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THE IMPACT OF "METRO C" IN ROME ON THE HOUSING MARKET

by Federica Daniele* and Elena Romito*

Abstract

An increase in land values is often considered the touchstone of the positive impact of the development of new public transport infrastructure on well-being in cities. In this paper, we evaluate the impact of the construction of "Metro C" - Rome third metro line - on the housing market and local economic activity. To overcome the potential threat posed by the non-random placement of transport infrastructure, we rely on the multiple synthetic control method approach. We detect a negative and statistically significant impact of the new infrastructure on average house prices in peripheral treated areas, reaching minus 137 EUR p/m2 3-year after treatment, roughly 5% of the pre-treatment level, driven by properties belonging to the higher end of the price distribution. We also find that the share of foreign population displayed a statistically significant increase in treated areas after treatment. According to the evidence, the metro might have thus been perceived as an amenity by poorer households and as a disamenity by richer ones. The latter can in turn either be a first-order effect of the development of the new metro line (e.g., due to noise, diminished safety) or a second-order one, mediated by the inflow of foreign population.

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1 Introduction

The availability of sound public transport infrastructure makes big cities attractive and allows them to thrive, by reducing congestion costs and cutting down emissions. An increase in land values is often considered the touchstone of the positive impact of the development of new public transport infrastructure on well-being in cities: if the new infrastructure brings about a reduction in congestion and by increasing the share of commuters taking public transport improves the air quality in selected areas, housing demand in those areas should increase and the cost of buying or renting a house follow suit. The mounting pressure to decarbonise cities, the rise of new green transport modes, such as active or shared mobility, and the increasing availability of geographically granular data restate the importance of transport infrastructure investment and the need to evaluate its impact on quality of life in cities.

In this paper, we evaluate the impact of the construction of "Metro C" in Rome on the housing market and local economic activity. With its 18,1 km of length, Metro C is the third city metro line. Rome transport system features 1,35 km of metro lines every 100.000 inhabitants, against 2,96 in Milan or 3,87 in London (Legambiente, 2021).[1] The absence of proper public transport infrastructure is reflected into a higher degree of car usage - 63 cars p/100 inhabitants against 49 in Milan or Naples - and congestion - the average commuting time in Rome local labor market is 3 times as large as the average Italian local labor market (Accetturo et al., 2019).[2] The development of Metro C determined a 44% expansion in the metro system total length (from 41,3 to 59,4 km), thus representing a relevant - and yet insufficient - step towards a greater sustainability of Rome transport system.

Evaluating the impact of transport infrastructure improvements is challenging given the typically non-random placement of transport infrastructure. A few examples of the non-random placement of transport infrastructure are: 1) the local government can decide that a new metro line must cross a declining neighborhood in order to revitalise it; 2) the local government can decide that a new metro line must cross a booming neighborhood in order to support its expansion through the provision of adequate infrastructure. In either case, a difference-in-difference estimation, obtained by comparing the impacted neighborhoods before and after the opening of the new metro line to the not impacted neighborhoods, will deliver biased estimates of the new transport infrastructure impact. To overcome the potential threat

[1] In 2021, the municipality of Rome had 2,78 million inhabitants. This number rises to 4,41 (for the year of 2018) if we consider the metropolitan area of Rome according to OECD definitions.

[2] Accetturo et al. (2019) analyse the differences with respect to the city size distribution across a subset of major European economies. They find that the relative size of Italian largest cities is lower compared to other countries, and argue that disproportionately high congestion costs due to insufficient infrastructure might penalise Italian largest cities compared to their European counterparts.

posed by the non-random placement of transport infrastructure, we rely on a synthetic control method approach (Abadie and Gardeazabal, 2003). According to this method, a basket of non-treated units ("synthetic control") is chosen so as to minimise the differences in outcomes between the treated unit and the synthetic control before the treatment occurs. Being our sample composed of multiple treated units, we implement an extension of the synthetic control method to multiple treated units (Cavallo et al., 2013).[3]

Our sample comprises a set of non-rural neighborhoods, comprising 89% of non-rural population, observed during 2006-2016. We define the treatment status depending on whether the distance between a given neighborhood (or unit, from here onwards we use these terms interchangeably) and the closest new metro line stop is less than 1 km. We account for anticipation effects in choosing the treatment date provided that our main results relate to house prices. While the new metro line effectively opened between 2014/2015, descriptive and narrative evidence indicates that the uncertainty surrounding the project effective implementation fell during the first semester of 2010, which we thus set as the start of our treatment period. We experiment with several house prices metrics available at the neighborhood level, specifically a house price value representative of house prices belonging to the lower and upper end of the price distribution, which we sub respectively as "minimum" and "maximum" house price, mimicking the terminology adopted by the data provider, and their average. We detect a negative and statistically significant impact on average house prices for the all-treated-unit sample. When we inspect potential sources of heterogeneity, we find that the negative impact at the aggregate level hides substantial heterogeneity, with the effect of the new metro line being large, negative and statistically significant in peripheral treated areas, amounting to a decline of 137 EUR in the price p/m2, roughly 5% of pre-treatment levels, three years after treatment. We further explore whether the statistically significant negative impact on average house prices in peripheral areas is primarily driven by the evolution of minimum or maximum house prices, or both. We find that prices belonging to the upper end of the price distribution are the ones negatively affected by the development of the new metro line in peripheral areas. This evidence supports the view that the new metro line might have been perceived as a disamenity by richer households in the presence of a segmented housing market (due to e.g., greater noise, diminished safety, see Ahfeldt et al. (2019)).

We investigate potential mechanisms with the data at our disposal, which are primarily related to the demographic structure of the analysed neighborhoods. In particular, we test

[3]The synthetic control method approach is based on the premise that an optimally chosen basket of non-treated units does a better job as control group than any non-treated unit alone.

whether given demographic groups grew in either absolute or relative size in treated areas compared to their synthetic control. We find that the share of foreign population grew in treated peripheral areas compared to their synthetic control and the ex-post difference in means to be statistically different from zero, as opposed to before treatment. We do not find, however, evidence of increasing overall population, which underscores the compositional nature of the just described observed changes. An increase in the foreign share in treated areas after treatment provides a further explanation for the negative impact of the new metro line on the price of properties belonging to the upper end of the price distribution. The inflow of foreign population might have been perceived as a disamenity by richer individuals, which thus reacted by relocating their demand elsewhere.[4] The just explained dynamic would provide an explanation for both the more negative impact on more pricey houses and the absence of a positive effect on overall population.

We further explore how the new infrastructure affected a number of additional outcomes we can measure. First of all, we estimate the impact of the new infrastructure on the business creation rate. The development of a new infrastructure might indeed expand the market that firms located close to the new infrastructure can access, which may induce the entry of new firms (Pogonyi et al., 2019). We detect a weakly positive but not statistically significant impact on the the number of new businesses per capita. We further investigate the impact of the new infrastructure on rental rates. We detect a marginally positive effect materialising after the opening of the most central metro station (in 2018). While some of the channels behind the impact of a new infrastructure on house prices might apply to rental rates as well, the literature has also highlighted some key differences between the home ownership and the rental housing market. For example, unlike house prices, rental rates do not reflect a valuation over the indefinite future but only over a fixed time-span (Melser, 2020). Furthermore, homeowners are likely to be very different types (e.g., older) than renters, and have thus different preferences.

It is possible that the infrastructure had a positive impact on some specific well-being dimensions, in spite of these being insufficient to compensate for negative channels and thus overturn the result of a negative impact on housing values. We therefore conclude our analysis by inspecting two dimensions of well-being in cities that might be impacted by the development of a new infrastructure, road safety and air quality. Using data of geolocated car accidents, we find a positive, albeit not statistically significant, association between road

[4] We are not the first ones to provide evidence in favor of a negative impact of immigration on house prices: Saiz and Wachter (2011) do so for the United States, Accetturo et al. (2014) for Italy, Sá (2015) for the United Kingdom, Balkan et al. (2018) for Turkey.

safety and proximity to the new metro line. Based on PM10 emissions data collected by the local environmental agency, we find that the monitoring stations displaying the largest drop in average emissions after the opening of the new infrastructure are the closest to the central end of the new infrastructure. The sparsity of monitoring stations and their disproportionate concentration in the eastern part of the city - where most of the industrial activity is concentrated - prevent us however from rigorously drawing the causal impact of the new infrastructure on air quality.

The paper proceeds as follows: Section 2 briefly introduces the new infrastructure; Section 3 outlines the empirical strategy and describes the data employed; Section 4 presents the results; Section 5 concludes.

Literature review This paper contributes to the literature on the evaluation of the impact of transport infrastructure on economic activity in cities. Several studies find a positive impact associated with the development of transit infrastructure on several indicators of economic activity, ranging from the level of house prices (Gibbons and Machin, 2005; Ahfeldt, 2011; Billings, 2011; Cervero and Kang, 2011; Casolaro and Budiakivska, 2018) to the productivity and number of firms located close to new metro stations (Pogonyi et al., 2019).[5] A positive impact of transit infrastructure development on house prices is typically interpreted as the consequence of increased housing demand, and therefore as a signal that the infrastructure effectively serves commuters' needs.

The improvement in accessibility stemming from transport infrastructure development, however, can also produce negative externalities, such as the increase in noise or crime, because of the improved access to the neighborhood provided to outsiders, or the low aesthetic value of rail stations (Ahfeldt et al., 2019). Hence, the net impact of a new infrastructure development on property values does not need to be positive. For instance, Bowes and Ihlanfeldt (2001) find a negative impact of the development of MARTA (Metropolitan Atlanta Rapid Transit Authority) rail system on the value of properties located in the proximity of the rail stations, and a positive impact for properties located further than three miles away.

The most closely related paper to ours is Casolaro and Budiakivska (2018), who employ the same empirical methodology as ours and evaluate the impact on house prices of a new tram line in Florence. They find that the new metro line impacted positively house prices and more so in peripheral treated units.

[5] Other papers focus more on the aggregate effects of the development of transport infrastructure, such as Tsivanidis (2019) and Heblich et al. (2020), who consider the impact on the spatial distribution of overall economic activity in cities, or Gonzalez-Navarro and Turner (2018), who look at the impact on cities' total size.

Better public transport accessibility does not need however to be associated with higher house prices. In cities where the cost of car ownership is too high for poorer residents (as it is the case, for example, in cities characterised by high levels of inequality), or where the value attached by cultural preferences to commuting via public transport is low, house prices might even be lower in areas characterised by higher public transport accessibility (OECD, 2020). Likewise, an improvement in transport infrastructure does not need to trigger gentrification, in the sense of richer households moving in the neighborhoods impacted the most and displacing poorer ones, therefore preventing the latter from benefiting from the new infrastructure. Indeed, a few recent studies evaluating the inequality impact of new transport infrastructure in non-OECD countries find that new transport infrastructure by causing an inflow of poorer families in the impacted neighborhoods turn out to disproportionately benefit poorer families (Balboni et al., 2021; Warnes, 2021).

2 Policy context

The Metro C stretches for 18,1 km (about a third of Rome metro system total length) and it has a total of 22 stations, with an average waiting time of 10 minutes (Fig.2). Metro C connects the eastern periphery of Rome with the city centre: the first portion of the metro - partly situated outside of the informal boundaries of the city (outside of the highway ring or *Grande Raccordo Anulare*) - runs through a sequence of low-density, social housing-intensive neighborhoods. The second portion is instead located entirely inside the *Grande Raccordo Anulare*. The end of the line that is located in the city centre, San Giovanni metro station, connects with Metro A, and it is the second connecting station of Rome metro system after Termini metro station.

In spite of being the third metro line of Rome, the total number of trips taken using Metro C in 2019 was 19 millions, a rather low number compared to Metro A (110 millions) and Metro B (80 millions) (Comune di Roma, 2019). Moreover, 28% of the total number of trips taken on Metro C used San Giovanni metro station as the starting point, against 14% and 10% of the station with the highest number of trips on the other two metro lines (in both cases Stazione Termini metro station). The remaining 13 millions of trips are divided among 21 metro stations, which therefore record on average about 600k trips per year (against more than 3,5 millions for an average Metro A metro stations and more than 2,5 millions for an average Metro B stations). Hence, traffic on Metro C appears to be substantially lower the other two metro lines.[6]

[6]Data on the yearly number of trips per metro stations are taken from *Roma Servizi per la Mobilità* - the

The first approved project of Metro C, with projected route very similar to the actual one, dates back to 1995. The construction of Metro C, however, started only in 2006 and continued intermittently until 2014, when the first (and largest) section of the metro was inaugurated, followed in 2015 by the opening of the remaining part. The many delays to which the project was subjected were primarily caused by the slow response of the public administration and justice system in settling the claims that arose during the course of the project execution with the private contractor in charge of the infrastructure development (Bolis et al., 2020).

Given these premises, it is challenging to identify the right time when the intervention might have started having an impact on social and economic activity. Some authors suggest setting the treatment date in correspondence of the new infrastructure opening (Yan et al., 2012) while some others suggest using the date of the announcement (Yiu and Wong, 2005; Agostini and Palmucci, 2008) to overcome potential anticipation effects. Following the second route, the ideal treatment date should be set around a time when it becomes clear that the project will be completed within a defined period. The complex and controversial case of Metro C clearly does not make the timing of the very first announcement a suitable candidate. Following the long period of uncertainty characterising the first decade of 2000's, at the beginning of 2010 become clear a tipping point for the project was close. While the municipality of Rome and the Regione Lazio officially notified that they would cover the expenses needed to bring the project to an end only in June 2010[7], the unofficial announcement by the major of the city arrived in April. This declaration has been acknowledged as a pivotal tipping point also from the local press, contributing to spread an optimistic feeling that the project was finally going to be brought to completion [8]. This narrative evidence supports setting the first semester of 2010 as treatment starting period. This choice is corroborated by raw evidence showing the gap between average house prices in the neighborhoods located within 1km from the future new stations and the remaining set of neighborhoods opening up at the beginning of 2010 (Fig.1).

city hall in-house company in charge of mobility management - website.

[7]The deliberations are the n.43756 (24 June 2010) and the n.185 (July 5 2010) for the municipality of Rome and Regione Lazio respectively.

