Direct and spillover effects of a new tramway line on the commercial vitality of peripheral streets. A synthetic-control approach

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The Synthetic Control Method

- SCM (Abadie et al., 2010 and 2015; Doudchenko and Imbens, 2017) is increasingly popular with social scientists interested in drawing causal claims with comparative case studies
- In the area of regional/urban economics, the SCM appears promising to assess the area-level effect of unique interventions, e.g. infrastructure creation, urban regeneration, etc.
- However, the SCM has been described and formalized under the non-interference assumption, which means that any spillover is assumed away. Assuming away spillovers may be unrealistic in some urban/regional policy settings
- One solution is to choose an aggregate enough unit of analysis that guarantees that the assumption is plausible (as spillovers end up being relegated within this wider unit of analysis). Unfortunately, this may make the analysis very rough
- A preferable solution is to keep the appropriate unit of analysis and extend the methodological framework in order to accommodate both direct and spillover effects

Our contribution(s)

- We extend the SCM framework for comparative case studies in order to allow for interference
- We define direct and spillover effects with comparative case studies and propose a novel SCM-based estimation approach
- We apply our approach to the analysis of an original problem of urban policy on which there is no previous causal literature

Motivating application (I)

- The creation of urban rail transport may have implications on the economic landscape of the streets that are served and generate spillovers on neighboring streets, also in terms of firm locations (Mejia-Dorantes et al., 2012)
- We focus on the direct and the spillover effects on commercial environment of the first tramway line built in Florence, Italy
- Previous literature has mostly looked at the changes in rent/property values associated with urban rail infrastructure, often outside of a proper causal framework (e.g. Cervero and Landis, 1993; Baum-Snow and Kahn, 2000; Pagliara and Papa, 2011; Budiakivska and Casolaro, 2018)
- For example, the construction site on street A might harm street A (direct effect), whereas neighboring streets might incorporate positive/negative spillovers. When the tramway is in operation, street A might become more attractive for shopping (direct effect), whereas neighboring streets might again incorporate positive (+ attractiveness) /negative (crowding out) spillovers

Motivating application (II)

After dismissing its historical tramway network in 1958, the city of Florence started the construction of a brand new tramway network (reserved lanes) in the mid 2000s

Construction of the first line, on which we focus, begun in early 2006, operation begun in 2010. From Florence railway station, this line crosses the river and goes along Talenti St. in the neighborhood of Legnaia, ultimately reaching the suburb of Scandicci

Construction of two further lines started from 2014 (in operation from 2018)

- Treated unit: Talenti St.
- Neighbors of treated unit: other streets in the Legnaia neighborhood, such as Pisana St., Pollaiolo St., etc.
- Outcomes of interest: Market size = Number of stores every 500 meters;
Market performance = Sales of the median store on the street
- Treatment period: from 2006 (Construction begun early 2006; Operation begun in 2010)
- Data: from 2004 to 2013. Sources: Italian Archive of Active firms, Italian Register of Firms, Tax Records.

Inspired by the retail sector literature (e.g. Klaesson and Öner, 2014), we perform the analysis on stores selling durable and non-durable goods separately (different frequency of purchase), as these two types are likely to have different market reactions

Setting

- Panel data setting with a set $\mathcal{N}$ of $1 + N$ units (streets) observed in time periods $t = 1, \ldots, T_1, \ldots, T$ (2004-2013)
- A single treated unit in $t = T_1, \ldots, T$ (2006-2013): Talenti St.
- Control units: $i = 2 \ldots N + 1$ (untreated streets in the city, peripheral areas only, clustered by neighborhood)
- Let $(i, \mathcal{N}_i, \mathcal{N}_{-i})$ be a partition of $\mathcal{N}$ around i (for each street, the rest of the set can be partitioned depending on whether the other streets belong to the neighborhood of i):

  $\mathcal{N}_i$ is the neighborhood of unit i:
  Set of all neighbors of unit i
  (Cardinality of $\mathcal{N}_i = |\mathcal{N}_i|$)

