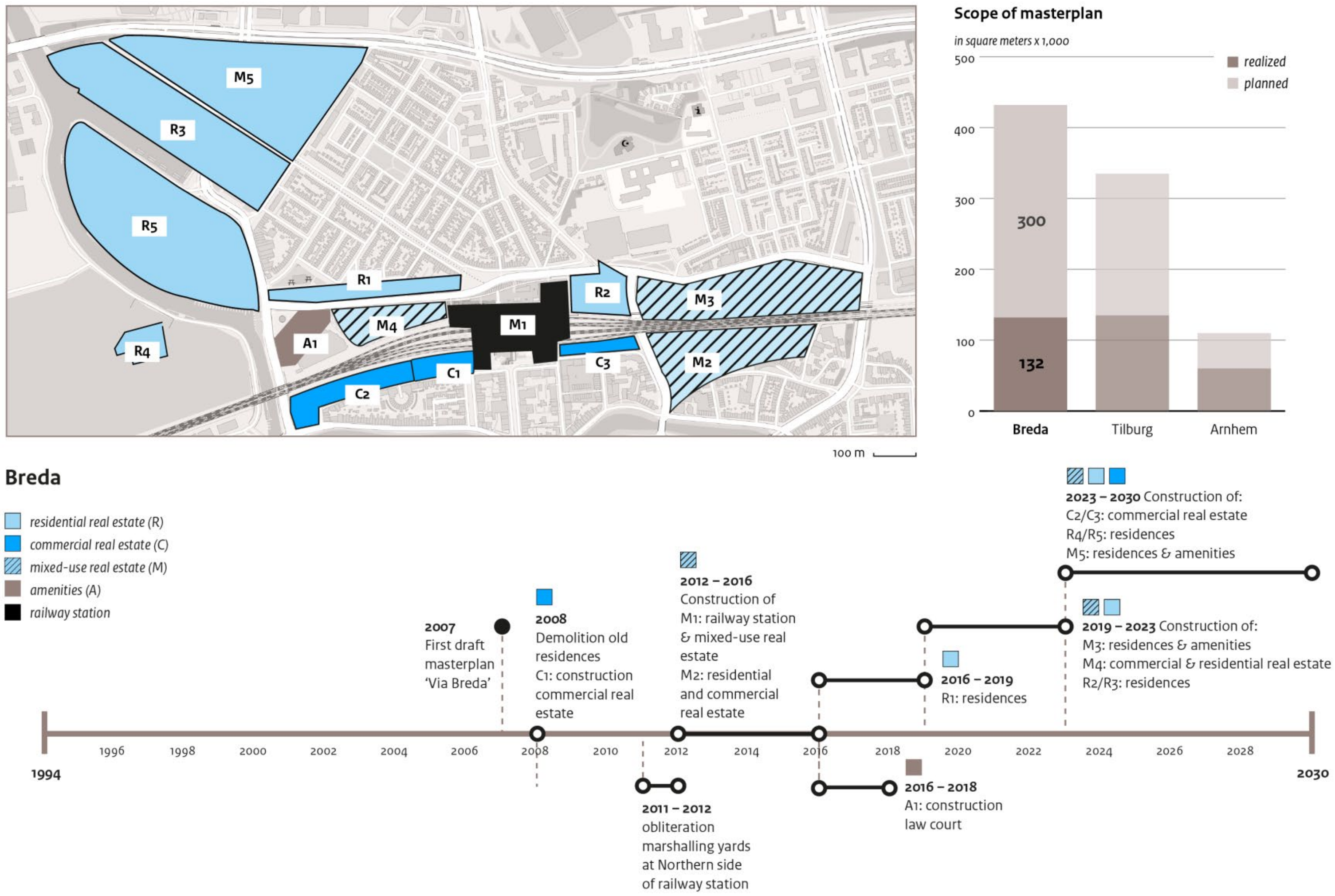

***Figure A1:** Timeline of construction sequences* - Breda

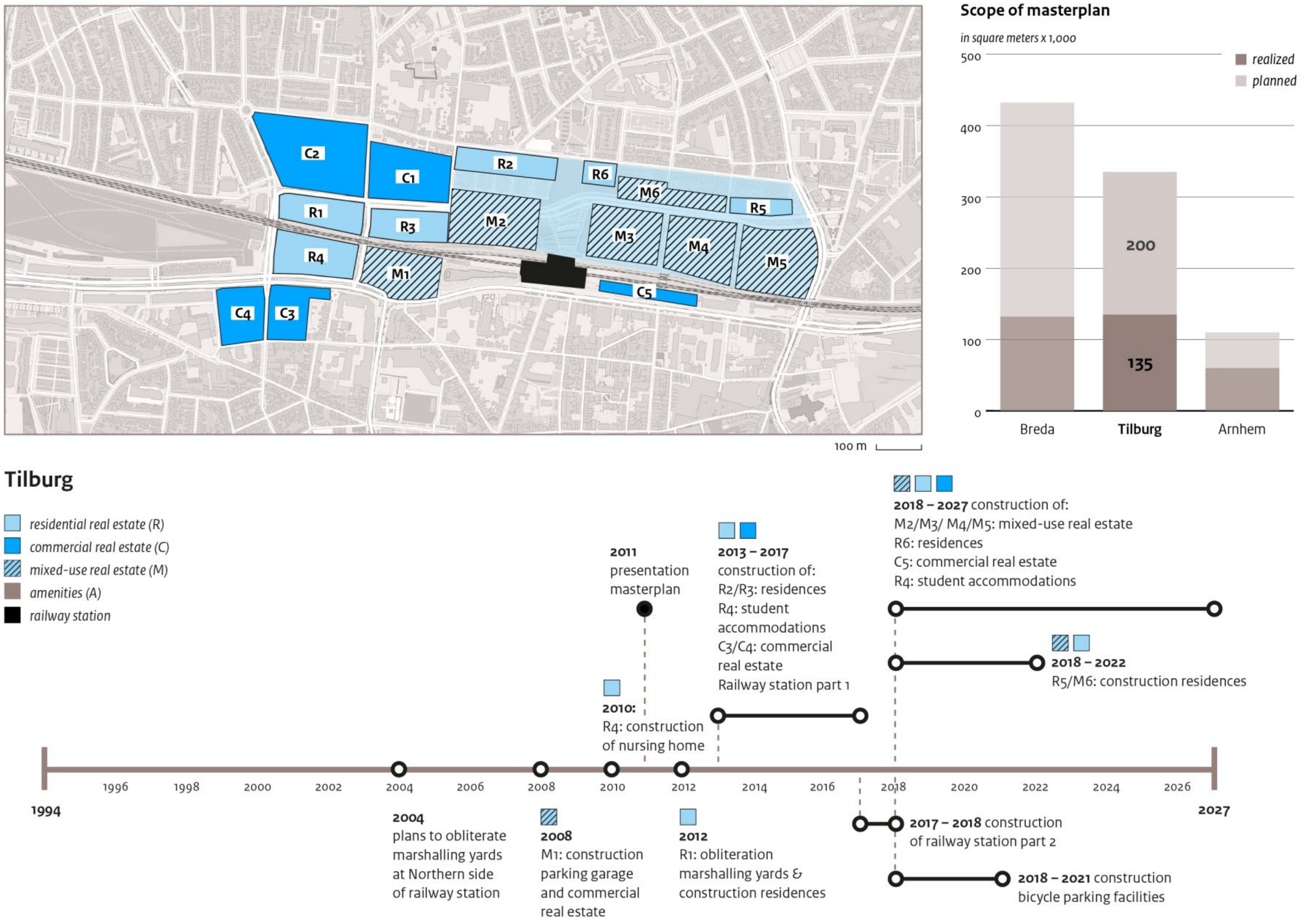

Figure A2: *Timeline of construction sequences* - Tilburg

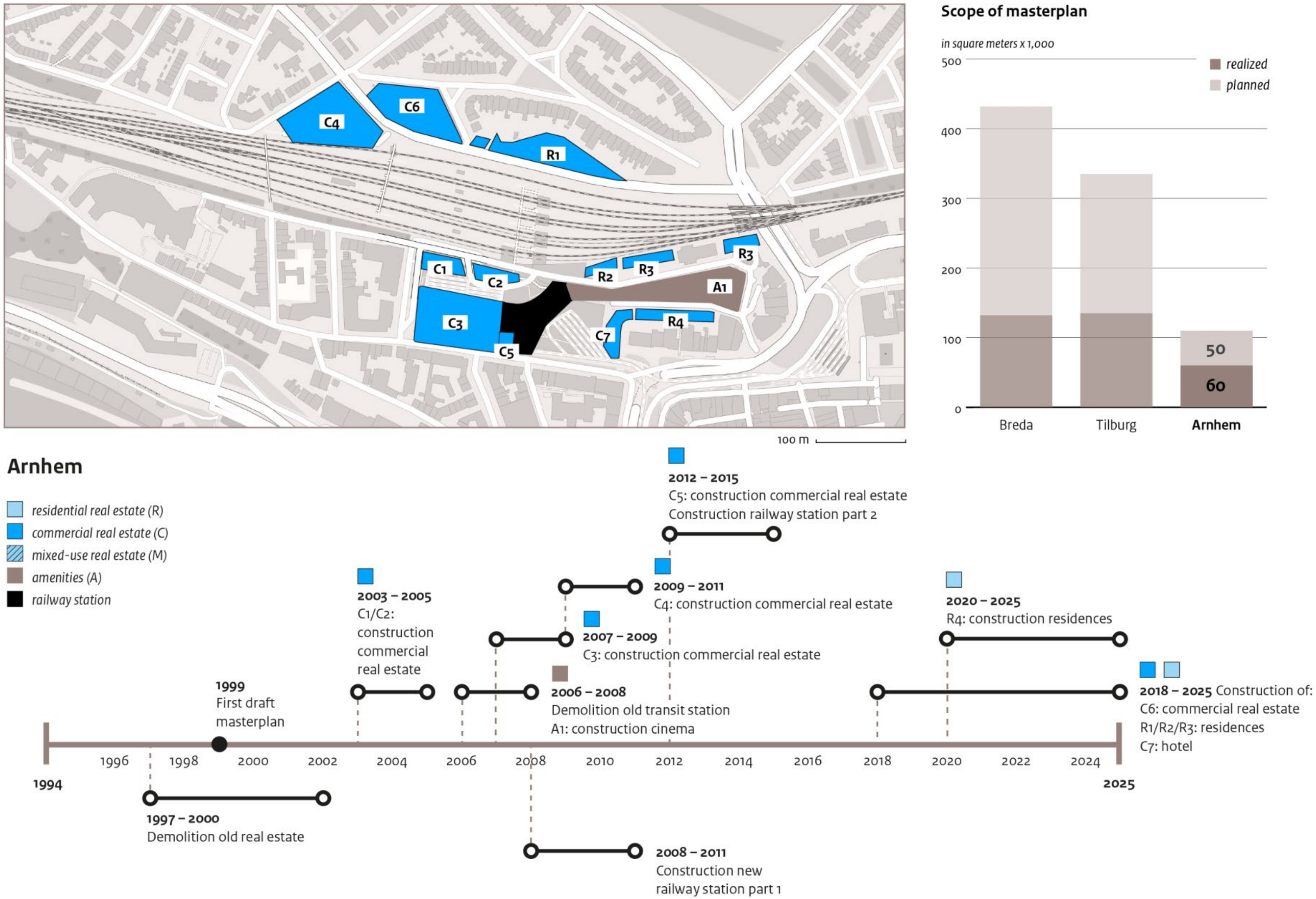

Figure A3: *Timeline of construction sequences* - Arnhem

Appendix B: *Tables*

Table A1: *Selection process of Residential Property Data*

Selection Criteria	*Number of observations*
1. Initial dataset (1985-2017)	3,554,880
2. Remove building land and garage box transactions	3,437,024
3. Remove cases with unknown dwelling type	3,427,456
4. Remove cases with no permanent residential function (caravan, living boat, recreational residence)	3,414,261
4. Remove cases with unknown building year	3,272,212
5. Remove cases with missing residential characteristics (see list used)	3,266,434
6. Remove cases with lot size of less than 1 m2 or more than 10000 m2	3,245,757
7. Remove cases with less living space (volume) than 12 m2 (20m3)	3,046,451
8. Remove cases with unreliable characteristics	2,722,519
9. Remove cases with transaction price outside of 0.5 and 99.5 percentile	2,695,263
10. Remove zip-codes with less than 50 transactions (1985-17)	2,678,890
11. Keep cities with at least 50.000 inhabitants, within concentric ring of three kilometer of railway station	675,779
12. Remove cases sold before 1994 (representability)	619,800