[8]These articles are still available from the press archives. See for example: La Repubblica Roma, 28 April 2010, *Metro C, il termine dei lavori slitta di due anni. Alemanno: "L'intera linea conclusa per il 2018"*

3 Empirical strategy

3.1 Multiple Synthetic Control Method

Our empirical strategy relies on the synthetic control method (SCM), firstly introduced by Abadie and Gardeazabal (2003) and further developed in Abadie et al. (2010) and Abadie et al. (2015). The synthetic control method is based on the idea that, when the units of observation are a small number of aggregate entities, a combination of unaffected units often provides a more appropriate comparison than any single unaffected unit alone (Abadie, 2021). According to the synthetic control method, the estimated impact is obtained by comparing the outcome variable for a given treatment unit against a synthetic counterfactual. The latter is obtained as a weighted combination of units belonging to the potential control group (also labelled donor pool), with weights chosen to minimise the distance between the treated unit and the synthetic counterfactual in terms of a set of pre-treatment variables that typically include the outcome variable (also labelled constrained variables).

The treatment effect at time t for a given treated unit i, $\widehat{\alpha}_{it}$, is then:

$$\widehat{\alpha}_{it} = Y_{it} - \widehat{Y}^C_{it} \quad \text{with} \quad \widehat{Y}^C_{it} = \sum_{J_i} \widehat{w}^*_j Y_{jt} \tag{1}$$

In eq.1, Y_{it} is the outcome for treated unit i at time $t \geq T_0$, with T_0 being the treatment starting period, $\hat{Y}^C_{it}$ is the outcome for the synthetic counterfactual, and $\widehat{w}^*_j$ is the w-weight assigned to unit j from the donor pool of unit i, J_i. The w-weights are obtained by solving the mean squared prediction error minimisation problem: $\min_W ||X_1 - X_0 W||_V$, where X_1 is a $k \times 1$ vector of k predictors for treated unit i, X_0 is a $k \times J_i$ matrix of k predictors for each of the J_i units belonging to treated unit i donor pool, and V is a matrix defining the importance of the individual predictors in the mean squared prediction error minimisation problem. For a detailed description of how to obtain the weights see Abadie and Gardeazabal (2003).

We implement the synthetic control method extension to the multiple treated units case as in Cavallo et al. (2013) and Acemoglu et al. (2016), according to which the overall effect is given by:

$$\widehat{\alpha}_t = I^{-1} \sum_{i=1}^{I} \widehat{\alpha}_{it} \tag{2}$$

where $\widehat{\alpha}_{it}$ is the estimated treatment effect for treated unit $i \in I$ as in eq.1.

Inference is conducted by means of in-space placebos (Abadie et al., 2015).[9] This methodology requires that the intervention is artificially assigned to each unit j belonging to the donor pool of unit i, J_i, to obtain a distribution of placebos, $\widehat{\alpha}_{it}^{PL} = \left\{\widehat{\alpha}_{jt}^{PL} : j \in J_i\right\}$. Then, the common approach is to let the probability that the treatment effect falls within the range of the estimates placebos be a measure of the coefficient of interest statistical significance. Operationally, the p-value is set equal to the proportion of placebo tests such that the estimated placebo is greater or equal (in absolute values) than the actual treatment effect:

$$p - value = Pr(|\widehat{\alpha}_{it}^{PL}| > |\widehat{\alpha}_{it}|)$$

The generalisation of this methodology to the multiple treated units case is proposed in Cavallo et al. (2013). It requires a set of placebos to be computed for each treated unit $i \in I$, $\widehat{\alpha}_{t}^{PL} = \left\{\widehat{\alpha}_{it}^{PL} : i \in I\right\}$. To account for the fact that averages calculated across a large number of observations tend to smooth out noise, they propose to set p-values equal to:

$$p - value = Pr(|\widehat{\alpha}_{t}^{PL}| \geq |\widehat{\alpha}_{t}|) \tag{3}$$

where $\widehat{\alpha}_{t}^{PL}$ denotes the distribution of $N^{PL} = \prod_I J_i$ all placebo averages that can be calculated across the treated units' donor groups. The p-value in eq.3 then gives the probability that the estimated (average) placebo is grater or equal (in absolute values) than the actual (average) treatment effect. Operationally, our implementation of the multiple SCM relies on the package `synth_runner` developed by Galiani and Quistorf (2017).

3.2 Data sources

The primary source of data we employ are house price data at the semester-level from *Osservatorio del Mercato Immobiliare* (OMI), an observatory under the Italian tax agency (*Agenzia delle Entrate*). Based on a sample of housing market transactions, OMI calculates the per square meter minimum and maximum sale price for each OMI zone (*zona OMI*). OMI zones are constructed by OMI with the objective of segmenting the Italian housing market into sufficiently homogeneous units. In 2011 there were 320 of such zones belonging to the municipality of Rome, classified into city centre (class B), near the city centre (class C), peripheral areas (class D), suburban areas (class E) and rural or extra-urban areas (class R) (Fig.3).[10]

[9] To be considered valid, this approach requires the treated unit error term to have the same distribution as those of the donor pool units.

[10] We only consider zones belonging to the municipality of Rome as, being all subject to the same legislation, provide a better potential control group in comparison to other zones that, albeit close, may be under different administrative regulation.

We drop OMI zones in class R from the analysis, and group class B-C (labeling them as "central") and D-E (labeling them as "peripheral"). The average surface for central OMI zones is approximately 1 km2, while it is approximately 4.5 km2 for peripheral ones. Importantly, the OMI taxonomy was revised in 2014. The revision entailed both a redrawing of the OMI zones and a reduction of their number. In order to account for this change in taxonomy, we report the post-2014 data to the 2011 OMI taxonomy, by using the share of overlapping surface between the two taxonomies as weight.[11]

Finally, while the OMI dataset contains information also on house prices in segments other than the residential one, we focus on residential property values since the database provides the most accurate information for this type of property.

Our house prices panel starts in 2006 and ends in 2016 and it consists of 220 OMI zones. We drop rural OMI zones from our analysis (N=272). Additionally, we drop those zones for which we do not have complete information either in the OMI dataset or in one of the other datasets we merge with the latter (N=237), and the OMI zones falling within the perimeter of the Xth *municipio* (N=220), since its coastal characteristics do not make it an appropriate term of comparison for the rest of the city. The selected sample comprises 89% of population residing in the 272 non-rural OMI zones.

"Minimum" and "maximum" house prices are defined by OMI as the lower and upper bound for the within-unit price distribution after having excluded outliers.[12] We use the minimum and maximum to calculate an "average" house price for each of the 220 OMI zones and semester during 2006-2016. Fig.4 portrays the evolution of the median average house price over time. The series displays a rapid increase just before the Great Recession, similarly to what happened to house prices in Italy at the aggregate level (Emiliozzi et al., 2018), a weaker recovery up to 2012, followed by a new slump caused by the sovereign debt crisis. The aggregate house price time series features a recovery in 2015, which is instead missing for the city of Rome.

As a second type of outcome, we look at the yearly rate of new businesses. We obtain the complete list of all new businesses opening up in the municipality of Rome with associated their full address and year of registration from the Italian business registry (Infocamere). The business registry contains the most geographically granular information on Italian economic activity. Yet, it features some issues. The large incidence of missing information with respect

[11]To give a concrete example, let's assume that numbers index the old taxonomy and letters the new one, and that OMI zone 1 intersects with OMI zones A and B, and that the two areas of overlaps are $s_{1,A}$ and $s_{1,B}$ with $s_1 = s_{1,A} + s_{1,B}$ being the total area of OMI zone 1. The (imputed) price in OMI zone 1 at time $t \geq 2014$ is $p_{1,t} = p_{A,t} \times (s_{1,A}/s_1) + p_{B,t} \times (s_{1,B}/s_1)$.

[12]Notice that we have very little information on average building characteristics in each OMI zone, which prevents us from implementing an hedonic adjustment of house prices.

to the industry of individual businesses is one of those.[13] Hence, while we would have liked to focus on the non-tradable sector since this would likely be more affected by the opening of the new transport infrastructure, we are unable to do so.

While the Infocamere dataset allows in principle to track business relocations (occurring for 6.5% of firm-year observations during 2006-2016), we do not focus on those and we retain for each business the address information at the time of (first) registration. This cleaning procedure delivers an average of 12,310 yearly registrations, and a total of 135,408 registrations during the period under consideration for the municipality of Rome. To these registrations correspond 65,416 unique addresses. We proceed with the geolocalisation of those using the OpenStreetMap-based `nominatim geopy` python library. After some data cleaning on the address strings, we are able to geolocalise roughly 90% of them. We then impute the geolocalised businesses to the corresponding OMI zone polygon. After this procedure, and restraining the sample to the set of OMI zones employed for this analysis, we end up with an average of 7,711 yearly registrations, ranging between 7,005 (in 2012) and 8,554 (in 2015) (Fig.5, panel (a)). The evolution of the (median) number of new registrations per thousand inhabitants across the OMI zones considered is instead reported in Fig.5 (panel (b)).

Finally, we add to our dataset a set of variables containing local population and housing stock characteristics that we use as controls. Some of these variables feature time variation, while some others do not and refer to the latest Census wave (2011). Table 1 contains a complete list of the variables used for the analysis, the period they refer to, the frequency and the data source. These data are originally available for a different geographical taxonomy (*"zona urbanistica"*) than the one employed by OMI: hence, we report them to the OMI zone level by assuming uniformly spatially distributed units (i.e., individuals, buildings) across *zone urbanistiche*, and assigning them to OMI zones proportionally to the surface overlap between the two taxonomies. Fig.6-7 displays their spatial distribution.

3.3 Using the SCM to estimate the impact of Metro C

Our baseline treatment definition considers as treated OMI zones whose centroid is less than 1000 meters far away from the new metro stations. Further, based on the reasons presented in Section 2, we set the treatment starting period equal to 2010H1. Our treatment definition delivers a total of 21 treated units and 199 units belonging to the donor pool.[14] Fig.8 shows

[13]The share of businesses with missing information on the corresponding ATECO code (where ATECO is the Italian classification of economic activity) depends on the year but it is on average 30%. This percentage was calculated after back-imputing industry information at the business level for those businesses for which industry information is not always missing.

[14]See Fig.13-33 for a list of the treated units and the location of the metro station within them.

the spatial distribution of treated vs. donor group units. The names of the full list of treated units is given in Table 2. We investigate the heterogeneous impact of the new transport infrastructure based on the proximity to the city centre. There are a few reasons for why the impact of the new infrastructure might be heterogeneous depending on whether the treated area belongs to the city centre or the periphery. Firstly, there is a complementarity between new transport infrastructure development and the pre-existing stock of transport infrastructure. This complementarity might be the cause of a stronger positive impact of the new infrastructure in central areas, which enjoyed a higher level of accessibility already before the new transport infrastructure was developed. Secondly, housing supply might have expanded in the period under consideration, thus neutralising the potential upwards pressure on house prices exerted by increasing housing demand next to the new infrastructure. This concern is less likely to be relevant in central areas, where housing supply tends to be more fixed due to higher development intensity.

Table 3 contains descriptive statistics for the variables included in the final sample over the pre-treatment period across the whole and treated sample, while Fig.6-7 displays their spatial distribution. Central treated units tend to have higher population density, as we would expect, and a lower share of buildings built after 1991 compared to the whole sample. Peripheral treated units feature a higher share of residential buildings and lower house prices. Both central and peripheral treated units are characterised by a lower ratio of employed to total population.

Our analysis considers several outcomes: i) the average house price, ii) the maximum house price, iii) the minimum house price, iv) the number of new businesses per 1000 inhabitants, v) the rental rate. The vector of predictors used to optimally select the vector of weights comprises: time-invariant population density, time-invariant employment rate, time-invariant housing stock characteristics (i.e., the share of buildings built after 1991, the share of residential buildings, the share of vacant apartments), the average population level and share of population between 25 and 39 years old during the pre-treatment period, and finally the starting value (2006H1), the value corresponding to the peak before the Great Recession (2008H1) and the last pre-treatment period value (2009H2) for the minimum and maximum house price, number of new businesses per capita, share of foreign population.[15][16]

[15]We include among the predictors more than one value for the share of foreign population in order to account for potentially spatially heterogeneous trends given the rise in the share of foreign population observed during the reference period.

[16]The SCM allows customisation of the v-weights, namely the weights defining the importance of the individual predictors when computing the synthetic counterfactual. We rely on the default settings, such that the choice of the v-weights is data driven, and based on the minimisation of the Mean Squared Prediction Error (MSPE) of the outcome variable over a set of the pre-treatment periods. Our v-weights will thus differ depending on the outcome, and so will the w-weights and the synthetic counterfactual.

To corroborate the validity of our empirical strategy, we assess the quality of the match resulting from the multiple SCM implementation. We compare by means of a balance test the treated unit values to their synthetic counterpart separately for each predictor, distinguishing between peripheral and central treated areas. The output is reported in Table 8 and 9.[17] Focusing first on the central treated areas subsample, the only variables with respect to which we can reject the null hypothesis of identical means in the treated sample and its synthetic control are population density and the share of buildings built after 1991, a result already anticipated in Table 3. Moving to peripheral treated areas, the synthetic control is unable to find a good match with respect to the 2011 share of employed population and the share of buildings built after 1991, but it manages to match pretty well all remaining predictors. This evidence reassures us about the credibility of the SCM methodology applied to our setting.

4 Results

4.1 Baseline results

Before discussing the results obtained through the SCM, we run a simple diff-in-diff regression, the output of which is displayed in Table 4. According to OLS evidence, average house prices declined in treated areas after Metro C construction works officially started (panel (a)). The effect is negative and statistically significant on maximum house prices (panel (b)), while it is also negative but not statistically significant on minimum house prices (panel (c)).

We build on these naive results by running our multiple SCM estimation, which allows to construct a better control group against which to compare the evolution of house prices in the treated areas. Fig.9 displays the output of this estimation for the case of average house prices. The three panels display the evolution of average house prices for the average treated area (solid line) and synthetic control (dashed line) for all treated units (panel (a)), central treated units (panel (b)), peripheral treated units (panel (c)). The magnitudes and statistical significance of the estimated impact of the new metro line at different leads date $t \geq T_0$ are reported in Table 5.[18] Table 5 highlights a statistically significant negative effect of the new metro line opening on average house prices when calculated on the all-

[17]While we include in the donor pool all non-treated units, both central and peripheral, regardless of the treated unit type being investigated, to give the SCM maximum freedom over the selection of an appropriate synthetic control, an alternative may be to consider only central (peripheral) areas in the exercise performed on central (peripheral) treated units. For the sake of robustness, we also perform this exercise, but results in terms of statistical significance are unchanged.

