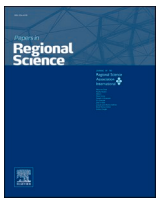
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The impact of natural disasters: How the 2009 earthquake transformed the economy of L'Aquila's labour market area

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ABSTRACT

We investigate the economic impact of the 2009 earthquake in the L'Aquila labour market area (Italy) through a synthetic difference-in-differences method applied to the 2004–2013 period. The shock immediately disrupted the local economy with a 27.3 % and 38.2 % reduction in employment and the number of firms. However, these effects are not statistically significant when measured 5 years after the earthquake, suggesting that a rebound process affected both dimensions. Such findings are the result of heterogeneous dynamics across the manufacturing and service sectors: the former showed a prolonged contraction in the number of employees and firms, whereas the latter experienced a strong recovery after a short-term negative effect. These dynamics have induced an increase in L'Aquila's sector dissimilarity from other local labour market areas in Italy.

1. Introduction

In recent years, territorial studies hosted a growing number of contributions regarding how regions adapt and react to shocks (Tan et al., 2020; Silva et al., 2021; Pierri et al., 2023; Zhang and Wang, 2023), i.e. how they prove to be resilient to unforeseen events. Among the various aspects under scrutiny, the effects of natural and environmental events play a significant role (Cavallo and Noy, 2009), specifically in studies aimed at understanding regional economies' reactions to earthquakes, tsunamis, floods, hurricanes and climate change. This strand of literature seeks to measure how quickly local populations and their activities recover from such shocks and emergencies (Martin, 2012). Although a shared definition on what a resilient region is and how to measure that capacity is still lacking, attempts to identify patterns so far have generally been based on case study analyses, in most cases referring to events occurred in Asian and American countries. Considering the "geographical diversity, variety and unevenness of resilience" (Pike et al., 2010, p. 71), though, conclusions drawn from single areas cannot be adopted immediately to make inferences.

This paper aims to add a European case study to the debate on regional resilience focusing on an area interested by a 6.3 Mw magnitude, 8.8 kms deep earthquake that hit the Italian town of L'Aquila (capital of Abruzzo region) and surrounding municipalities on April 6, 2009. Besides such event (the most tremendous earthquake in terms of physical damage and community displacement occurred in Italy after 1980), we reckon the area is of interest also because its economic performances had already been negatively influenced by the weakening of public policies support after the 1990s (Barone et al., 2016; Iapadre and Mariani, 2020), so much so that it was recently identified as being 'trapped' (Iammarino et al., 2020).

Other contributions provide evidence on how the economy of the area has changed after the event, even though some specifications are needed. Regarding the geographical scale of analysis, Di Pietro and Mora (Di Pietro and Mora, 2015) and Mendoza et al. (Mendoza et al., 2020) respectively use data at the provincial (NUTS 3) and regional (NUTS 2) level, both of which include areas that were not hit by the earthquake.

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Researchers adopting L'Aquila's labour market area (LMA)[1] as spatial unit of analysis, need to consider that in 2011 the Italian National Statistics Institute (ISTAT) made some relevant changes in the list of municipalities that compose each Italian LMA; this makes accurate comparisons spanning from before the earthquake to most recent years more difficult, even though L'Aquila's LMA varied only marginally. In a report dedicated to the economy of the area ten years after the event, Banca d'Italia (Banca d'Italia, 2019) deliberately did not report comparisons with other LMAs in Abruzzo due to major changes they underwent across the 2011 revision.

In our paper, we concentrate on the L'Aquila area with the aim to go further in depth on analysing changes in its economic fabric using a time span of 10 years (2004–2013). In particular, we study the short-term impact of the earthquake by measuring its effects 1 year after the event when policy packages of support were not implemented, yet. Moreover, we study how the recovery process unfolds until 5 years after the disaster to provide a medium-term analysis on the L'Aquila's LMA resilience capacity. We chose LMAs as spatial unit of analysis, since we consider they better identify the area hit by the earthquake, excluding other areas that were less or not affected but still form part of the province of L'Aquila (NUTS3 level) or of the Abruzzo region (NUTS 2 level). We use a dataset freshly elaborated by ISTAT[2] that allows for comparisons within and across LMAs netting out the changes in their composition that occurred in 2011; this dataset, that, to the best of our knowledge, was not used so far in analysing the area we selected, considers LMAs as they were made up in 2001 and reports data until 2020 over this consistent set of administrative units.