Table A2: *Data Description Variables used in Stage 1*

Variable	Description
Transaction price	Transaction price of the dwelling, deflated in 2017 euro's
Structural Attributes	
Floor space (m^2)	The number of square meters floor space of the dwelling
Living space (m^3)	The number of cubic meters living space of the dwelling
Number of rooms	The number of rooms in the dwelling
Number of floors	The number of floors in the dwelling
Dwelling Quality	
Maintenance quality inside (1-9)	Quality of maintenance inside the dwelling, ranging from bad (1), bad to mediocre, mediocre, mediocre to reasonable, non-reported or reasonable, reasonable, good, good to excellent, and excellent (9)
Maintenance quality outside (1-9)	Quality of maintenance at the exterior of the dwelling, ranging from bad (1), bad to mediocre, mediocre, mediocre to reasonable, non-reported or reasonable, reasonable, good, good to excellent, and excellent (9)
Maintenance of garden (1-5)	Quality of maintenance of the garden, ranging from no garden existent (1) to in neglected , normal, good, or very-well-kept state (5)
Dwelling view	Separate dummy variables indicating whether the dwelling has a view on either a park, open water, a forest, or the view is unobstructed
Parking space	Dummy variable indicating whether the dwelling has a parking space
Central-heating system	Dummy variable indicating whether the dwelling has a central heating system
Isolation quality (0-5)	Dwelling has no isolation (0), one-layered isolation, two-layered, three-layered, four-layered, or 5-layered (or full) isolation
Building period	Dummy variable indicating whether the residence was built in 1500-1905, 1906-1930, 1931-1944, 1945-1959, 1960-1970, 1971-1980, 1981-1990 ,1991-2000, or ≥ 2001
Dwelling type	
i) Apartment	
Downstairs	Dummy variable indicating if the dwelling is an apartment and located downstairs of a building
Upstairs	Dummy variable indicating if the dwelling is an apartment and located upstairs of a building
Porch	Dummy variable indicating if the dwelling is an apartment and located in a porch flat
Galery	Dummy variable indicating if the dwelling is an apartment and located in a gallery flat
Other	Dummy variable indicating if the dwelling is an apartment and either located in a maisonette, or comprises both the upper and lower floor
ii) House	
Intermediate	Dummy variable indicating if the dwelling is a house and located in between other houses
Corner	Dummy variable indicating if the dwelling is a house and located at a corner
Semi-detached	Dummy variable indicating if the dwelling is a house and is semi- detached from other houses
Detached	Dummy variable indicating if the dwelling is a house and is completely detached from other houses

Table A3: *Data Description - Predictors Stage 2*

Variable	Description	Source
Density (logarithmic number of jobs)	Natural logarithm of the total number of jobs	Central Bureau of Statistics (CBS) – LISA employment register
Culture (number of km^2 cultural heritage)	Protected groups of real estate, due to their public interest, either because of their beauty, their spatial or structural coherence or their scientific or cultural-historical value. These groups comprise at least one monument.	Ministry of Education, Culture and Science – Rijksdienst voor het Cultureel Erfgoed
Percentage inhabitants between 15-24 years old		Central Bureau of Statistics (CBS) –Woon en buurtkaarten
Percentage inhabitants with Non-Western background	Non-Western immigrant status designated if the parent or grandparents were not born in the Netherlands.	Central Bureau of Statistics (CBS) –Woon en buurtkaarten
Socio-economic status	The socio-economic status of a neighborhood is derived from a number of characteristics. These include: the average level of education, income and position on the labor market.	Bureau for Social and Cultural analyses (SCP) – Statusscores
Percentage inhabitants with lower education	Lower-educated status designated if the person has at most completed elementary schooling	Ministry of Housing, Spatial Planning and the Environment. Drawn from the three publications: VROM (1998) *WBO1998: release 1.0* VROM (2002) *WBO2002: release 1.0* VROM (2005) *WoON2006: release 1.2*
Satisfaction residents about schooling-amenities (1-10)	Mean value of residents' satisfaction with schooling facilities in neighborhood, ranging from 1 (not satisfied at all) to 10 (very satisfied)	
Satisfaction residents about green-amenities (1-10)	Mean value of residents' satisfaction with green amenities in neighborhood, ranging from 1 (not satisfied at all) to 10 (very satisfied)	
Future expectations neighborhood (1-3)	Mean expectation of residents that the quality neighborhood will decline (1), stay the same (2) or improve (3)	
Satisfaction quality of surrounding buildings (1-5)	Mean value of residents' satisfaction with surrounding buildings, ranging from 1 (very satisfied) to 5 (not satisfied at all)	