[18]The p-value is calculated as the share of placebos such that the estimated impact is larger in absolute value than the one calculated on treated areas. For more details see 3.

treated-unit sample (col.1). Different results emerge when estimating the impact on central and peripheral areas separately, with the impact on central areas being not statistically significant (col.2), in contrast with the impact on peripheral treated areas being negative and statistically significant (col.3) and reaching minus 137 EUR p/m2 three years after treatment, corresponding to approximately 5% of the last pre-treatment house price value.[19]

We investigate the drivers of the statistically significant impact in peripheral areas by re-running the multiple SCM on both maximum and minimum house price. Fig.10 shows the output of the multiple SCM applied to the minimum (left panel) and maximum (right panel) house price. Table 6 reports the estimated treatment effect and statistical significance level for these two outcomes at different leads. While we do not detect a statistically significant effect on minimum house prices, in peripheral treated units the maximum house price drops during the whole time-span considered after the new metro line opening, displaying a negative and statistically significant difference with the synthetic control, that reaches minus 174 EUR p/m2 three years after treatment. Hence, according to the evidence just presented, the new metro line opening had a negative impact on average house prices in peripheral treated areas, which was driven by a persistent decline in house prices belonging to the upper end of the price distribution, while it left unaffected average house prices in central treated areas.

We further explore two additional potential sources of heterogeneity related to our main outcome of interest, namely the maximum house price. The first potential source of heterogeneity is related to whether the new metro stations are located above or under ground. The opening of construction sites might have caused local house prices to decline in areas hosting overground metro stations due to the greater disturbance caused to local residents by overground construction sites. We explore this possibility in the second column of Table 7. We detect less negative, albeit not statistically significant, coefficients for the impact of the new metro on maximum house prices compared to the overall scenario shown in col.1 of the same Table. A second potential source of heterogeneity comes from the higher degree of connectedness of certain metro stations: areas located close to better connected metro stations might indeed benefit more from the development of the new infrastructure, thanks to the existence of potential network effects. Re-estimating the SCM only on the subset of better connected treated units delivers not statistically significant estimates, in line with the argument that greater connectivity might temper down the negative channels through which

[19] One potential issue with the multiple SCM is the non-necessary unique solution to the minimisation problem delivering the optimal weighting matrix (Abadie, 2021). We investigate whether this is a valid source of concern in our setup by comparing the multiple SCM coefficients to the coefficients obtained by averaging the individual SCM estimations applied separately to all treated units, since individual SCM estimations are exempt from the multiple equilibria potential issue highlighted in Abadie (2021). The coefficients obtained in either way are very similar, thus reassuring us about the validity of our method.

the construction of the new metro line affected the local real estate market (col.3 of Table 7).

4.2 Robustness

We implement a few robustness checks. First, we tackle the issue of the overlap between our sample period and the Great Recession that hit the housing market of Rome during the second half of 2008 (Fig.4). It is possible that non-treated areas experienced a deeper recession compared to treated ones on the eve of our treatment date, which would bias negatively our results since these areas would have a greater gap to make up for in the recovery phase. In order to account explicitly for this potential confounding factor, we construct a variable measuring the recession depth, equal the percentage point difference at the unit level between house prices in 2009H1 and 2008H1 (respectively the trough and peak of the recession), and include it in our set of predictors (Table 10, col.2). The estimated impact is slightly more negative than in the baseline (col.1), but the difference is negligible. Second, we investigate potential spillover effects by re-running the estimation after the exclusion of areas lying between 1km and 2km from the new metro stations from the donor pool. The idea behind this test is that these units, by being closer to treated areas, might be subject to spillovers. The results are displayed in column 2 of Table 10. The estimated impact is slightly higher than in the baseline (col.1), thus ruling out the hypothesis of potential spillover effects biasing our results. Further, we exclude from the donor pool units less than 1km far from a stop of metro line B1, which opened during our treatment period in 2012 (Table 10, col.4). The results are robust to this robustness check as well.

4.3 Mechanisms

The evidence provided thus far supports the view that the new metro line might have been perceived as a disamenity by richer households in the presence of a segmented housing market (due to e.g., greater noise, diminished safety, see Ahfeldt et al. (2019)).

We investigate further potential mechanisms by exploring demographic changes in treated areas vs. their synthetic control counterpart following the opening of the new infrastructure. In Fig.11 we plot the share of individuals between 25 and 39 years of age (panel a-b), the share of foreign individuals (panel c-d), the population level (panel e-f) for the average treated unit and the average synthetic control.[20] The right column displays for each variable the

[20]For the construction of the synthetic control we use the same optimal weights obtained from the SCM applied to the maximum house price estimation. Since we are interested in understanding the mechanism besides our main direct effect (on prices), we chose to rely on this difference-in-differences type of analysis, as proposed by Barone and Mocetti (2014), rather than running a new SCM on each demographic variable. In fact, the latter would be less meaningful for our purpose as it would require a different optimal vector of

difference in means and the confidence intervals for the difference-in-means t-test, before and after treatment. Peripheral treated areas do not differ in a statistically significant way from their synthetic counterpart before the treatment, while they feature after treatment a significantly higher share of foreign individuals, which might have more difficulties affording a vehicle and for whom the new metro line might have thus represented an amenity.

The statistically significant increase in the foreign population share following the development of the new infrastructure provides a second potential mechanism for the statistically significant drop in the price of properties belonging to the upper end of the price distribution. The inflow of foreign individuals might have been perceived as a disamenity by richer ones, who reacted by relocating their demand elsewhere in the city. The fact that the negative impact quickly dies out as we move away from the new metro stops is compliant with the typically very localised nature of disamenities (Table 11). This mechanism would explain 1) why the negative impact is observed only for houses belonging to the upper end of the price distribution and 2) why we do not observe a significant change with respect to total population, underscoring the compositional nature of the observed demographic changes. We are not the first ones to provide evidence in favor of a negative impact of immigration on house prices: Saiz and Wachter (2011) do so for the United States, Accetturo et al. (2014) for Italy, Sá (2015) for the United Kingdom, Balkan et al. (2018) for Turkey.

An alternative explanation to the lack of a positive impact of the new infrastructure on housing values would be that while the new line represented a transport infrastructure innovation, the actual magnitude of this innovation (in terms of overall average connectivity improvement) is uncertain due to the limited length of the metro system compared to the city extension. In order to effectively test this hypothesis, we would need to have access to commuting data, which are unfortunately unavailable.[21] This mechanism would attenuate the (positive) accessibility channel, thus making a net positive impact of the new infrastructure on housing values less likely to emerge.

4.4 Other outcomes

In this section, we analyse the impact of the new infrastructure on a number of additional outcomes. We start with the business creation ratio, as measured by number of new businesses (p/'000s inhabitants). The new infrastructure may in fact impact business creation through a standard market access channel. According to this, following the development of the new

weights for each run, resulting in different control groups and making the analysis less informative about the mechanism underlying the impact on house prices.

[21] According to Comune di Roma (2019), in 2019 the total number of trips was 19 millions for Metro C, a small fraction of those taking place via Metro A (110 millions), or Metro B (80 millions).

infrastructure, it becomes easier to reach the shopping destinations located nearby this. Then, the market - and therefore potential demand - that can be accessed by individual businesses located nearby the new infrastructure expands, which lures new businesses into the market (Pogonyi et al., 2019). We rerun the multiple SCM applied to the number of new businesses (rescaled by '000s of residents) created in a given OMI zone and year. The output is shown in Table 12 (col.1). While the estimated treatment tends to have a positive sign, we are unable to detect a statistically significant impact of the new infrastructure on the number of new businesses, regardless of the lead considered.[22] Potential time heterogeneity in the estimated impact might have been relevant in this case since it is possible that this outcome reacts to the new infrastructure only at the effective opening date.[23] The effect is however not statistically significant neither in 2010 (lead= 1) nor in 2014 when the new metro line was effectively inaugurated (lead= 9).[24]

One possibility for why we are unable to detect a statistically significant impact of the new infrastructure on the number of new businesses is our geographically coarse treatment definition. For instance, Pogonyi et al. (2019) find that the Jubilee Line Extension in 1999 caused locations located within 750 meters from new metro stations to experience an increase in the number of local units, and locations located between 1250 and 2000 meters to experience a decline in the number of local units, in line with the existence of displacement effects.[25] The reason why we cannot detect a statistically significant impact might thus have to do with the fact that our coefficient averages the (potentially positive) impact for short distances with the (potentially negative) impact for longer ones.

We further assess the impact on the rental rate. Treatment time for this variable must be set differently, in that there is no particular reason to observe an anticipation effect in the rental market. The opening of Metro C metro stations took place in three different tranches, although it should be remarked that 21 out of 22 metro stations all did open between 2014H2 and 2015H2.[26] We do not detect any impact of the new infrastructure on the average rental rate except for the last two treatment periods included in the sample, after the opening of the last and most central metro station (San Giovanni). This evidence points towards the

[22]The results do not differ between central and peripheral treated areas.

[23]If businesses do not own their facilities but rather rent them, we might expect business creation to go up after the opening of the new metro line, rather than at the time when construction works resumed and it became clear that the new metro line was going to be completed.

[24]We estimate the effect also for 2016 and this does not overturn the basic result based on previous years' estimates of a volatile sign and a never statistically significant coefficient.

[25]This result is not fully comparable with ours since the authors consider the number of businesses, while we focus on the number of new businesses due to the lack of precision with which exit is measured in the Infocamere dataset.

[26]The opening of the Pantano-Centocelle portion took place in November 2014; the portion Centocelle-Lodi opened on the 29th of June 2015 while the last metro station, San Giovanni, opened in May 2018.

complementarity of infrastructure investment with connecting pre-existing infrastructure.

It is possible that the infrastructure had a positive impact on some specific well-being dimensions, in spite of these being insufficient to compensate for negative channels and thus overturn the result of a negative impact on housing values. We here inspect two of these potential well-being dimensions. The first one is road safety. If the new metro line succeeded at decongesting streets by inducing a modal shift for residents that were before used to commute via car, then it is reasonable to expect that after the opening of the new metro stations road safety in areas closeby increased relative to road safety in more distant areas. We retrieved from Rome municipality open data website the log of all car accidents occurred in the city since 2006. Unfortunately, for each accident we only know the name of the street where it took place. We exclude the *strade consolari*, a set of streets whose first construction dates back to ancient times, characterised by a radial structure departing from the city centre and stretching out in different directions of the peninsula. Additionally, we drop Via Cristoforo Colombo, the street connecting the city centre of Rome with Ostia, Rome coastal district.[27] We then geolocalise these streets, which entails finding a latitude-longitude pair that can be considered as the street centroid, and assign them to the OMI zone containing the thus-found centroid. We then aggregate the number of accidents at the OMI zone/semester level and finally run a diff-in-diff regression along the lines of the the one used in Table 4 to investigate whether after the opening of the new metro stations road safety increased in areas located closer to these compared to more distant ones. The results, displayed in Table 13, reveal a positive albeit not statistically significant correlation between road safety and the opening of the new metro stations.

Finally, we downloaded monthly data of PM10 emissions from the local environmental agency website (ARPA Lazio). Emissions are measured consistently starting from 2010 for 14 meteorological stations located within the boundaries of Rome municipality according to historical definitions. Monitoring stations are too few and appear to be disproportionately concentrated in the eastern side of the city, where the development of Metro C took place and where industrial activity is concentrated, which makes this dataset unsuited to conduct a proper inference exercise. These data can however still be analysed from a qualitative perspective. In Fig.12 we plotted the ratio between the average level of PM10 emissions after the opening of Metro C and before for each station. This ratio is generally below one, underscoring the generalised decline in emissions observed during the period under consideration.

[27]The excluded streets are: Via Appia, Via Aurelia, Via Cassia, Via Salaria, Via Flaminia, Via Tiburtina, Via Nomentana, Via Prenestina, Via Ardeatina, Via Laurentina, Via Trionfale, Via Cornelia, Via Ostiense, Via Collatina, Via Pontina, Via Cristoforo Colombo.

While there the two stations displaying the most pronounced declines in the level of PM10 emissions are indeed the closest ones to the new infrastructure - the meteorological stations of Preneste and Tiburtina - it is hard to draw a conclusion based on such a small and selected sample.

5 Conclusion

A transport infrastructure improvement can affect residents' welfare through multiple channels, often moving in opposite directions. A transport infrastructure improvement typically increases brings along an increase in accessibility, but it can also be matched by an increase in noise or crime, which, together with the potential unsightliness of the stations, can be perceived negatively by local residents.

The evaluation of the impact on nearby house prices is generally regarded as the touchstone for the net sign and magnitude of these positive/negative externalities. In this paper, we evaluate the impact of the construction of "Metro C" in Rome on the housing market and local economic activity. To overcome the potential threat posed by the non-random placement of transport infrastructure, we rely on a multiple synthetic control method approach, which compares the average treated unit to the average synthetic control. We detect a negative and statistically significant impact on average house prices, but only in peripheral treated areas. The impact 3-year after treatment reaches minus 137 EUR p/m2, roughly 5% of the pre-treatment level. We find the statistically significant negative impact on average house prices in peripheral areas to be driven by the evolution of the price of properties belonging to the upper end of the price distribution, thus lending support to the view that the new metro was perceived as a disamenity by richer households. We further show how the demographic structure changed in treated areas after treatment, with the share of foreign population surging compared to their synthetic control. The inflow of foreign individuals might have been perceived as a disamenity by richer ones, who reacted by relocating their demand elsewhere in the city, thus providing a second alternative explanation for the observed drop in the price of more expensive properties.

So long as an increase in house prices can be regarded as a way to gauge whether a new infrastructure succeeds at creating value for residents, according to our analysis the development of Metro C might have not succeeded at creating value for the average resident. Our analysis underscores the need for improving the entire execution process concerning the development of new infrastructure, from planning to implementation, by making it more timely and data-driven and deploying complementary policies, from land zoning to housing policy to fiscal incentives.