  $\mathcal{N}_{-i}$ is the complement set of $\mathcal{N}_i$:
  Set of all units other than i that are not in $\mathcal{N}_i$
  (Cardinality of $\mathcal{N}_{-i} = |\mathcal{N}_{-i}|$)

  (For example, when i = Talenti St., $\mathcal{N}_i$ hosts the other streets in Legnaia, and $\mathcal{N}_{-i}$ hosts streets located in other city neighborhoods)
- $Y_{i,t}$ = Observed outcome at time $t = 1, \ldots, T$

Potential outcomes

- Let $W_i \in \{0, 1\}$ be a binary treatment variable representing the treatment assignment of unit i in each $t = T_1, \ldots, T$ (tramway 1 = *YES* or 0 = *NO*)
- For each i, the partition $(i, \mathcal{N}_i, \mathcal{N}_{-i})$ defines the following partitions of the treatment vector
$$\mathbf{W} = (W_i, \mathbf{W}_{\mathcal{N}_i}, \mathbf{W}_{\mathcal{N}_{-i}})$$
(treatment received by street i, by its neighbors, and by faraway streets)
- Potential outcomes (PO) at time $t = T_1, \ldots, T$:
$$Y_{i,t}(w_i, \mathbf{w}_{\mathcal{N}_i}, \mathbf{w}_{\mathcal{N}_{-i}})$$
(the PO of i is not only a function of whether i has or has not the tramway, as would be assumed under the SUTVA (Rubin, 1974; Imbens and Rubin, 2015), but also of the treatment status of all the other streets)
- Some of these PO are observed, whereas others are not

Partial interference

- We now introduce the assumpion of Partial Interference, which states that PO of street i can only be a function of its own treatments status and of the treatment status of the members of its own group of neighbors (e.g. Sobel, 2006; Hong and Raudenbush, 2006; Hudgens and Halloran, 2008)

> Partial Interference. For all $(w_i, \mathbf{w}_{\mathcal{N}_i}, \mathbf{w}_{\mathcal{N}_{-i}})$, and $(w_i^*, \mathbf{w}^*_{\mathcal{N}_i} \mathbf{w}^*_{\mathcal{N}_{-i}})$ with $w_i = w_i^*$ and $\mathbf{w}_{\mathcal{N}_i} = \mathbf{w}^*_{\mathcal{N}_i}$, then
> $$Y_{i,t}(w_i, \mathbf{w}_{\mathcal{N}_i}, \mathbf{w}_{\mathcal{N}_{-i}}) = Y_{i,t}(w_i^*, \mathbf{w}^*_{\mathcal{N}_i}, \mathbf{w}^*_{\mathcal{N}_{-i}})$$

- In our application, it amounts to assume that interference may occur within the streets belonging to the same neighborhood
- We believe this is reasonable in our setting, since those who patronize stores in one peripheral area will hardly move to other distant peripheral areas because of the one tramway line!
- Under Partial Interference, the potential outcomes $Y_{i,t}(w_i, \mathbf{w}_{\mathcal{N}_i}, \mathbf{w}_{\mathcal{N}_{-i}})$ can be re-written as $Y_{i,t}(w_i, \mathbf{w}_{\mathcal{N}_i})$, i.e. removing the linkage with the treatment assignment of faraway units $\mathbf{w}_{\mathcal{N}_{-i}}$

Causal estimands

- **Potential outcomes of interest under Partial Interference** (observed PO, unobserved PO): For $t = T_1, \ldots, T$

$$Y_{1,t}(1, \mathbf{0}_{|\mathcal{N}_1|}) \qquad Y_{1,t}(0, \mathbf{0}_{|\mathcal{N}_1|}) \qquad Y_{1t}(0, (1, \mathbf{0}_{|\mathcal{N}_1|-1}))$$

$$Y_{i,t}(0, (1, \mathbf{0}_{|\mathcal{N}_i|-1})) \quad Y_{i,t}(0, (0, \mathbf{0}_{|\mathcal{N}_i|-1})) \qquad i \in \mathcal{N}_1$$

$$Y_{i,t}(0, \mathbf{0}_{\mathcal{N}_i}) \qquad i \notin \mathcal{N}_1$$

- **Direct effect for the treated unit/street**

$$\tau_1 = Y_{1t}(1, \mathbf{0}_{|\mathcal{N}_1|}) - Y_{1,t}(0, \mathbf{0}_{|\mathcal{N}_1|})$$