Tabel A4: *Predictor means and V-matrices*

	Breda	*Synthetic Breda*	*V – matrix*	*Tilburg*	*Synthetic Tilburg*	*V – matrix*	*Arnhem*	*Synthetic Arnhem*	*V – matrix*
Density (natural logarithm of number of jobs)	11.20	11.09	0.11	11.17	11.11	0.47	10.79	10.77	0.20
Culture (number of km^2 cultural heritage)	2.95	2.23	0.03	1.57	1.55	0.27	2.60	0.77	0.00
Percentage inhabitants between 15-24 years old	12.62	12.68	0.43	17.31	17.28	0.05	14.43	14.43	0.46
Percentage inhabitants with lower education	18.68	18.94	0.06	34.60	24.32	0.00	21.87	22.04	0.01
Percentage inhabitants with Non-Western background	11.95	11.34	0.01	13.58	13.52	0.14	17.49	17.28	0.08
Socio-economic status (−2, 5)	−0.52	−0.37	0.00	−1.07	−1.03	0.05	−1.20	−0.98	0.02
Satisfaction residents about quality of schools (1-10)	6.81	6.12	0.01	5.24	5.41	0.00	5.78	5.57	0.11
Satisfaction residents about green-amenities (1-10)	5.54	5.67	0.05	5.07	5.34	0.00	5.58	6.04	0.00
Future expectations neighborhood (1-3)	1.82	1.85	0.11	1.83	1.82	0.02	1.75	1.88	0.01
Satisfaction quality of surrounding buildings (1-5)	2.48	2.41	0.19	2.61	2.37	0.00	2.42	2.42	0.11

Notes: The table presents the predictor variable affinity between the treatment city and its respective synthetic version. The columns v-matrix reports the predictive power designated to each of the predictors in the synthetic control methodology. A description of the predictors is provided in Appendix Table A1. All values in the table respond to the average of a concentric ring of three km around the railway station. The exception being the Density and Culture variable which respond to the sum.

Table A5: *Inference estimates of in-time placebo tests*

	Breda				Tilburg				Arnhem			
		In-Time Placebo				*In-Time Placebo*				*In-Time Placebo*		
	Subsampling	2 Years	4 Years	6 Years	Subsampling	2 Years	4 Years	6 Years	Subsampling	2 Years	4 Years	6 Years
Pre-inter-vention	−0.002	0.005	−0.002	−0.004	−0.003	−0.007	−0.005	−0.007	−0.006	−0.007	−0.001	0.002
	(0.006)	(0.007)	(0.009)	(0.007)	(0.004)	(0.006)	(0.007)	(0.006)	(0.006)	(0.009)	(0.008)	(0.008)
2002-03												0.014
												(0.009)
2004-05											−0.014	−0.014
											(0.008)	(0.011)
2006-07				−0.007				−0.010		−0.017	−0.018	−0.015
				(0.011)				(0.009)		(0.012)	(0.009)	(0.010)
2008-09			0.008	−0.011			−0.005	−0.007	−0.028	−0.034	−0.037	−0.036
			(0.008)	(0.012)			(0.008)	(0.010)	(0.007)	(0.011)	(0.009)	(0.013)
2010-11		0.0008	0.006	0.007		−0.012	−0.012	−0.009	−0.004	−0.018	−0.012	−0.006
		(0.011)	(0.011)	(0.011)		(0.011)	(0.011)	(0.010)	(0.008)	(0.008)	(0.007)	(0.008)
2012-13	−0.006	−0.009	0.005	−0.003	0.013***	−0.006	−0.010	−0.003	−0.027	−0.037	−0.030	−0.038
	(0.007)	(0.007)	(0.007)	(0.009)	(0.004)	(0.007)	(0.010)	(0.011)	(0.008)	(0.009)	(0.010)	(0.010)
2014-15	−0.010	−0.007	0.003	−0.007	0.053***	0.047	0.048	0.049	−0.069	−0.084	−0.073	−0.064
	(0.010)	(0.008)	(0.008)	(0.010)	(0.005)	(0.010)	(0.012)	(0.011)	(0.007)	(0.013)	(0.012)	(0.013)
2016-17	−0.018	−0.009	0.012	0.002	0.046***	0.040	0.046	0.042	−0.026	−0.032	−0.023	−0.023
	(0.012)	(0.009)	(0.009)	(0.010)	(0.004)	(0.009)	(0.013)	(0.013)	(0.008)	(0.011)	(0.010)	(0.012)

Notes: The subsampling columns refer to the results presented in Figure 4 and Table 6. The in-time placebo procedures present the outcomes where the treatment date is reassigned to respectively two, four, and six years earlier. The values above the dotted lines indicate the in-time placebo effects. All reported values present the average difference between the treatment unit and the synthetic control, adhering to the period shown on the left side of the table. The average is computed after operating 200 synthetic control method procedures, using randomly drawn subsamples of the donor pool at two-third of the original size. The standard error is reported between parentheses.