Appendices

A Tables

Table 1: Data sources

Variable	Period, frequency	Source
Population density (p/km2)	2006-2016	Rome municipality
Population ('000s)	2006-2016	Rome municipality
Employed (%)	2011	Population census
Foreigners (%)	2006-2016	Rome municipality
Population 25-39 (%)	2006-2016	Rome municipality
Post-1991 buildings (%)	2011	Buildings' census
Residential buildings (%)	2011	Buildings' census
Vacant apts. (%)	2011	Buildings' census
Minimum house price	2006H1-2016H2	OMI
Maximum house price	2006H1-2016H2	OMI
Average house price	2006H1-2016H2	OMI
New firms (p/'000s inhabitants)	2006-2016	Infocamere

Table 2: List of treated units

Name	Centre/Periphery	
1	ESQUILINO (PIAZZA VITTORIO)	Centre
2	TIBURTINO B (VIA DI CASAL BERTONE)	Centre
3	PRENESTINO LABICANO 1 A (PIAZZA DEL PIGNETO)	Centre
4	PRENESTINO LABICANO 1 B (VIA CONTE DI CARMAGNOLA)	Centre
5	PRENESTINO LABICANO 1 C (VIA LABICO)	Centre
6	PRENESTINO-LABICANO 1 (VIA DEL PIGNETO)	Centre
7	TUSCOLANO 1 (VIA TARANTO)	Centre
8	APPIO LATINO 1 (PIAZZA TUSCOLO)	Centre
9	PRENESTINO-LABICANO 2 (VIA DEI GORDIANI)	Periphery
10	PRENESTINO-CENTOCELLE (PIAZZA DEI MIRTI)	Periphery
11	ALESSANDRINO (VIALE ALESSANDRINO)	Periphery
12	PRENESTINO-LABICANO 2 A (VIA ROMOLO BALZANI)	Periphery
13	DON BOSCO 2 A (VIA DEI ROMANISTI)	Periphery
14	TORRENOVA (VIA DI GIARDINETTI)	Periphery
15	TORRE GAIA A (VIA ERCOLE MARELLI)	Periphery
16	TORRE ANGELA D (VIA ACQUARONI)	Periphery
17	TORRENOVA A (VIA DELLA SORBONA)	Periphery
18	BORGHESIANA (VIA DI FONTANA CANDIDA)	Periphery
19	TORRE MAURA (VIA DELL'AQUILA REALE)	Periphery
20	TORRE GAIA (VIA DI TORRE GAIA)	Periphery
21	TORRE SPACCATA (VIA DEI COLOMBI)	Periphery

Table 3: Descriptive statistics

	All			Treated, CNT			Treated, PER		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Density (p/km2)	6622	61	23906	16952	11678	21073	6223	1812	16875
Population ('000s)	10	0	45	17	7	28	14	4	45
Employed (%)	49	42	69	47	46	49	46	42	49
Foreigners (%)	11	2	35	13	8	21	10	5	12
Population 25-39 (%)	22	15	37	21	19	21	22	17	26
Post-1991 buildings (%)	11	0	56	1	0	3	7	1	23
Residential buildings (%)	74	25	99	75	66	83	81	63	93
Vacant apts. (%)	11	0	42	7	3	17	10	1	23
Minimum house price	3206	1910	8738	3205	2625	4450	2459	2106	2754
Maximum house price	4334	2505	11700	4448	3725	5625	3353	2767	3813
Average house price	3770	2207	10219	3826	3175	5038	2906	2437	3277
New firms (p/'000s inhab.)	5	0	68	4	1	8	2	1	4
N	220			8			13		

Notes: the data are averages at the unit level during the pre-treatment period. Numbers are rounded to the nearest integer.

Table 4: OLS evidence - all treated areas

Panel A:	Average house price			
	(1)	(2)	(3)	(4)
Treated*Post	-93.55	-93.55	-220.64***	-80.89**
	(78.814)	(77.021)	(54.178)	(39.143)
Panel B:	Maximum house price			
Treated*Post	-151.43*	-151.43*	-295.52***	-154.83***
	(90.526)	(88.267)	(62.096)	(45.584)
Panel C:	Minimum house price			
Treated*Post	-35.67	-35.67	-145.75***	-6.94
	(67.920)	(66.510)	(47.306)	(38.452)
N	4840	4840	4840	4840
Time FE		X	X	X
Controls			X	X
Unit FE				X

Notes: the table displays the results of the regression $Y_{it} = \alpha_i + \alpha_t + \beta Treated_i * Post_t + \gamma X_{it} + e_{it}$. Robust standard errors. Statistical significance: * 0.10 ** 0.05 *** 0.01.

Table 5: Impact of Metro C on average house prices

Lead	All	Centre	Periphery
1	-38***	-44**	-35**
2	-58***	-40	-69***
3	-70***	-68+	-72**
4	-71**	-44	-87**
5	-68*	-26	-93*
6	-86*	-4	-137**
N	21	8	13

Notes: estimated impact and p-values for the SCM applied to average house prices. The estimated impact is the difference between solid and dashed lines in Fig.9. Statistical significance: + 0.15 * 0.10 ** 0.05 *** 0.01. See Section 3 for an explanation of how p-values are computed.

Table 6: Impact of Metro C on minimum and maximum house prices in peripheral treated areas

Lead	Max house price	Min house price
1	-52**	-6
2	-82**	-38
3	-86*	-19
4	-112**	-20
5	-118*	-18
6	-174**	-34
N	13	13

Notes: estimated impact and p-values for the SCM applied to maximum and minimum house prices in peripheral areas. The estimated impact is the difference between solid and dashed lines in Fig.10. Statistical significance: + 0.15 * 0.10 ** 0.05 *** 0.01. See Section 3 for an explanation of how p-values are computed.

Table 7: Impact of Metro C on maximum house prices: other sources of heterogeneity

Lead	Overall	Overground stations	Better connected areas
1	-52***	-30	-86*
2	-80***	-58	-128+
3	-97**	-89	-110
4	-114**	-107	-135
5	-113**	-90	-143
6	-129**	-116	-75
N	21	6	3

Notes: better connected areas are areas located within 1km of Metro C new stations and within 1km of pre-existing Metro A/B stations. These are: Esquilino (located close to Metro C San Giovanni metro station and Metro A Vittorio Emanuele metro station), Tuscolano 1 (located close to Metro C Lodi metro station and Metro A Re di Roma metro station), Appio Latino 1 (located close to Metro C San Giovanni metro station and Metro A Re di Roma metro station). Statistical significance: + 0.15 * 0.10 ** 0.05 *** 0.01.

Table 8: Constrained variables test for central treated areas

	Treated		Synthetic control		Difference	
	Mean	Std	Mean	Std	Difference	p-value
Density (2011)	17037	3894	12256	2422	-4781	0.01
Population (average)	16793	7536	14285	3173	-2508	0.40
Employed (2011)	47	1	47	1	0	0.62
Foreigners (start)	12	4	11	4	-0	0.96
Foreigners (peak)	13	4	13	4	-0	0.99
Foreigners (end)	15	4	15	4	0	0.83
Population 25-39 (average)	20	1	21	1	0	0.33
Post-1991 buildings (2011)	1	1	3	2	2	0.05
Residential buildings (2011)	75	6	70	6	-6	0.08
Vacant apts. (2011)	7	5	10	4	3	0.22
Min price (start)	2943	550	2957	546	14	0.96
Min price (peak)	3362	614	3406	594	44	0.89
Min price (end)	3206	589	3274	605	67	0.82
Max price (start)	4056	642	4056	640	-1	1.00
Max price (peak)	4750	637	4749	637	-1	1.00
Max price (end)	4488	671	4565	696	78	0.82
New firms (start)	4	3	4	3	0	0.95
New firms (peak)	4	3	4	3	0	0.88
New firms (end)	4	3	4	3	0	0.74
N	8	.	8	.	.	.

Notes: constrained variables balance test between treated units and their synthetic counterfactual. The synthetic control weights are obtained by running the SCM on maximum house prices for each individual treated unit separately.

Table 9: Constrained variables test for peripheral treated areas

	Treated		Synthetic control		Difference	
	Mean	Std	Mean	Std	Difference	p-value
Density (2011)	6184	4514	4978	3431	-1206	0.45
Population (average)	13781	11804	11257	6739	-2523	0.51
Employed (2011)	46	2	48	1	2	0.00
Foreigners (start)	8	2	8	2	0	0.84
Foreigners (peak)	11	2	11	2	0	0.98
Foreigners (end)	14	4	13	3	-1	0.26
Population 25-39 (average)	22	2	23	2	0	0.61
Post-1991 buildings (2011)	7	6	11	5	5	0.05
Residential buildings (2011)	81	9	75	5	-6	0.04
Vacant apts. (2011)	10	6	9	4	-0	0.94
Min price (start)	2267	243	2268	210	1	0.99
Min price (peak)	2615	241	2622	242	7	0.94
Min price (end)	2365	251	2391	244	25	0.80
Max price (start)	3037	301	3038	301	2	0.99
Max price (peak)	3577	396	3577	394	1	1.00
Max price (end)	3258	304	3341	337	83	0.52
New firms (start)	2	1	2	1	0	0.99
New firms (peak)	2	1	3	1	0	0.42
New firms (end)	2	1	3	1	0	0.58
N	13	.	13	.	.	

Notes: constrained variables balance test between treated units and their synthetic counterfactual. The synthetic control weights are obtained by running the SCM on maximum house prices for each individual treated unit separately.

Table 10: Impact of Metro C on the maximum house price in peripheral treated units: robustness checks

Lead	Baseline	w/recession depth	Spillover	w/o metro B1
1	-52**	-69***	-62***	-51**
2	-82**	-87**	-100***	-82**
3	-86*	-101**	-121**	-93*
4	-112**	-119**	-148***	-120**
5	-118*	-118*	-149**	-123*
6	-174**	-178**	-199***	-179**
N	13	13	13	13

Notes: including recession depth among the constrained variables (col.2); excluding from the donor pool areas between 1km and 2km far from new metro stations (col.3); excluding from the donor pool areas less than 1km far from line B1 metro stations (col.4). Statistical significance: + 0.15 * 0.10 ** 0.05 *** 0.01.

Table 11: Impact on maximum house prices for peripheral treated areas: alternative treatment definition

Lead	$d < 1km$	$d < 2km$	$d < 3km$
1	-52**	-39**	-12
2	-82**	-61**	-13
3	-86*	-87**	-28
4	-112**	-96**	-18
5	-118*	-77*	-1
6	-174**	-138***	-47

Notes: treated areas are those areas located within 1 (col.1), 2 (col.2), 3 km (col.3) from the new metro stops. Statistical significance: + 0.15 * 0.10 ** 0.05 *** 0.01.

Table 12: Impact of Metro C on other outcomes on all treated areas

Lead	Business creation rate	Rental rate
1	-.20	-.12
3	-.33	-.13
5	.02	.12
7	.36	.25*
9	.04	-.05
11	-.11	.43**
N	21	21

Notes: for the business creation ratio the treatment time is 2010H1; for the rental rate is 2014H2. Statistical significance: + 0.15 * 0.10 ** 0.05 *** 0.01.

Table 13: Impact of Metro C on road safety

	(1)	(2)	(3)	(4)
Post*Treated	-4.0	-3.6	3.7	-17.4
	(17.3)	(17.3)	(13.7)	(11.3)
N	4300	4300	4300	4300
Time FE		X	X	X
Controls			X	X
Unit FE				X

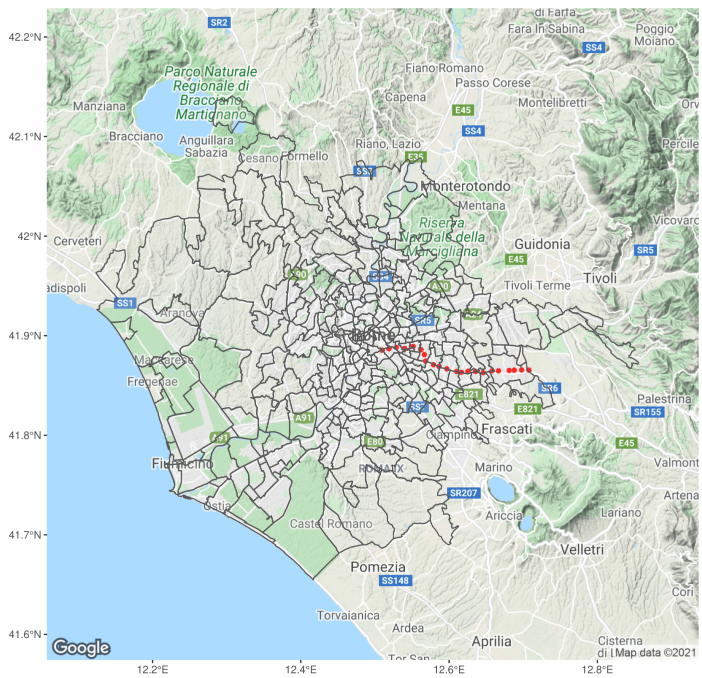
Notes: the table displays the results of the regression number of accidents$_{it} = \alpha_i + \alpha_t + \beta Treated_i * Post_t + \gamma X_{it} + e_{it}$. Robust standard errors. Statistical significance: * 0.10 ** 0.05 *** 0.01. $Post_t$ is set equal to 2014H2 for the stations between Pantano and Parco di Centocelle (excluded), 2015H2 for those between Parco di Centocelle and Lodi (excluded) and 2018H1 for Lodi and San Giovanni.

B Figures

Figure 1: Average house prices evolution in neighborhoods within 1000 meters from the new metro stops and other neighborhoods

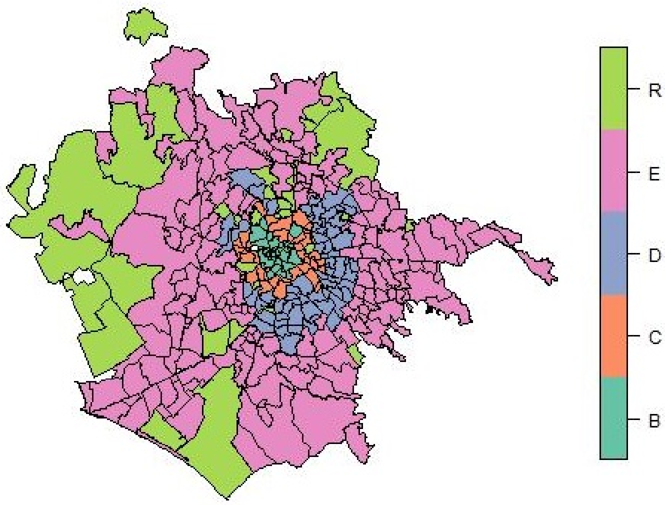
Notes: the house prices series have been rescaled by the starting period value.