- **Spillover effect for $i \in \mathcal{N}_1$, i.e. for a street close to the treated one**

$$\delta_i = Y_{i,t}(0, (1, \mathbf{0}_{|\mathcal{N}_i|-1})) - Y_{i,t}(0, (0, \mathbf{0}_{|\mathcal{N}_i|-1}))$$

- **Spillover for the treated unit/street in the hypotetical scenario where the treatment was assigned to one its neighbors**

$$\gamma_1 = Y_{1t}(0, (1, \mathbf{0}_{|\mathcal{N}_1|-1})) - Y_{1,t}(0, \mathbf{0}_{|\mathcal{N}_1|})$$

A Synthetic Control Approach

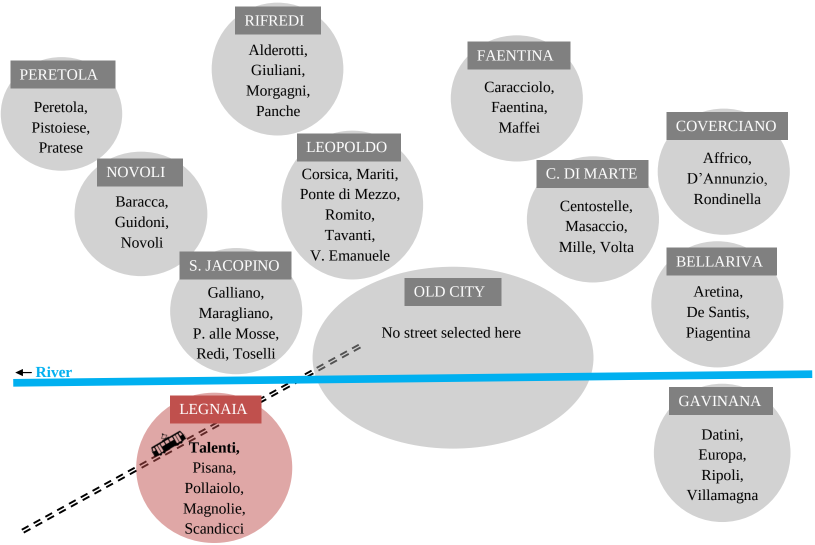
For the estimation of the causal effects τ_1, δ_i and γ_1, we first need to impute the unobserved potential outcomes. How can we do it?

- For each $i \in \{1\} \cup \mathcal{N}_1$:
  $\widehat{Y}_{i,t}(0, \mathbf{0}_{|\mathcal{N}_i|}) = \sum_{j \in \mathcal{N}_{-i}^{(i)}} \hat{\lambda}_j^{(i)} Y_{j,t}(0, \mathbf{0}_{|\mathcal{N}_j|})$, where $\hat{\lambda}_j^{(i)}$ are the optimal weights derived from the Abadie et al. (2010) procedure
  The imputed value is a weighted average of faraway streets' outcomes
  To guarantee general comparability to the streets under analysis, faraway controls are pre-selected using a matching method based on the Mahalanobis distance, starting from several pre-intervention descriptors of the commercial environment both in the streets themselves and in their neighbors)

- $\widehat{Y}_{1t}(0, (1, \mathbf{0}_{|\mathcal{N}_1|-1})) = \sum_{j \in \mathcal{N}_1} \hat{\theta}_j^{(1)} Y_{j,t}(0, (1, \mathbf{0}_{|\mathcal{N}_1|}))$, where $\hat{\theta}_j^{(i)}$ are the optimal weights derived from the Abadie et al. (2010) procedure
  (The imputed value is a weighted average of the streets in the neighborhood other than the treated one)