In the analysis, we bring evidence on variations in the number of firms and employees for 16 economic sectors and show results for 12 sub-sectors related to the manufacturing sector.[3] Furthermore, we add results on per capita income level, and sector diversification of the area with respect to other LMAs in Italy. Eventually, we interpret them in relation to policy prescriptions that three public institutions elaborated on the specific case of L'Aquila soon after the event took place, i.e. the then called Italian Ministry for Territorial Cohesion, the Organisation for Economic Co-operation and Development (OECD), and the Centre for services, assistance, studies and training for the modernisation of public administrations (Formez PA). Analysing L'Aquila's LMA with recent data is useful to inform policy making, since the long reconstruction process is still ongoing, as are interventions to help the socio-economic, territorial and cultural fabric recover from the shock; as of 2022, indeed, around 10.9 billion euros were allocated for the physical reconstruction of the area[4] and 319 million euros were earmarked for its economic development.[5] Considering more public funds will be spent for the reconstruction (only 56 % of it is considered to having been completed as of 2022) and for local development projects (the Italian National Recovery and Resilience Plan, PNRR, allocated 1.78 billion euros for this purpose in the bordering areas hit by the 2009 and 2016–17 earthquakes), a measurement of how the economy of the region has reacted so far can be useful in guiding policy plans for the near future.

We find that the 2009 earthquake significantly disrupted L'Aquila's LMA in terms of employment and number of firms. Indeed, both variables show an immediate reduction compared to the counterfactual, with an average treatment effect respectively equal to −27.3 % and −38.2 % in the same year when the disaster occurred. However, such an impact is not statistically significant five years after the event, due to a sharp recovery in the number of employees and firms.

We highlight how such a result is the combined effect of heterogeneous dynamics involving the manufacturing and service sectors. The former is subject to prolonged effects both in terms of employees (-10.4 %) and number of firms (-14.7 %) that are still significant 5 years after the earthquake. The latter experiences a strong economic recovery suggesting a not significant effect in terms of employees and firms' reduction with respect to the counterfactual, as measured 5 years after the event.

We further disaggregate results in terms of manufacturing subsectors and service sectors. In particular, we highlight that the earthquake generated a strong negative impact in terms of employment in the "electronics" (-36.9 %), "other manufacturing" (-29.4 %), "food" (-27.5 %), and "wood-paper" (-13.9 %) sub-sectors. These industries accounted for almost half of the total manufacturing employment before the event (40 %), as shown in Table B2. Conversely, some exceptions are found in the "chemicals" (30.8 %), "metallurgy" (21.1 %), "electrical components" (19.1 %), and "transport" (8.3 %) sub-sectors, all of which record an increase in employment with respect to the counterfactual. However, it is worth noticing that these sub-sectors only account for one quarter of L'Aquila's LMA employment in the manufacturing sector, as reported in Table B2 (25 %).

Conversely, across service sub-sectors we find a strong recovery mainly driven by reconstruction activities such as the "construction" (+48.9 %) and "real estate"[6]; sectors (+12.2 %).

Finally, we provide evidence that such structural changes in the local economic structure of L'Aquila's LMA contribute to a significant growth of the local sector diversification. Such a pattern is mainly the result of a growth in the relevance of the "construction", and "support services" sectors. We do not observe a significant impact of the earthquake in terms of income per capita respectively 1 and 5 years after the disaster. Such a finding may be justified by the relevant financial support the area received after the event.

Overall, this paper provides an original contribution with respect to previous studies discussing the impact of L'Aquila earthquake under different facets. First, our study presents higher accuracy and granularity in terms of analysed spatial units, enabling a more precise identification of the impact of the disaster. Second, we rely on a wider sectoral disaggregation allowing us to disentangle the earthquake effect across a larger group of activities than in the extant literature. By doing so, we aim to provide a precise understanding of which were the most disrupted sectors and which, conversely, may drive the economic recovery. Finally, we differentiate from previous studies that mainly focus on employment and labour income, since we also estimate effects in terms of the number of local firms and sector diversification, thus fuelling the debate on the resilience of L'Aquila's LMA.