Figure 2: Metro C and the municipality of Rome



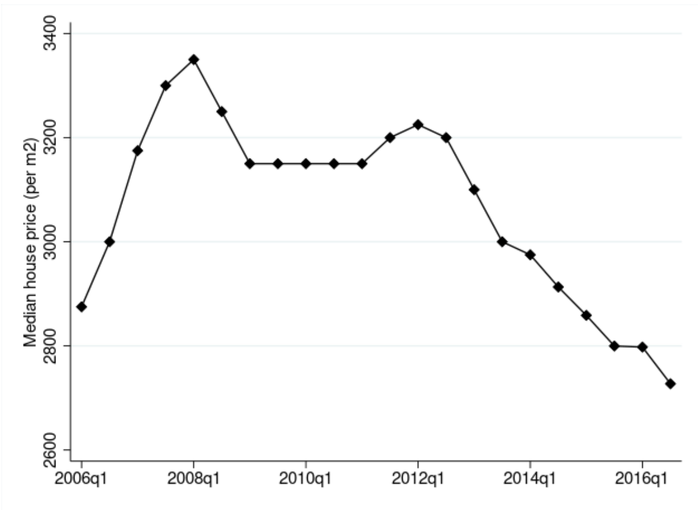
Notes: the black polygons identify the 2011 Osservatorio del Mercato Immobiliare (OMI) zones for the municipality of Rome; the red dots correspond to the new metro stops.

Figure 3: OMI taxonomy of peripheralness degree



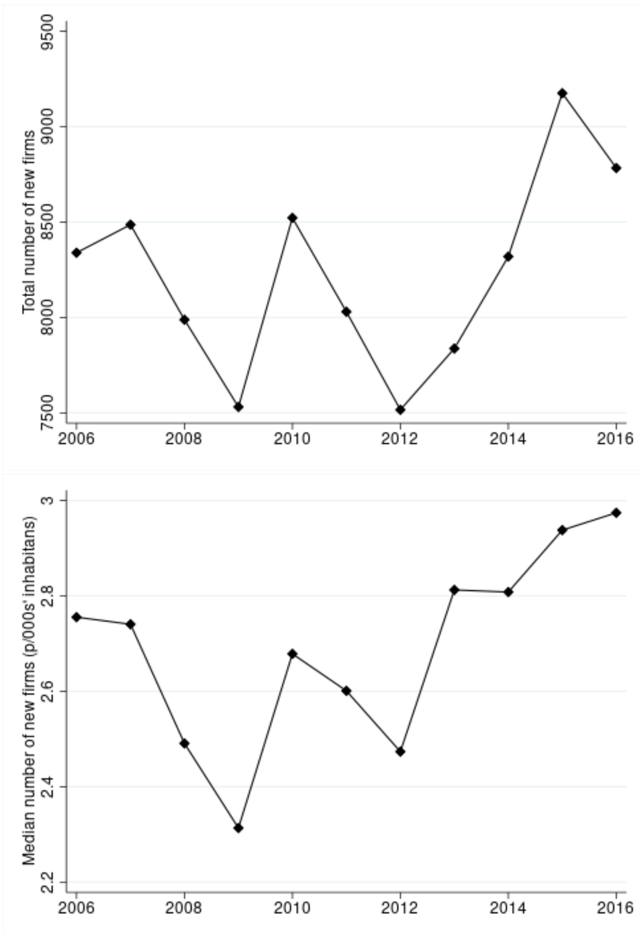
Notes: B = city centre; C = near to the city centre; D = peripheral; E = suburban; R = rural.

Figure 4: Evolution of the housing market in the municipality of Rome



Notes: the black dots correspond to the median value of the distribution across OMI zones.

Figure 5: Evolution of business creation in the municipality of Rome



Notes: the black dots correspond to the median value of the distribution across OMI zones.

Figure 6: Spatial distribution of variables employed for the analysis 1/2

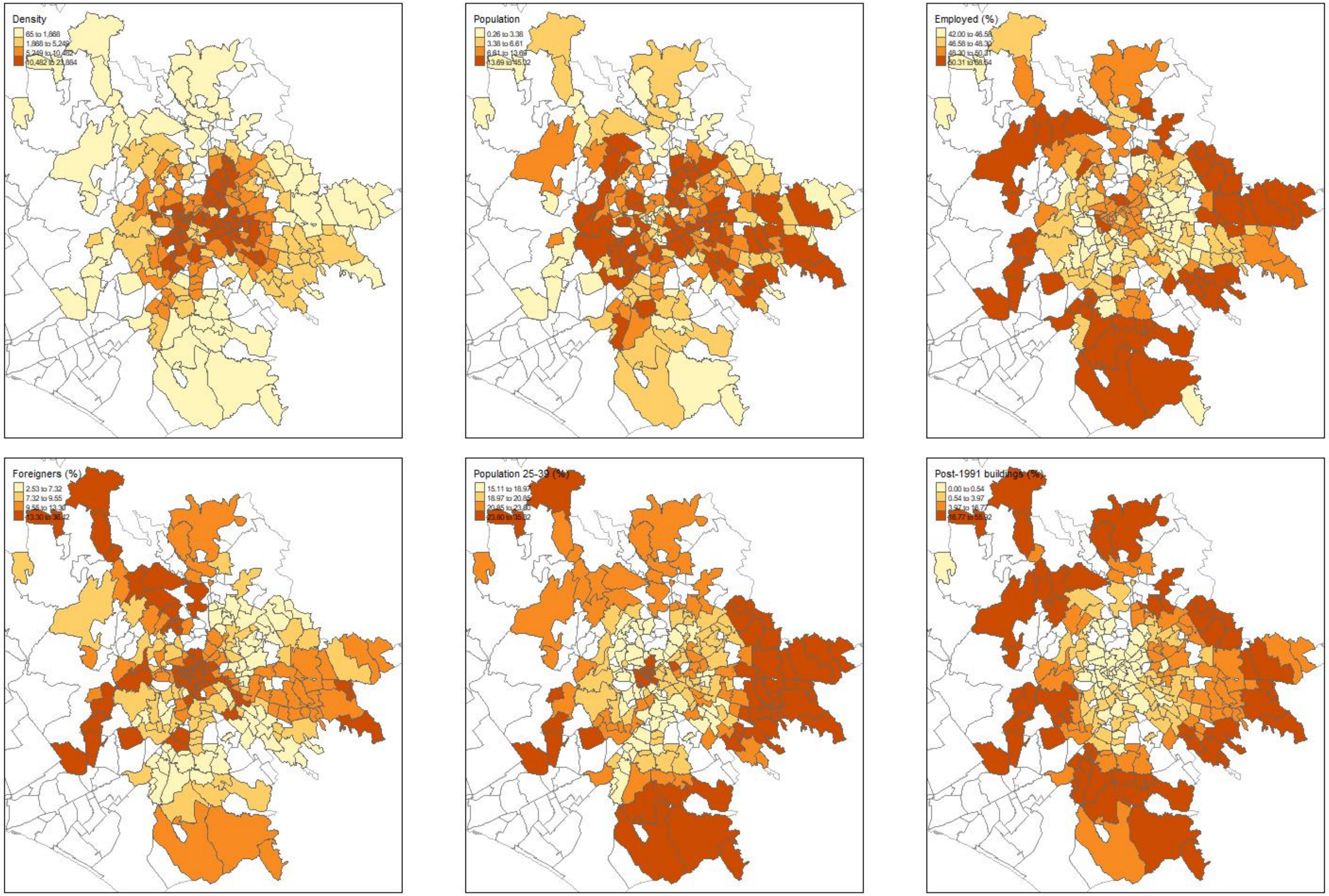


Figure 7: Spatial distribution of variables employed for the analysis 2/2

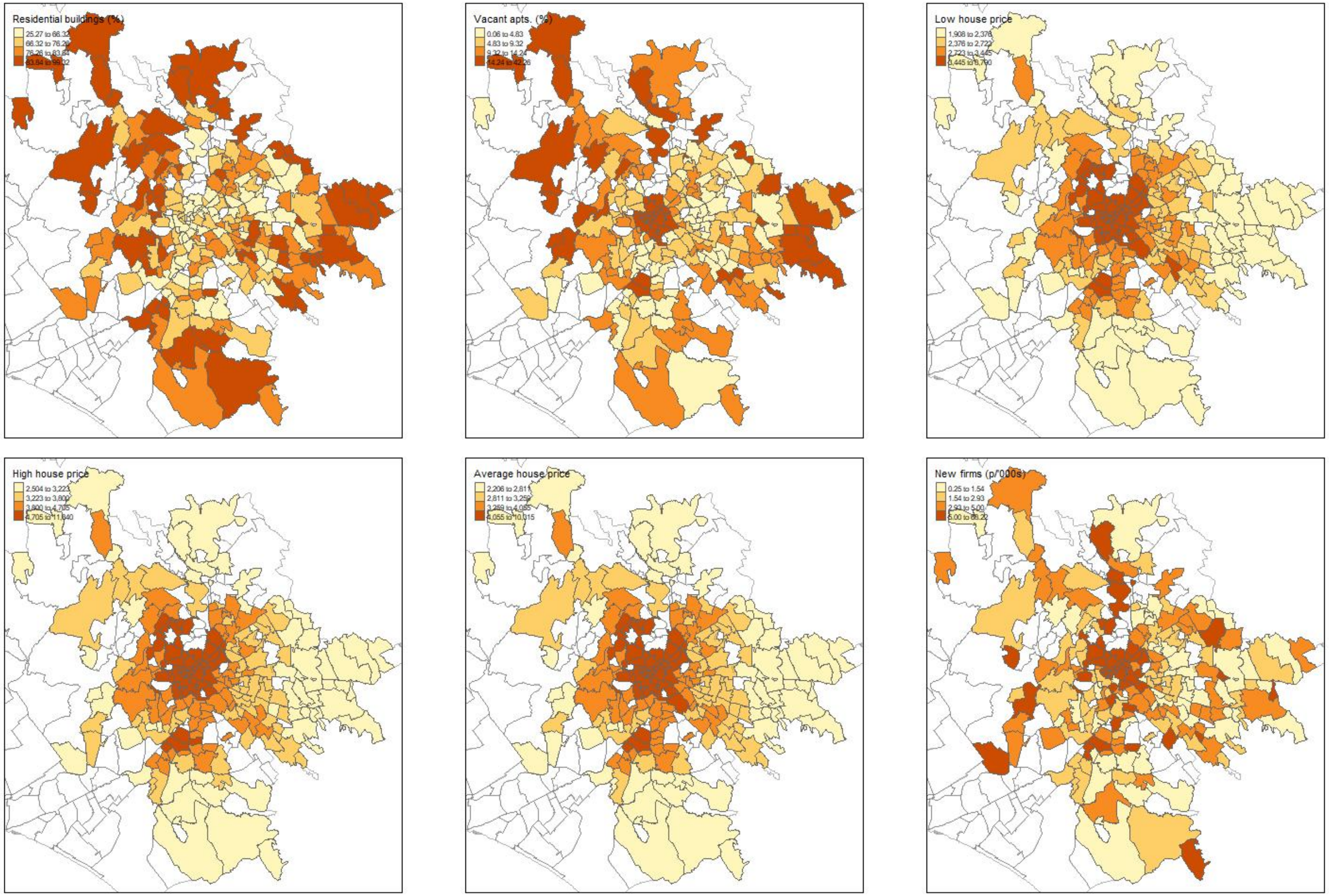
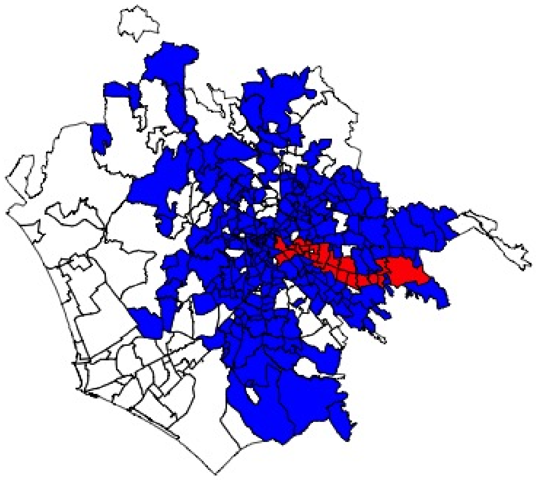
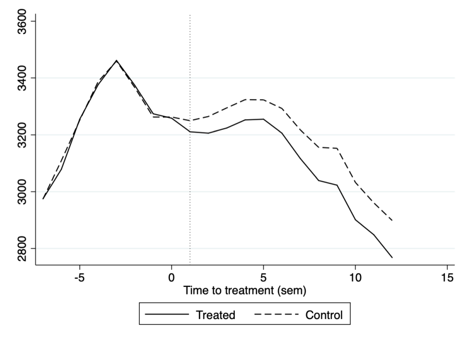


Figure 8: Treated units and donor pool

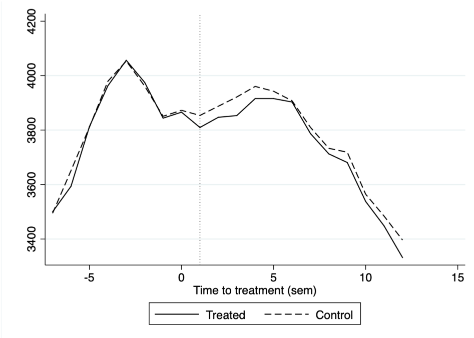


Notes: red (blue) zones belong to the treatment group (donor pool). An area is treated if the centroid is less than 1000 meters distant from the new metro stations.

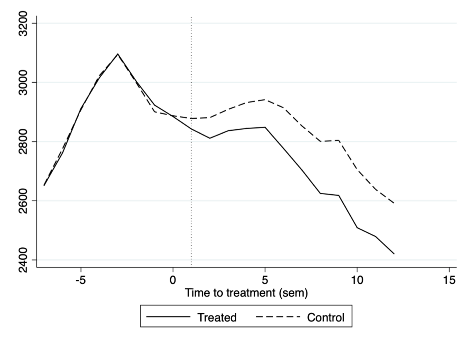
Figure 9: Impact of Metro C on average house prices



(a) All treated areas



(b) Treated areas in the city centre

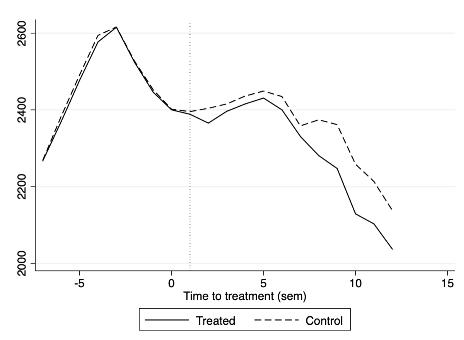


x

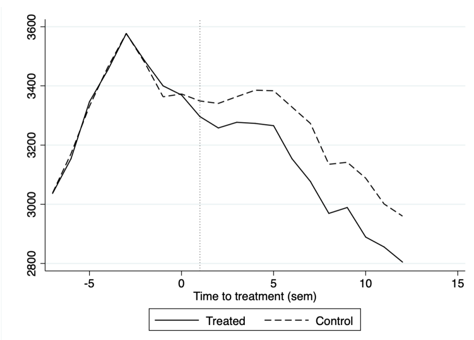
(c) Treated areas in the periphery

Notes: the solid line identifies the average treated area, the dashed line the average synthetic control.