Table A6: *Is there a differential change in travel times toward the railway station?* – North versus south

	Breda North-side				Tilburg North-side				Arnhem North-side			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	NNW	NSW	NNE	NSE	NNW	NSW	NNE	NSE	NNW	NSW	NNE	NSE
Bicycle	0,00%	–20,00%	–5,88%	–12,50%	10,0%	–20,0%	–21,4%	–44,4%	0,00%	0,00%	0,00%	0,00%
Car	0,00%	–16,67%	–18,18%	–33,33%	0,0%	–20,0%	–7,7%	–16,7%	–11,11%	0,00%	0,00%	0,00%
	Breda South-side				Tilburg South-side				Arnhem South-side			
	SSW	SNW	SSE	SNE	SSW	SNW	SSE	SNE	SSW	SNW	SSE	SNE
Bicycle	28,57%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Car	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%

Notes: The table shows whether there is a differential pre-reform – post-reform change in travel times towards the railway station, for eight selected districts in the treatment cities towards the railway station. The eight selected districts are distributed to four districts at the north side of the railway station and four districts at the south-side of the railway station. The four districts are correspondingly distributed in one district at the north-west (NW), one district at the south-west (SW), one district at the north-east (NE), and one district at the south-east (SE). Taking Breda as an example, column (1) shows that at far distances from the railway station at the Western side of Breda, either at the northern or the southern side of the railway station, the travel times towards the railway station did not change or even increased. Column (2) shows that at close distance of the railway station at the northern side the travel times did decrease, while this was not the case at the southern side of the railway station. This same pattern is shown by columns (3) and (4): at close distances to the railway station at the north-eastern-side, the travel times decreased much more than further away, while at the south-eastern side, the travel times towards the railway station were not different whether a resident lives at close or large distances from the railway station. This same pattern is shown by the travel time differences in Tilburg, shown in columns (5) to (8). The travel times in Arnhem did barely change over time.
Data source: Authors' calculations based on historical maps in Google Earth.

Table A7: *Can the effects be attributed to differences in travel time due to accessibility of transit network?*

	Breda		Tilburg		Arnhem	
	Actual	Synthetic	Actual	Synthetic	Actual	Synthetic
Post-intervention period						
2008-09	-	-			-1.2%	-0.6%
2010-11	-	-			-3.5%	-2.3%
2012-13	0.2%	-0.4%	−1.4%	-1.5%	−2.3%	−1.8%
2014-15	-0.4%	-0.3%	−0.8%	-0.5%	−0.4%	−0.2%
2016-17	−0.1%	-0.2%	−0.5%	-0.6%	−0.5%	−0.4%

Notes: The table shows the change in weighted generalized travel times of the treatment cities relative to their synthetic controls, for the each of the periods shown at the left side of the table. For both railway stations in the treatment cities and in the control cities, a weighted generalized travel time indicator was computed in three steps. First, for each railway station, a generalized travel time is available capturing its integrated efficiency to all other individual railway stations destinations in the Netherlands. That is, how efficient the railway station is from itself (point A) to a destination (point B). This generalized travel time indicator comprises the sum of the in-vehicle time, the frequency, and a transfer penalty (requirement to switch to other trains/modality while travelling from point A to point B). That is, for each railway station combination and each year, we have a number of over 300 generalized travel times, equaling the number of unique railway station combinations in the Netherlands. In the second step, for each railway station we compute the percentage of travelers going to a particular destination (from point A to 300 destinations in the Netherlands). Then we compute a weighted generalized travel time indicator for that railway station. We do this by multiplying the percentage of travelers from point A to one of the 300 railway stations in Netherland by its generalized travel time. Since we do this for each year separately, in the third step, we are able to compute the percentage-point differences in the weighted generalized travel time for each railway station separately. The synthetic versions are computed using the average weights obtained by the subsampling results (Section 5.3).
Data source: Authors' calculations based on data by ProRail Netherlands

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