[1] Labour market areas (LMAs, "sistemi locali del lavoro - SLL" in Italian) are sub-regional geographical areas where the bulk of the labour force lives and works, and where firms can find the main part of the labour force necessary to occupy the jobs they can offer. LMAs are defined on a functional basis, the key criterion being the proportion of commuters who cross the LMA boundary on their way to work. The Italian National Statistics Institute (ISTAT) counts 611 LMAs across the country; each one of them is composed by a list of municipalities, whose main last modification dates to 2011, when the 15th Population Census took place (for further details, see: https://www.istat.it/en/tag/labour-market-areas/).

[2] This dataset is not yet publicly available and was kindly shared by ISTAT with our research team to support this study. The ISTAT file discloses information related to the number of firms and employees by sector with reference to 2001 LMAs for our period of analysis (2004–2013). This dataset is particularly useful, as it provides information on a stable set of LMAs, thus avoiding inconsistencies of other publicly available dataset including heterogenous sets of LMAs over different years, due to major changes in LMAs structure occurred in 2011.

[3] We perform our analysis on all 16 NACE rev.2 one-digit sectors on which ISTAT disclosed data at LMA level in terms of number of employees and firms. Similarly, we conduct an analysis for the whole set of manufacturing subsectors (12, as identified according to NACE two-digit sectors) where the national statistical office provides data in terms of number of employees.

[4] Source: www.opendataricostruzione.gssi.it/home.

[5] Source: www.opendatalaquila.it/appsmaps/sviluppo-economico/.

[6] In the ISTAT classification, "real estate" includes building administrators, a job title required to handle reconstruction paperwork for apartment blocks.

The paper is organized as follows: Section 2 reviews the literature on regional economic resilience, with a focus on natural disasters, and frames our case study; Section 3 reports data and the empirical methodology we adopted; in Section 4, we show and discuss our econometric results; Section 5, eventually, draws conclusions and highlights the main contributions of this research.

2. Theoretical background and research framework

2.1. The notion of "resilience" and its relation to our case study

The appearance of the term "resilience" in scientific texts ascribes to at least three interpretations or uses of the term, known as 'engineering', 'ecological', and 'adaptive' resilience (Pendall et al., 2010; Martin, 2012; Davoudi and Porter, 2012; Martin and Sunley, 2015; Modica and Reggiani, 2015; Wilson, 2017).

'Engineering' resilience, initially applied to materials and buildings, refers to the capacity of a system to return to its previous equilibrium state after a turbulence. 'Ecological' resilience not only considers how quick a system finds a new 'normality' after a turbulence, but also how much stress it can absorb before needing to find an alternative stability. Finally, 'adaptive' resilience, focuses on the capacity of a system to reorganize its form and/or function in the prevision of, or after, the shock, so as to minimize its impact.

Along with a growing strand of literature, it is under this third conceptualization of resilience that we analyse the capacity of the L'Aquila area to adapt to the shock. By studying the short- and the medium-term effects of the earthquake, we contribute to the debate on the economic resilience to natural disasters through an analysis on how territories reconfigure their socio-economic structure and develop new growth trajectories. Such an approach considers resilience not much as a capacity to 'bounce back' to a pre-defined state (as in the engineering view), but rather as the ability to 'bounce forward' towards new scenarios, paths or organizational forms (Pike et al., 2010; Manyena et al., 2011). This paradigm is thus particularly consistent with our framework of analysis aiming to assess the capacity of a regional economy to adapt its structure (firms, workers, technologies, institutions) to go over the shock (Reggiani et al., 2002; Simmie and Martin, 2010; Boschma, 2015). The 'adaptive' conceptualization of resilience also enables to scrutinize the socio-political processes that underpin territorial resilience, therefore allowing us to discuss our results in relation to the policy agendas that were designed to help L'Aquila's LMA better cope with the shock (Weichselgartner and Kelman, 2015).

In most cases, studies on the economic resilience of territories to natural events analyse and compare single or multiple cases, and then try to inductively draw general conclusions. A crowded debate aims to analyse macroeconomic output effects after natural shocks. No general consensus has emerged so far: some authors argue that such events are unlikely to affect economic growth (Cavallo et al., 2013), some others find negative effects (Raddatz, 2009), and other authors find the activation of "Schumpeterian" destruction dynamics even in the short run (Skidmore and Toya, 2002).

A growing number of contributions also now highlights that national and local governments play a crucial role in the territories' capacity to positively react to shocks both in developed and developing countries (Noy, 2009; Barone and Mocetti, 2014; Mendoza et al., 2020). How disasters caused by natural events affect labour markets at a local scale is a research area that needs further analysis. Some general trends that are emerging in relation to earthquakes show that public intervention to finance the reconstruction process usually boosts economic activity in the short run, offsetting the destruction of physical capital generated by the quake and that a shift in employment towards non-tradeable sectors, mostly construction, is usually observed (Trezzi and Porcelli, 2014; Basile et al., 2023).