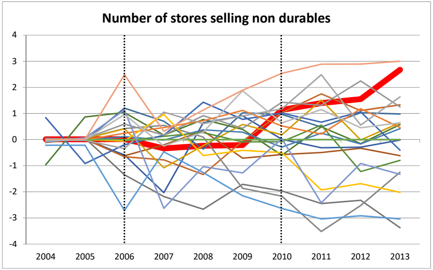
- Both $\hat{\lambda}_j^{(i)}$ and $\hat{\theta}_j^{(i)}$ build a synthetic control that, prior to the intervention, is very similar to the unit under analysis in terms of: the lagged values of its outcome; the lagged values of the mean outcome of its neighbors

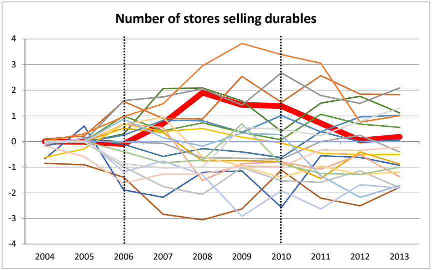
Florence as you've never seen it before

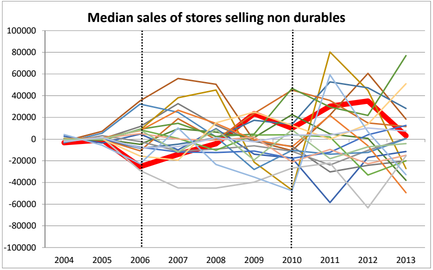


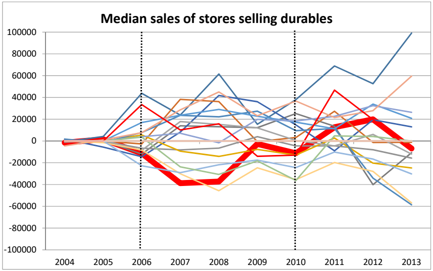
Estimated direct effect and placebo tests

Talenti St.



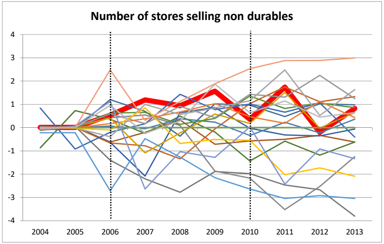


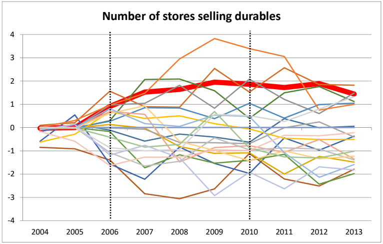


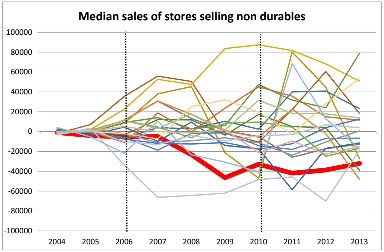


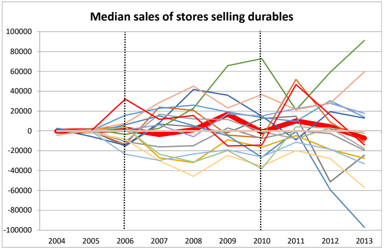
Estimated spillover effect and placebo tests I

As an example, let us look at the **spillover effect on Pisana St.**, which runs parallel to Talenti approx 300 meters South