Figure 10: Impact of Metro C in peripheral treated areas



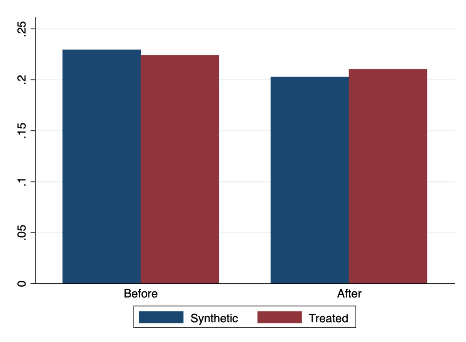
(a) Min house price



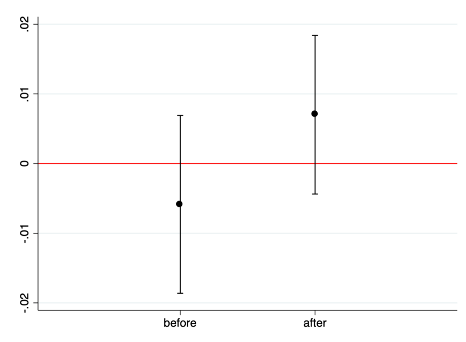
(b) Max house price

Notes: the solid line identifies the average treated area, the dashed line the average synthetic control.

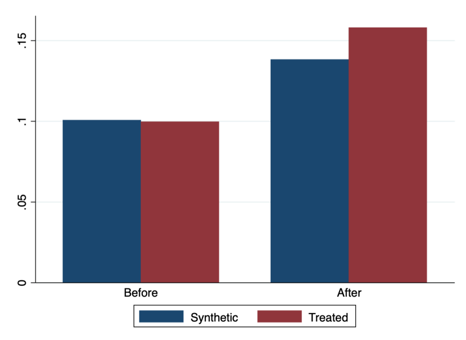
Figure 11: Demographic trends before and after treatment in peripheral treated vs. synthetic control group areas



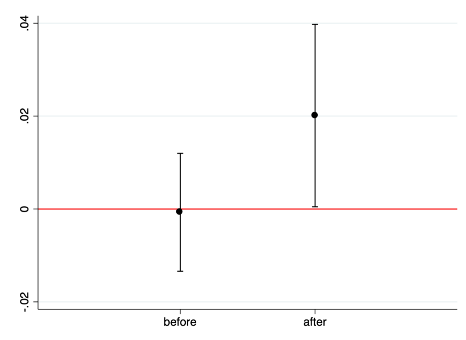
(a) 25-39 yrs old share



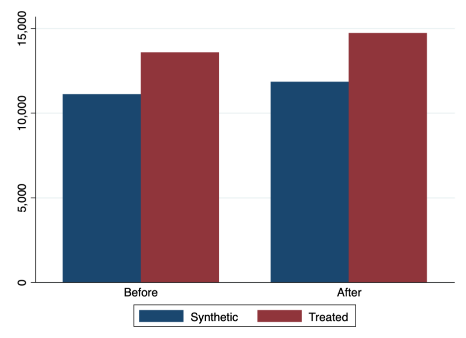
(b) 25-39 yrs old share: t-test



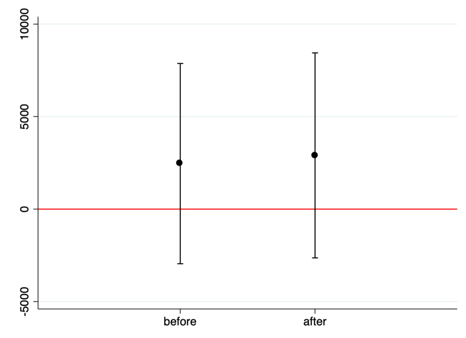
(c) Foreigners share



(d) Foreigners share: t-test



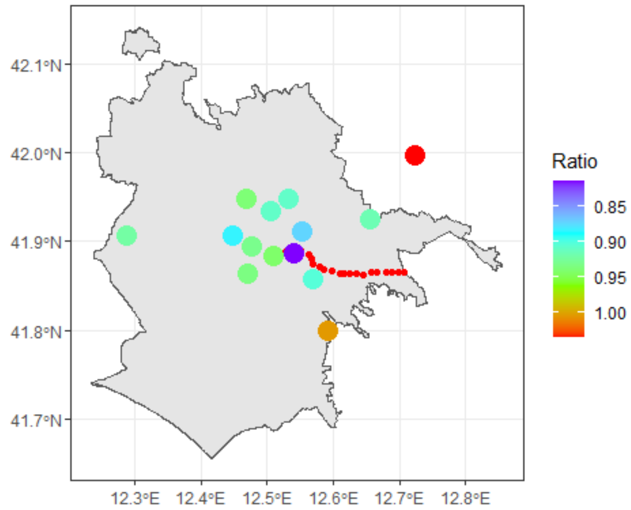
(e) Population



(f) Population: t-test

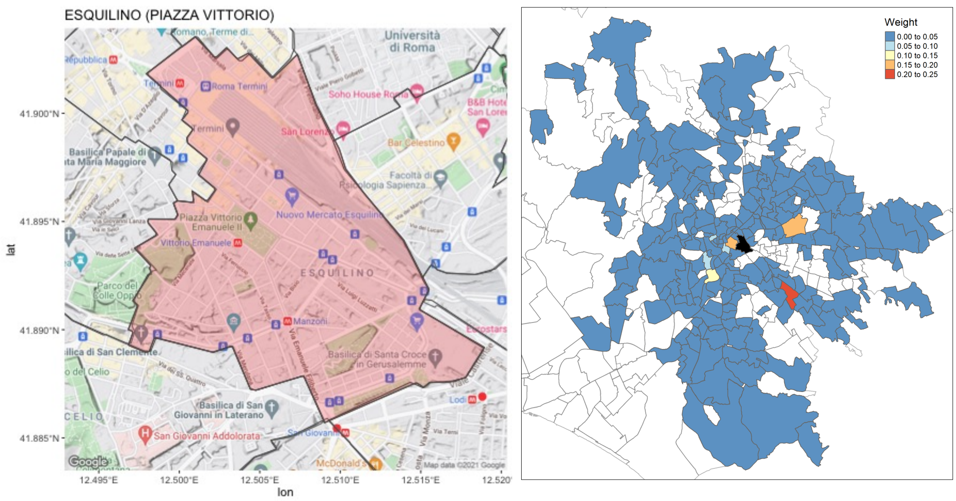
Notes: pre/post-treatment average for treated areas and synthetic counterfactual. The synthetic control weights are obtained by running the SCM on maximum house prices for each individual treated unit separately.

Figure 12: Ratio between average emissions after and average emissions before the opening of Metro C



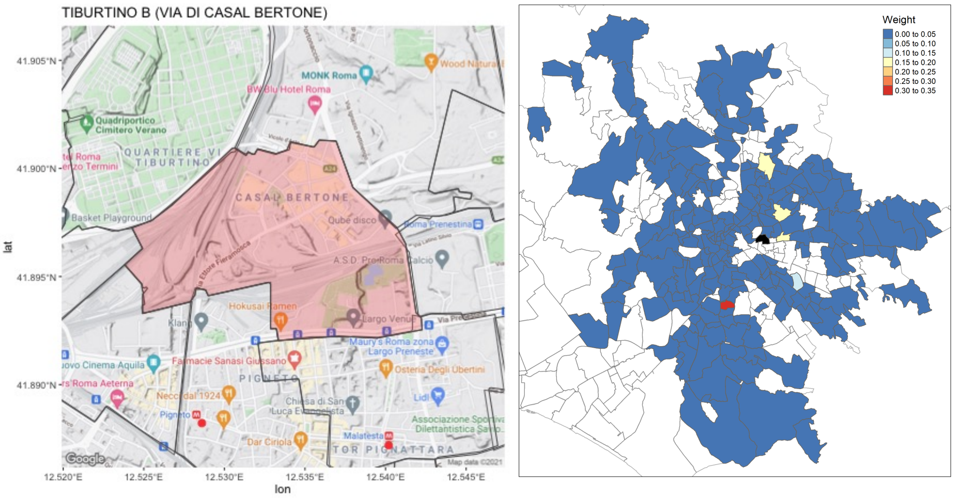
Notes: PM10 emissions are measured; the figure plots the ratio between average emissions at the meteorological station-level after treatment (t >2014H2) and average emissions before treatment. Source: *ARPA Lazio*.

Figure 13: ESQUILINO (PIAZZA VITTORIO)



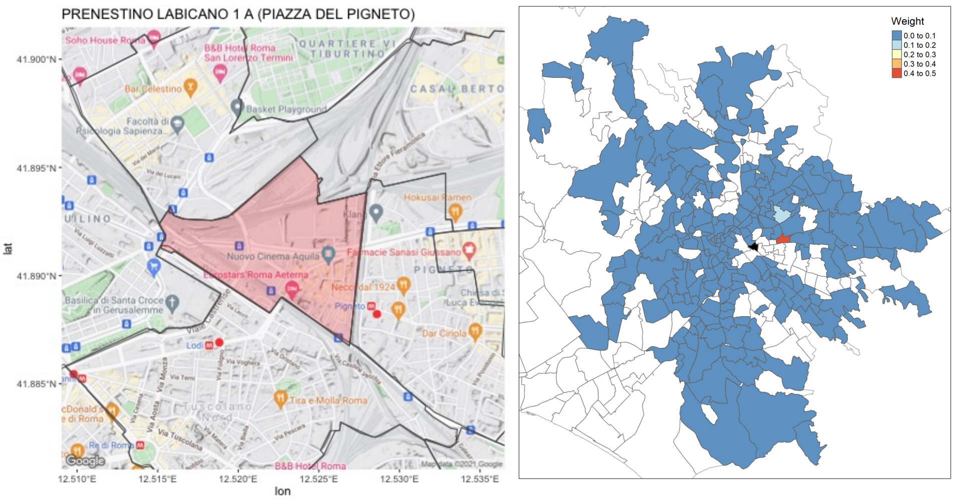
Notes: the treated area (left), spatial distribution of the synthetic control weights (right). The synthetic control weights are obtained by running the SCM on maximum house prices for each individual treated unit separately.

Figure 14: TIBURTINO B (VIA DI CASAL BERTONE)



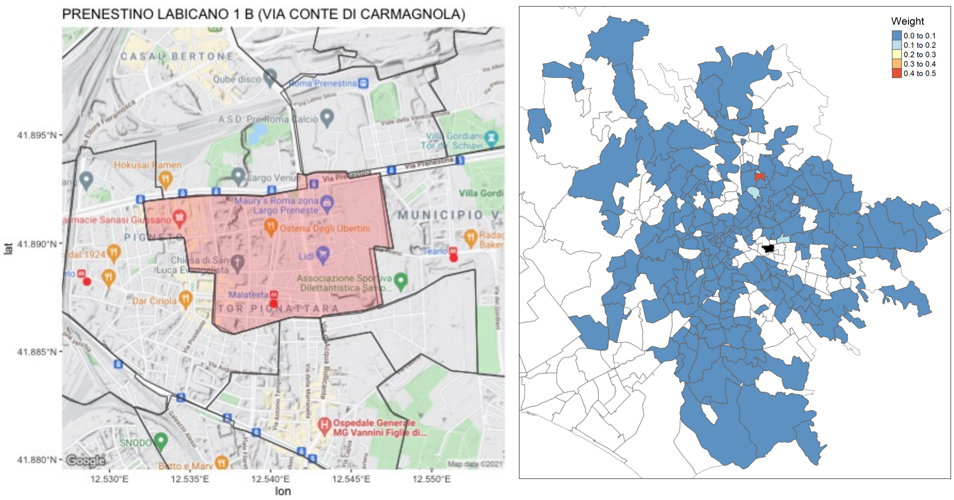
Notes: the treated area (left), spatial distribution of the synthetic control weights (right). The synthetic control weights are obtained by running the SCM on maximum house prices for each individual treated unit separately.

Figure 15: PRENESTINO LABICANO 1 A (PIAZZA DEL PIGNETO)



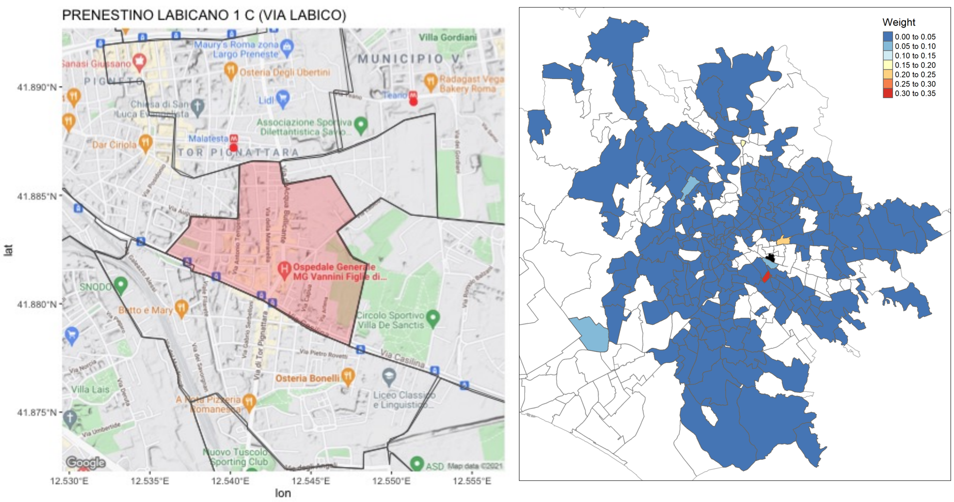
Notes: the treated area (left), spatial distribution of the synthetic control weights (right). The synthetic control weights are obtained by running the SCM on maximum house prices for each individual treated unit separately.