A few studies were also specifically dedicated to analysing the L'Aquila case, either as a standalone one, or in comparative terms. The first of the two previously mentioned trends was found in the area by Trezzi and Porcelli (Trezzi and Porcelli, 2014), who concentrated on local fiscal multipliers, concluding that public funds allocated for reconstruction prevented a fall in the economic activity of the area. The second trend was highlighted by Basile et al. (Basile et al., 2023). in an analysis comparing the 2009 earthquake with two other seismic events that recently occurred in Italy (known as Emilia-Romagna in 2012 and Central Italy in 2016). In their results, the L'Aquila earthquake appears to show the most negative impact compared to the other two events, both on aggregate employment rate and in terms of a stronger persistence of the effect of the shock over time. Eventually, they found that the increased employment rate in the construction sector only partially offset job reductions in other sectors (especially in manufacturing).

In one of the first econometric analyses after the seismic event, Di Pietro and Mora (Di Pietro and Mora, 2015) gathered data from the 15 months following the earthquake and found that the employment likelihood fell in the quarter immediately after the event and then increased in the next four quarters. Regarding output and employment following seismic events, Porcelli and Trezzi (Porcelli and Trezzi, 2019), comparing data from 22 earthquakes occurred in Italy between 1986 and 2011 (therefore including L'Aquila), found that following an earthquake, the observed contraction of output and employment is generally small or even negligible; eventually, Mendoza et al. (Mendoza et al., 2020) compared the case with earthquakes occurred in Ecuador and Chile, concluding that Abruzzo seemed to experiment short run effects in working hours for women, but not in workers' salaries.

2.2. Research framework

We further define our case study following a classification proposed by Faggian et al. (Faggian et al., 2018), who suggest identifying three dimensions when analysing territorial shocks: the kind of shock, its geographical area and the temporal framework of analysis (see Fig. 1).

Regarding the first point, a distinction has been proposed to divide what has been referred to as "one-time shocks" (Pendall et al., 2010, p. 78) or "'out-of-the-ordinary' events" (Martin and Sunley, 2015, p. 14), and what the same authors respectively call "slow-burn stresses" or "pressures". The first group includes sudden events that are usually exogenous in nature, such as an earthquake is. The latter encompasses crises that develop slowly and gradually over time, as could be

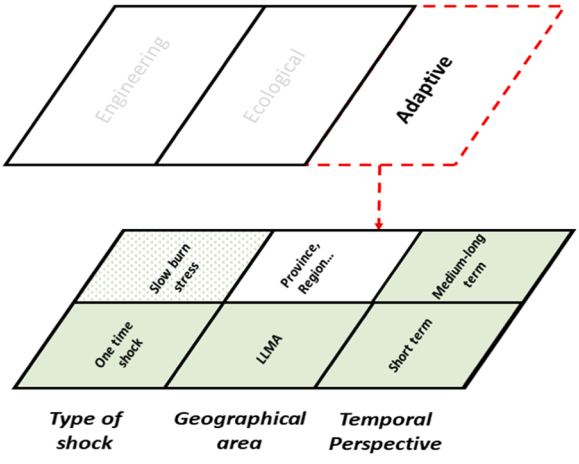


Fig. 1. The plot summarises our framework of analysis. The upper layer clarifies which conceptualization of resilience we refer to; the lower layer highlights how we position in terms of type of shock, geographical area and time perspective when we analyse the earthquake according to a framework proposed by Faggian et al. (Faggian et al, 2018). Regarding the type of shock, we analyse the L'Aquila 2009 earthquake, a one-time shock. However, due to the contemporary financial recession and sovereign debt crisis, we consider the L'Aquila's LMA as also subject to slow-burn sources of distress.