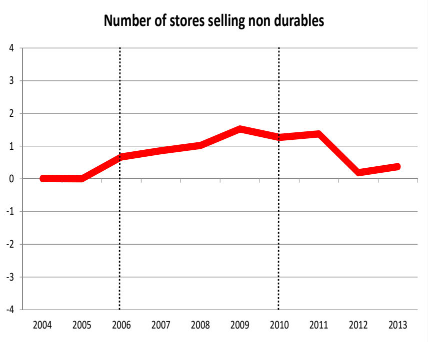


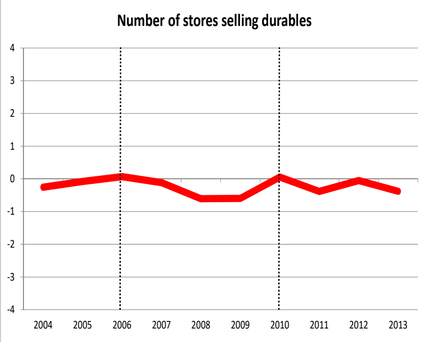




Estimated spillover effect and placebo tests II

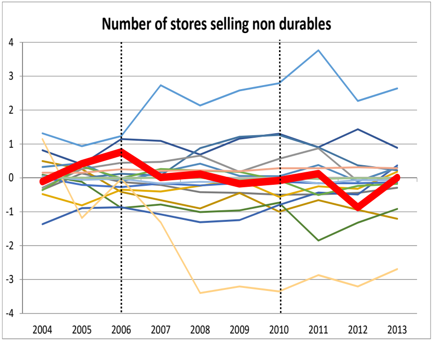
- Notice that each street in the neighborhood has its own estimated spillover effect
- We may calculate the average of the spillover effects estimated for each street in the neighborhood of Legnaia
- Apparently, spillovers on different streets are not the same

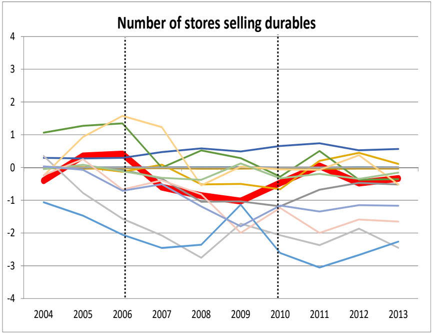




Estimated spillover for Talenti had the tramway been located somewhere else in the neighborhood

Talenti St.





Concluding remarks

- **Original methodological contribution of this paper**. Generalization of the Synthetic Control Method for causal inference to account for interference
- The idea originates from a substantive problem of urban policy, and could be translated into practice thanks to a wide availability of appropriate data

- **Very original application**. Among the multiple aspects that should be accounted for when assessing the effects of urban rail infrastructure, we focus on one understudied aspect: its effects on the commercial environment
- **Direct effect of the tramway**. Lower sales at the start of construction, then increase in the number of stores selling non-durable goods along the tramway lane
- **Spillover effect of the tramway**. Tramway has some positive spillovers on the number of stores selling durable goods in Pisana St.
- Spillovers are not positive on every neighboring street
- However, the spillovers of the tramway tend to be non-negative on average

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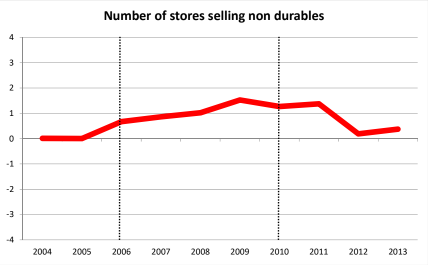
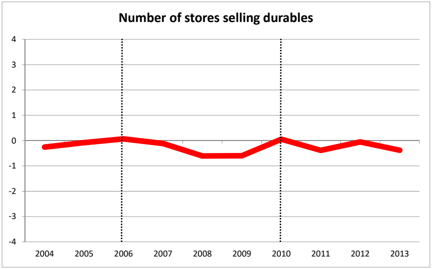
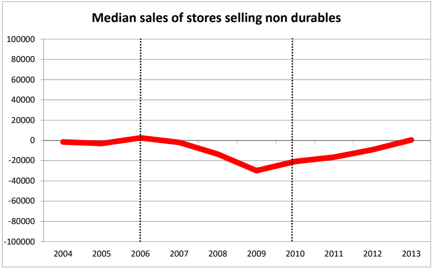
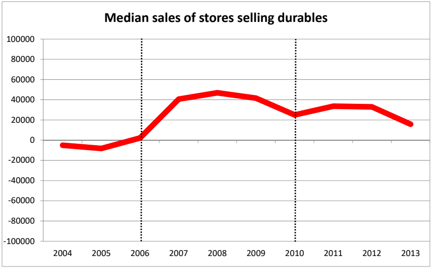
Estimated spillover effect and placebo tests II









Estimated spillover for Talenti had the tramway been located somewhere else in the neighborhood