Figure 16: PRENESTINO LABICANO 1 B (VIA CONTE DI CARMAGNOLA)



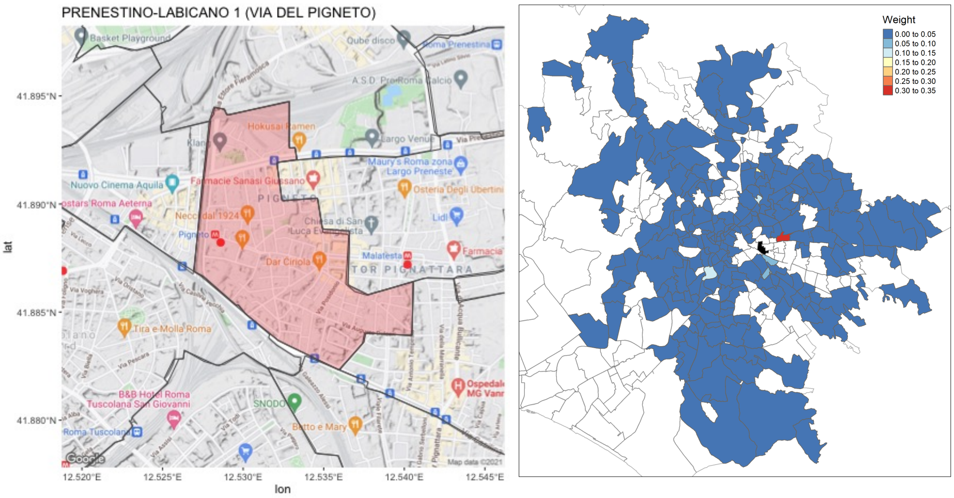
Notes: the treated area (left), spatial distribution of the synthetic control weights (right). The synthetic control weights are obtained by running the SCM on maximum house prices for each individual treated unit separately.

Figure 17: PRENESTINO LABICANO 1 C (VIA LABICO)



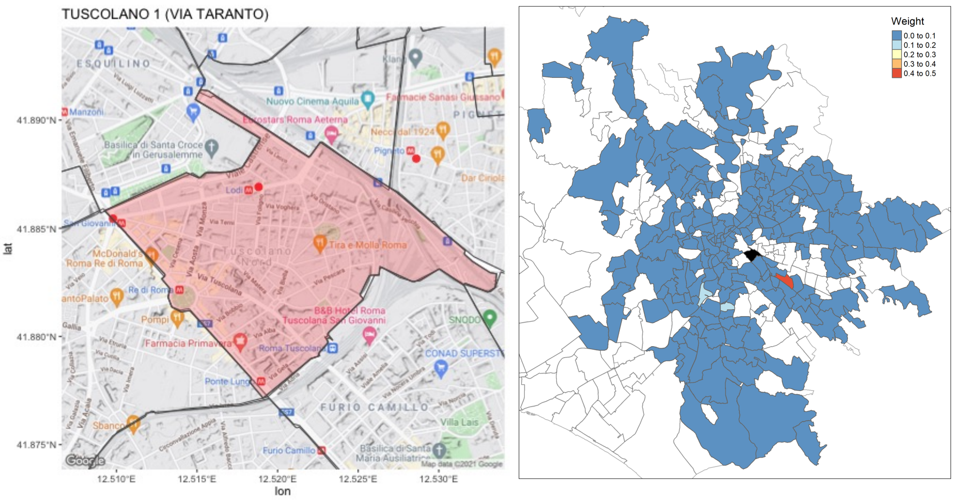
Notes: the treated area (left), spatial distribution of the synthetic control weights (right). The synthetic control weights are obtained by running the SCM on maximum house prices for each individual treated unit separately.

Figure 18: PRENESTINO-LABICANO 1 (VIA DEL PIGNETO)



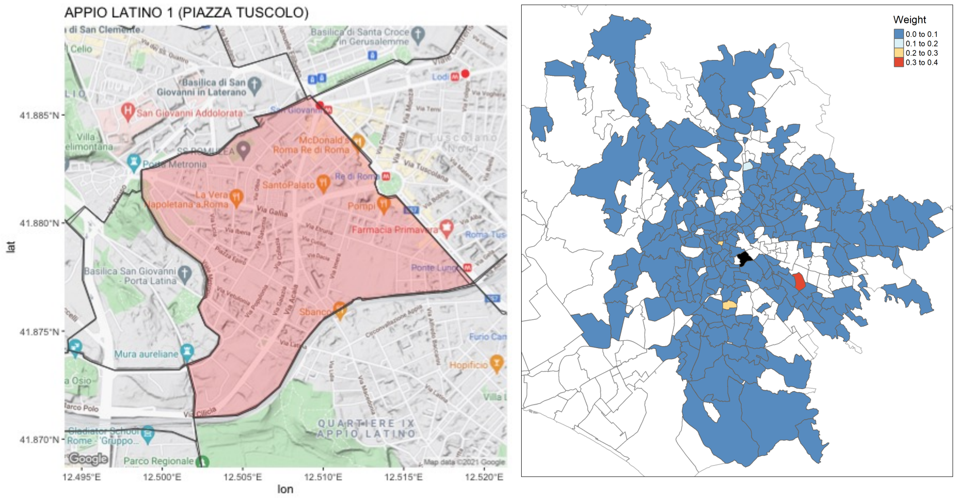
Notes: the treated area (left), spatial distribution of the synthetic control weights (right). The synthetic control weights are obtained by running the SCM on maximum house prices for each individual treated unit separately.

Figure 19: TUSCOLANO 1 (VIA TARANTO)



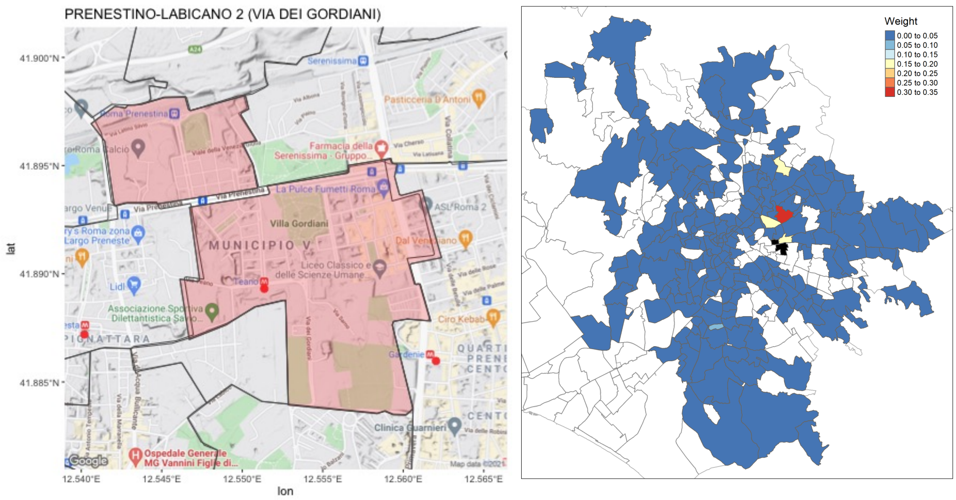
Notes: the treated area (left), spatial distribution of the synthetic control weights (right). The synthetic control weights are obtained by running the SCM on maximum house prices for each individual treated unit separately.

Figure 20: APPIO LATINO 1 (PIAZZA TUSCOLO)



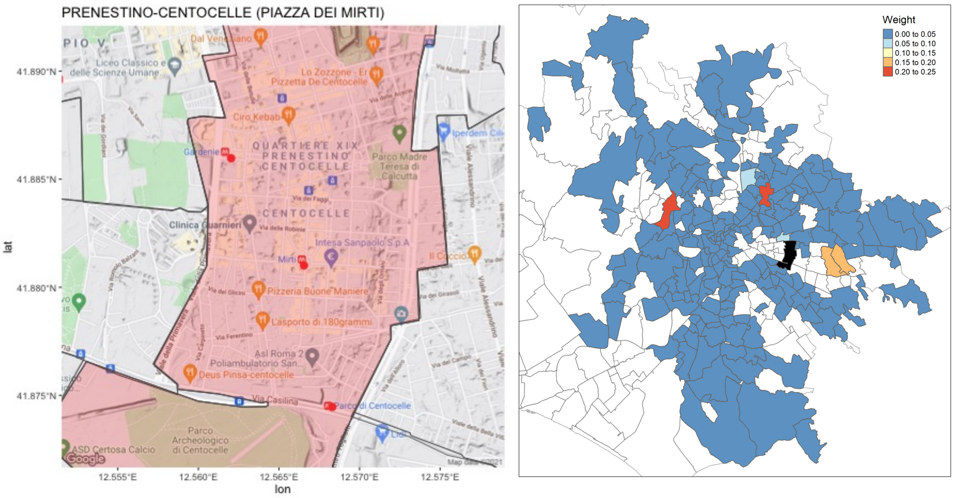
Notes: the treated area (left), spatial distribution of the synthetic control weights (right). The synthetic control weights are obtained by running the SCM on maximum house prices for each individual treated unit separately.

Figure 21: PRENESTINO-LABICANO 2 (VIA DEI GORDIANI)



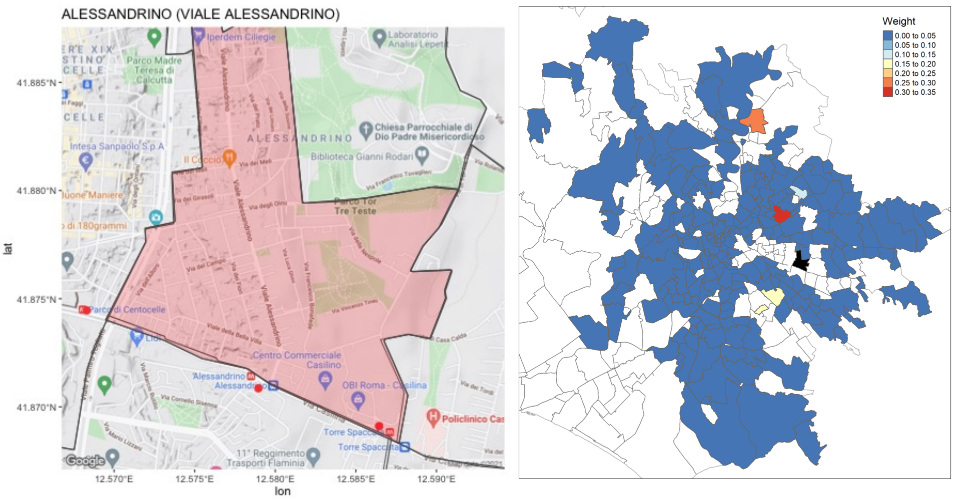
Notes: the treated area (left), spatial distribution of the synthetic control weights (right). The synthetic control weights are obtained by running the SCM on maximum house prices for each individual treated unit separately.

Figure 22: PRENESTINO-CENTOCELLE (PIAZZA DEI MIRTI)



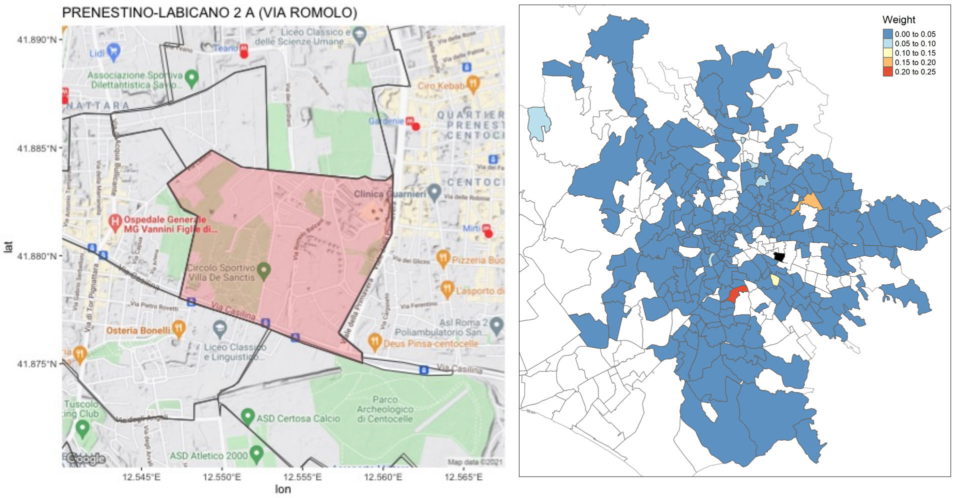
Notes: the treated area (left), spatial distribution of the synthetic control weights (right). The synthetic control weights are obtained by running the SCM on maximum house prices for each individual treated unit separately.

Figure 23: ALESSANDRINO (VIALE ALESSANDRINO)



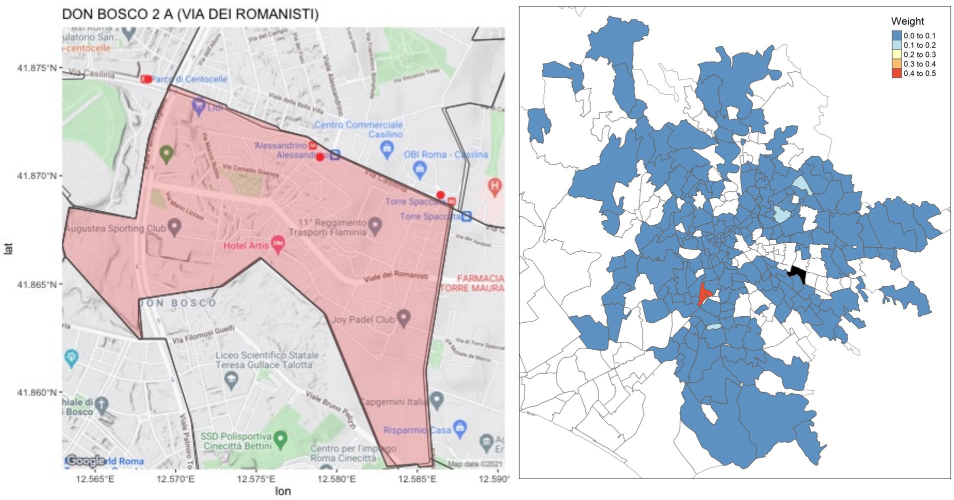
Notes: the treated area (left), spatial distribution of the synthetic control weights (right). The synthetic control weights are obtained by running the SCM on maximum house prices for each individual treated unit separately.