de-industrialization processes or climate change effects. While experiencing the effects of the earthquake, the area we investigate was also subject to at least two "slow-burn" pressures that developed at a larger scales. One regards the 2008 global financial and economic crises and the 2010 European sovereign debt crisis, which strongly affected Italy. Both in the first (Faggian et al., 2018) and in the second case (Accetturo et al., 2022), Italian southern regions (that, according to ISTAT, include Abruzzo) proved to be vulnerable, increasing their divide with respect to northern and central administrative regions. The area we identified includes municipalities (20 out of 29) that are considered to be "inner areas" by the Italian National Strategy for Inner Areas (SNAI); this is relevant since peripheral areas seem to have suffered the consequences of the financial and economic crisis more than urban areas (Dijkstra et al., 2013; Urso et al., 2019). Even before recent crisis, the Abruzzo region had already reduced its economic growth, despite possessing a territorial capital and heritage of exceptional value, that in many cases is underutilized. After experiencing a fast growth of its economic structure between the 1960s and the early 1990s, the region entered a period of declining economic growth, ageing population and depopulation (OECD, 2013, p. 13); that was when both extraordinary public policies in Southern Italy came to an end, and when the region became no longer eligible for the Objective 1 EU structural funds programmes, therefore showing the weaknesses of its development bases (Barone et al., 2016; Iapadre and Mariani, 2020). In a recent European Commission report (Iammarino et al., 2020), Abruzzo was identified as an example of a European region that has fallen into a 'regional development trap', a concept that refers to regions that "face significant structural challenges in retrieving past dynamism or improving prosperity for their residents" (Diemer et al., 2022, p. 487). For all these reasons, policy agendas elaborated after the earthquake (later discussed) suggested considering the reconstruction as an opportunity to also enhance those territorial resources that were identified to better suit emerging local scenarios and re-think the development paths of the areas. Such policies are still being implemented, therefore measuring their impact is a goal for future analysis. Nonetheless, some trends are already observable in the medium term; we discuss and relate them to policy prescriptions in the "empirical evidence" and "conclusions" sections of this paper (respectively Sections 4 and 5).

Regarding the geographical dimension, we decided to use data on L'Aquila's LMA for two main reasons: identifying the affected territories as the set of municipalities falling within the seismic area according to a related governmental decree[7] (in green in Fig. 2, left panel), L'Aquila's LMA results to be the statistical unit of analysis encapsulating most of the affected municipalities.[8] Data at the provincial level (NUTS 3) would include 79 more municipalities that were not considered to be affected by the quake. Secondly, measuring the damage intensity through the Mercalli scale, the municipalities included in the selected LMA also proved to be the most 'physically' affected by the earthquake. Fig. 2 (right panel) shows that the highest intensity was observed in the municipalities of L'Aquila, San Pio delle Camere, Sant'Eusanio Forconese and Villa Sant'Angelo, representing the only administrative units with a Mercalli intensity equal or larger than 9.0. A lower earthquake magnitude was observed in the other LMAs of Abruzzo, as the average Mercalli scale for municipalities in our treated LMA is 6.8, whereas the same figure ranges between 5.0 (Chieti) and 5.9 (Popoli) when considering our control units. Notice also that the Mercalli scale was not disclosed for other municipalities in the region that were located far from the epicentre (left blank in Fig. 2, right panel), since they did not experience any significant damage.

[7] President of the Council of Ministers, Decree No. 3, April 16, 2009, supplemented by Decree No. 11, July 17, 2009, issued by the Commissioner designated for this purpose.

[8] Fig. 2, left panel, highlights that only 3 municipalities out of 32 were not considered to be part of the seismic area in the L'Aquila's LMA.

Lastly, the temporal framework we identified conceives two intervals: considering the earthquake happened on April 6, 2009, we analyse short-run effects using the timeframe 2004–2009, and we discuss medium-term results through the timeframe 2004–2013.

3. Data and methods

3.1. Empirical approach

We adopt a synthetic difference-in-differences (SDID) method recently introduced by Arkhangelsky et al. (Arkhangelsky et al., 2021) to investigate the impact of the 2009 earthquake on the L'Aquila's LMA over the time frame 2004–2013. This allows us to observe how the effects of the disaster unfold over a 5 years' time horizon. We rely on this approach given its suitability for examining a setting where a single unit is subject to a treatment and where other causal inference methods such as a traditional DID cannot be applied to an insufficient number of treated entities.

SDID aims to assess the effect of a treatment by comparing the outcome variable of the treated entity to a counterfactual scenario (synthetic control). This synthetic control is constructed by combining the outcome variable of various elements in the control group (referred to as the donor pool) whose weights are calculated based on the similarity of observable characteristics between the treated entity and the control group in the period preceding the treatment.

Within this methodolody, the Average Treatment Effect on the Treated (ATT) is computed as the difference between the outcome variable of the treated entity and that of the synthetic control during the post-treatment period. In particular, the ATT ($\hat{\tau}^{sdid}$) is estimated based on a two-ways fixed effects regression:

$$\left(\hat{\tau}^{sdid},\ \hat{\mu},\hat{\alpha},\ \hat{\beta}\right)=\underset{\tau,\mu,\alpha,\beta}{argmin}\left\{\sum_{i=1}^{N}\sum_{t=1}^{T}\left(Y_{i,t}-\mu-\alpha_i-\beta_t-W_{i,t}\tau\right)^2\hat{w}_i^{sdid}\hat{\lambda}_t^{sdid}\right\} \tag{1}$$

where $Y_{i,t}$, is our dependent variable (see Section 3.2 for further details), μ is a constant, α_i and β_t are LMAs and years fixed effects. Index i refers to LMAs, while subscript t indicates years. We provide short- and medium-term estimates of the ATT. The former measures the impact of the earthquake 1 year after it occurred, thus considering the period 2004–2009. By doing so, we expect to isolate the effect of the disaster from confounding factors related to reconstruction policies. Medium-term estimates compare how the economy of L'Aquila developed with respect to the counterfactual until 5 years after the event, thus providing an insight on the first recovery actions by focusing on the time frame 2004–2013.

Furthermore, in the formula, $W_{i,t}$ is a dummy variable equal to 1 for treated units during the post-treatment period and 0 otherwise. Finally, $\hat{w}_i^{sdid}$ represents the unit parameter allowing to weight more those LMAs that show more similar characteristics in the pre-treatment period to our treated unit. In particular, weights are assigned to the donor pool in order to match pre-exposure trends of the treated unit and of the synthetic control, in order to weaken the reliance on parallel trend assumptions. Similarly, $\hat{\lambda}_t^{sdid}$ represents a time coefficient enabling to weight more those pre-treatment years that are on average more similar to the post-treatment period.

Based on an algorithm elaborated by Arkhangelsky et al (Arkhangelsky et al., 2021)., we use the following formula to compute units' weights $\hat{w}_i^{sdid}$, with the aim to minimize the difference between the outcome variable of the control elements and of the treated unit before the treatment started:

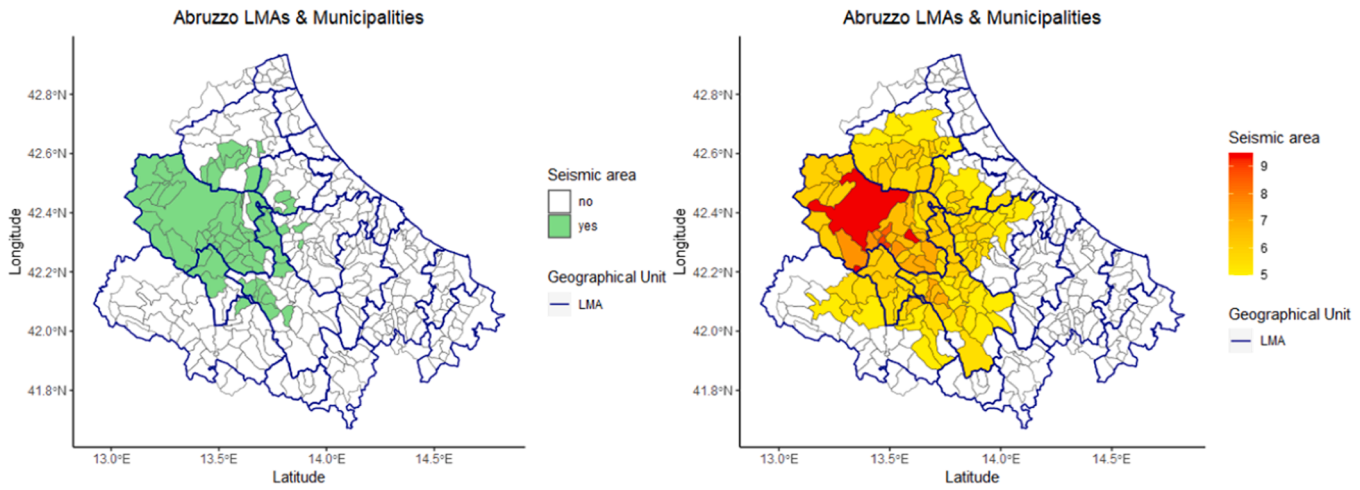


Fig. 2. The left panel shows the LMAs in the Abruzzo region through the blue line. Black lines border municipalities. In green, we colour those municipalities that were included in the seismic area. The right panel shows the 2009 earthquake intensity expressed through the Mercalli Scale. Input data are sourced from the National Institute for Geophysics and Volcanology (INGV) as disclosed by Galli and Camassi (Galli and Camassi, 2009). We colour each administrative unit with the maximum value of the Mercalli scale associated by the mentioned study with each municipality of Abruzzo. We report in white those municipalities for which the Mercalli scale related to the 2009 earthquake was not provided.

$$(\widehat{w}_0, \widehat{w}^{sdid}) = \underset{w_0 \in R,\ w^{sdid} \in \Omega}{argmin} \left\{ \sum_{t=1}^{T_{pre}} \left(w_0 + \sum_{i=1}^{N_{co}} w_i Y_{i,t} - \frac{1}{N_{tr}} \sum_{i=N_{co}+1}^{N} Y_{i,t} \right)^2 + \zeta^2 T_{pre} \|w\|_2^2 \right\} \tag{2}$$

$$\Omega = \left\{ w \in R_+^N : \sum_{i=1}^{N_{co}} w_i = 1, \quad w_i = \frac{1}{N_{tr}} for\ all i = N_{co}+1, \quad \ldots, \quad N \right\} \tag{3}$$

In the formula, N_{co} and N_{tr} respectively represent the number of control and treated units, with $N = N_{co} + N_{tr}$. In our setting, N_{tr} is equal to 1, as our only treated unit is the LMA of L'Aquila. On the other hand, in order to optimize the identification of the most appropriate synthetic control, the donor pool is constituted by all the other Italian LMAs that did not experience a seismic event during the analysed period. In particular, we removed from the control group 12 LMAs located between Emilia-Romagna and Lombardy that in 2012 experienced an earthquake (Basile et al., 2023). Therefore, N_{co} is equal to 672.[9] Furthermore, T_{pre} refers to the years included in the pre-treatment period, corresponding to 2004–2008 in our framework of analysis. ζ is a regularization parameter, that is computed through the following formula:

$$\zeta = (N_{tr} T_{post})^{\frac{1}{4}} \widehat{\sigma} \tag{4}$$

where T_{post} refers to the years in the post-treatment period (2009–2013),[10] and $\widehat{\sigma}$ is computed as follows:

$$\widehat{\sigma} = \frac{1}{N_{co}(T_{pre}-1)} \sum_{i=1}^{N_{co}} \sum_{t=1}^{T_{pre}-1} (\Delta_{it} - \overline{\Delta}) \tag{5}$$

with

$$\Delta_{it} = Y_{i(t+1)} - Y_{it} \tag{6}$$

$$\overline{\Delta} = \frac{1}{N_{co}(T_{pre}-1)} \sum_{i=1}^{N_{co}} \sum_{t=1}^{T_{pre}-1} (\Delta_{it}) \tag{7}$$

The weight w_0 differentiates the SDID from the seminal synthetic control method (SCM) introduced by Abadie and Gardeazabal (Abadie and Gardeazabal, 2003) and Abadie et al. (Abadie et al., 2010). Indeed, by the means of this coefficient, Eq. (2) points to obtaining parallel trends in the outcome variable of treated and control units in the pre-treatment period, thus adding more flexibility with respect to the traditional SCM approach, aiming to perfectly match the dependent variable of treated entity and synthetic control before the start of the treatment. The possibility to rely on this extra flexibility in the estimation of unit weights is related to the introduction of fixed effects in Eq. (1) that allow to absorb the presence of constant differences between alternative units.