Figure 24: PRENESTINO-LABICANO 2 A (VIA ROMOLO BALZANI)



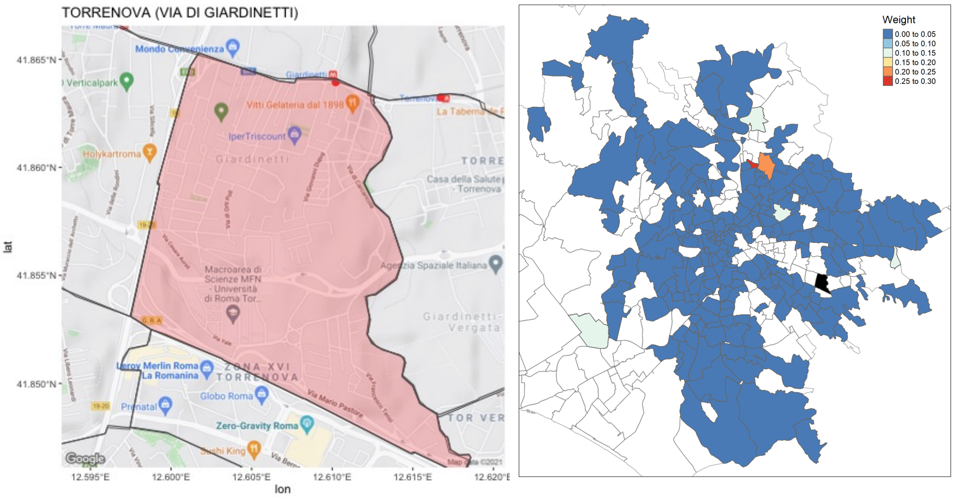
Notes: the treated area (left), spatial distribution of the synthetic control weights (right). The synthetic control weights are obtained by running the SCM on maximum house prices for each individual treated unit separately.

Figure 25: DON BOSCO 2 A (VIA DEI ROMANISTI)



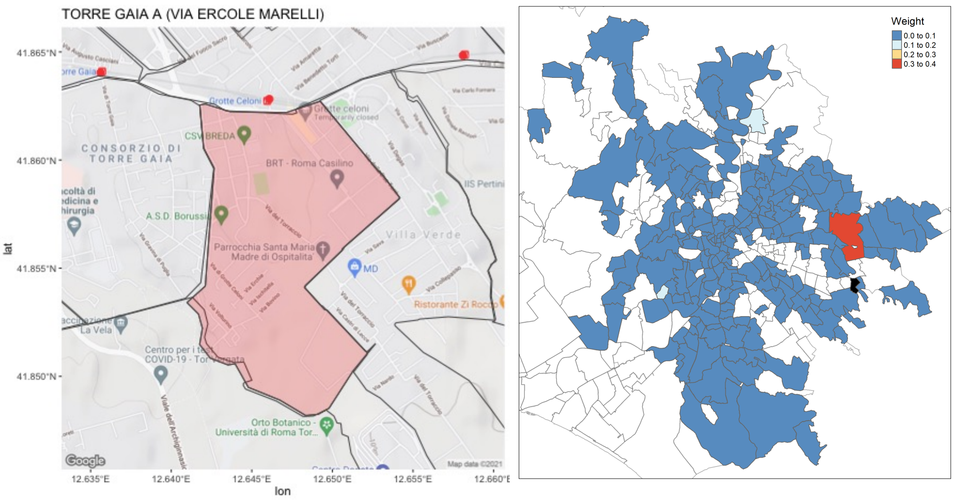
Notes: the treated area (left), spatial distribution of the synthetic control weights (right). The synthetic control weights are obtained by running the SCM on maximum house prices for each individual treated unit separately.

Figure 26: TORRENOVA (VIA DI GIARDINETTI)



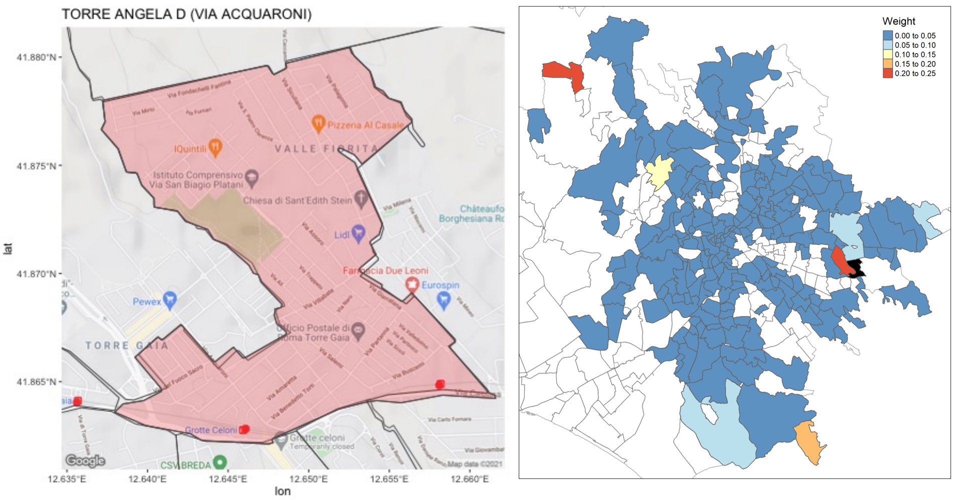
Notes: the treated area (left), spatial distribution of the synthetic control weights (right). The synthetic control weights are obtained by running the SCM on maximum house prices for each individual treated unit separately.

Figure 27: TORRE GAIA A (VIA ERCOLE MARELLI)



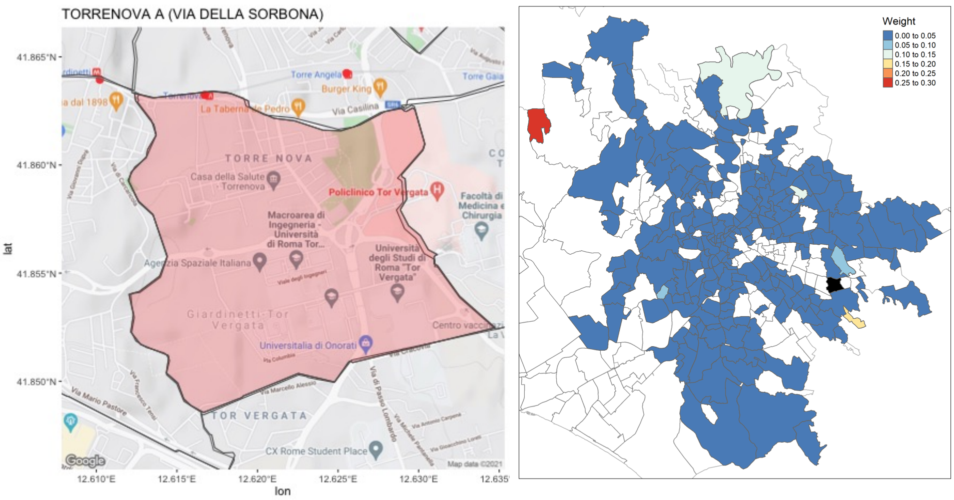
Notes: the treated area (left), spatial distribution of the synthetic control weights (right). The synthetic control weights are obtained by running the SCM on maximum house prices for each individual treated unit separately.

Figure 28: TORRE ANGELA D (VIA ACQUARONI)



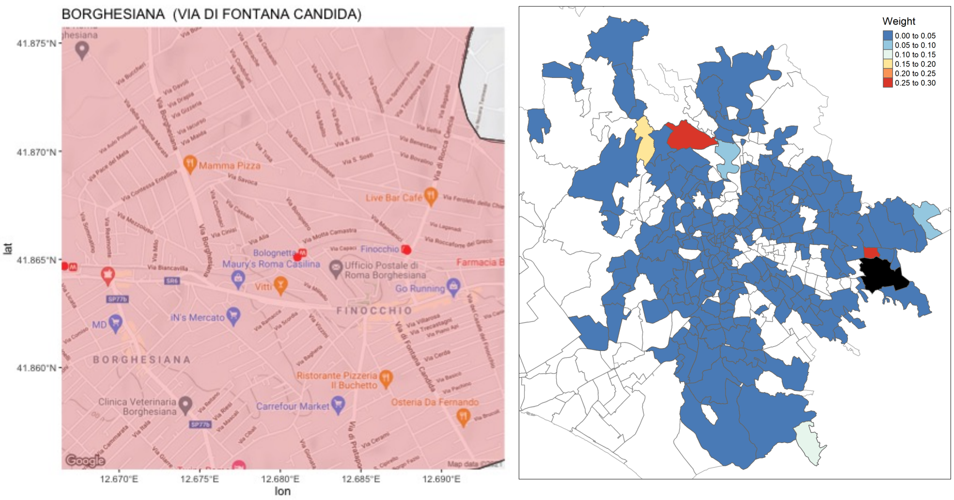
Notes: the treated area (left), spatial distribution of the synthetic control weights (right). The synthetic control weights are obtained by running the SCM on maximum house prices for each individual treated unit separately.

Figure 29: TORRENOVA A (VIA DELLA SORBONA)



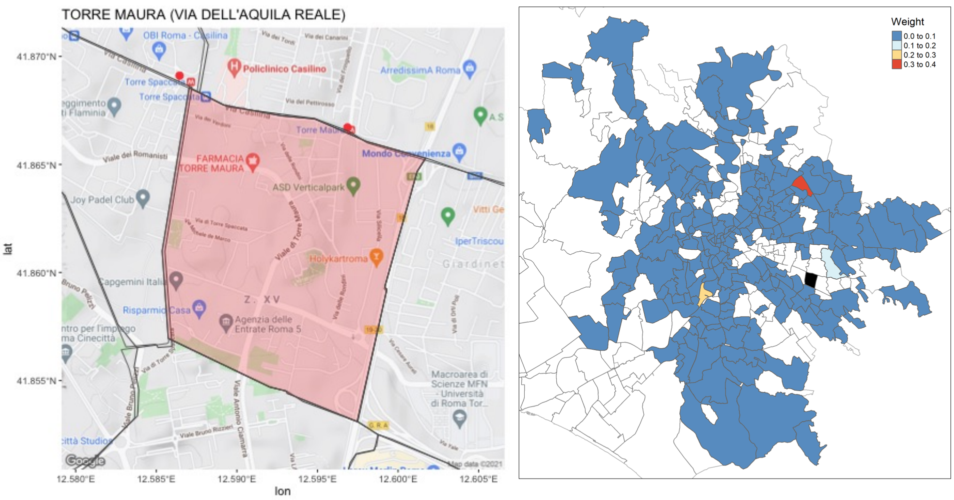
Notes: the treated area (left), spatial distribution of the synthetic control weights (right). The synthetic control weights are obtained by running the SCM on maximum house prices for each individual treated unit separately.

Figure 30: BORGHESIANA (VIA DI FONTANA CANDIDA)



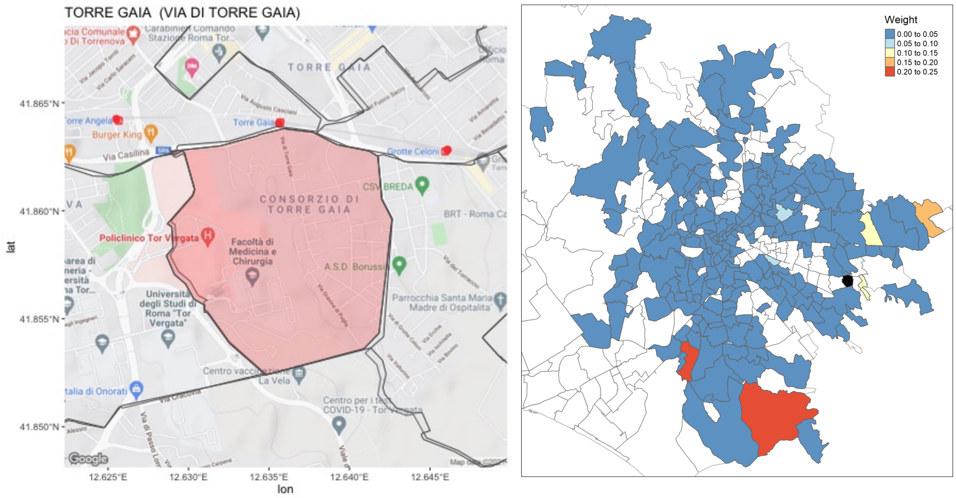
Notes: the treated area (left), spatial distribution of the synthetic control weights (right). The synthetic control weights are obtained by running the SCM on maximum house prices for each individual.

Figure 31: TORRE MAURA (VIA DELL'AQUILA REALE)



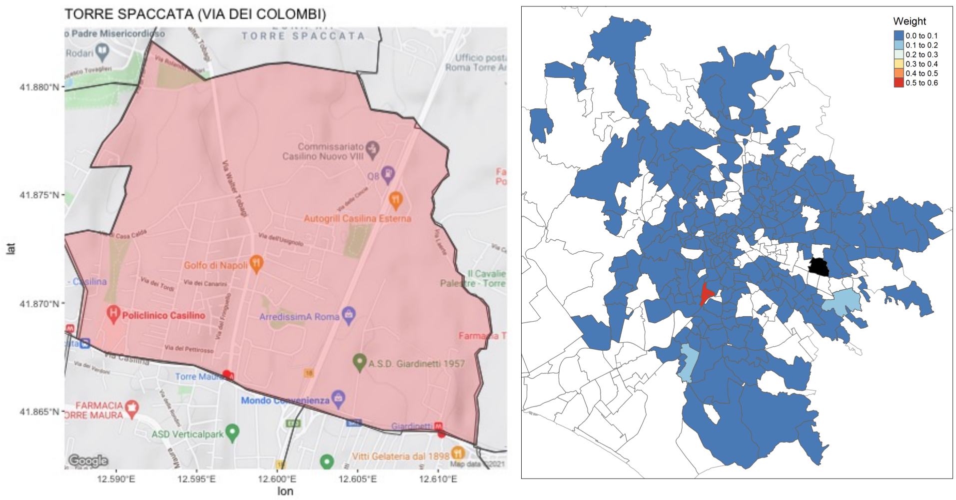
Notes: the treated area (left), spatial distribution of the synthetic control weights (right). The synthetic control weights are obtained by running the SCM on maximum house prices for each individual treated unit separately.

Figure 32: TORRE GAIA (VIA DI TORRE GAIA)



Notes: the treated area (left), spatial distribution of the synthetic control weights (right). The synthetic control weights are obtained by running the SCM on maximum house prices for each individual treated unit separately.

Figure 33: TORRE SPACCATA (VIA DEI COLOMBI)



Notes: the treated area (left), spatial distribution of the synthetic control weights (right). The synthetic control weights are obtained by running the SCM on maximum house prices for each individual treated unit separately.

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