In addition, we rely on the following formula to compute time weights ($\widehat{\lambda}_t^{sdid}$) to reduce bias and increase the precision of our estimates by taking into account the similarity between years in pre- and post-treatment periods:

$$(\widehat{\lambda}_0, \widehat{\lambda}^{sdid}) = \underset{\lambda_0 \in R,\ \lambda^{sdid} \in \Lambda}{argmin} \left\{ \sum_{i=1}^{N_{co}} \left(\lambda_0 + \sum_{t=1}^{T_{pre}} \lambda_t Y_{i,t} - \frac{1}{T_{post}} \sum_{t=T_{pre}+1}^{T} Y_{i,t} \right)^2 \right\} \tag{8}$$

$$\Lambda = \left\{ \lambda \in R_+^T : \sum_{t=1}^{T_{pre}} \lambda_t = 1, \quad \lambda_t = \frac{1}{T_{post}} for\ all t = T_{pre}+1, \quad \ldots, \quad T \right\} \tag{9}$$

[9] Here we report the list of the 12 LMAs we removed from the donor pool since they were at least partly subject to the Emilia-Romagna earthquake occurred in May 2012: Bologna, Carpi, Correggio, Cremona, Ferrara, Guastalla, Lugo, Mirandola, Modena, Parma, Reggio nell'Emilia, Viadana. We also checked our list of LMAs included in our donor pool with the international disaster database which is available at the following link: https://climate-adapt.eea.europa.eu/it/metadata/portals/em-dat-the-international-disaster-database-year-of-launch.

[10] The earthquake occurred on April 6, 2009. Year 2009 is thus considered to be our year 0, i.e. when we begin to measure the event's impact.

In the formula, $T = T_{pre} + T_{post}$ and T_{post} is the total number of years of exposure to the treatment.

We rely on the algorithm version including time-varying exogenous covariates $X_{i,t}$ (see Section 3.2 for further details) to better assess the similarity in observable characteristics between treated and control units. In particular, adjustments for such regressors are incorporated by estimating the SDID on the residuals of the following equation:

$$Y_{it}^{res} = Y_{it} - X_{it}\widehat{\beta} \tag{10}$$

3.2. Variables description

This section contains a description of the set of variables we use in the empirical analysis as our dependent ($Y_{i,t}$) and control variables ($X_{i,t}$).

In terms of the outcome variable $Y_{i,t}$, we consider alternative dimensions to assess the earthquake impact. In line with previous works focusing on effects of the L'Aquila's earthquake (Di Pietro and Mora, 2015; Porcelli and Trezzi, 2019; Basile et al., 2023), we consider the employment index with reference to year 2006 as our first dependent variable. In order to avoid that size factors affect our results, we measure the employment index as the ratio between the number of employees in LMA i in year t ($Employees_{it}$) and the number of employees in year 2006 in the underlying LMA. In formula:

$$Employment\ index_{it} = \frac{Employees_{it}}{Employees_{i,2006}} \tag{11}$$

We use this definition of our variable of interest since we are interested in detecting the patterns of disruption and recovery of the local employment; this index well represents differences in growth, as it allows us to identify percentages variations of employment with respect to the reference year. Similar definitions of the dependent variable have been applied in literature also by Barone et al. (Barone et al., 2016) and Scotti et al. (Scotti et al., 2023) to study the impact of public policies of financial support on alternative economic variables of treated units.

In addition, we distinguish from previous studies by analysing economic dynamics after the earthquake also in terms of the number of firms in the underlying LMA. Consistently with our previous approach for the employment dimension, we define our dependent variable as the firm index with reference to year 2006, computed as the ratio between the number of firms in the underlying year ($Firm_{it}$) and the number of firms in year 2006:

$$Firm\ index_{it} = \frac{Firm_{it}}{Firm_{i,2006}} \tag{12}$$

This measure provides a complementary perspective with respect to the employment variable since it enables to assess the attractiveness of L'Aquila's LMA after the earthquake as an area to start new business activities.

Data related to the yearly number of employees and firms at LMA level over the period 2004–2013 are disaggregated across sectors, based on the Nomenclature of Economic Activities (NACE) rev.2. Table 1 summarizes the variables we used in our analysis and specifies the sources of information.

To enrich our analysis, we consider two additional indicators as our dependent variable. One is income per capita, since we also want to estimate the earthquake impact on the local level of wealth. Such variable is in line with what Kirchberger (Kirchberger, 2017) and Mendoza et al. (Mendoza et al., 2020) adopted to analyse the earthquake impact on wages, and with Barone and Mocetti (Barone and Mocetti, 2014), who focused on the Gross Domestic Product (GDP) per capita.

Also in this case, we define our dependent variable as the income per capita index with reference to the year 2006, computed as the ratio between the income per capita in the underlying year ($Income\ per\ capita_{it}$) and the income per capita in year 2006:

Table 1
Definition and Sources of variables employed in our empirical analysis.

Variable class	Variable Name	Source of Data
Dependent Variable	Employment Index	Authors elaboration based on ISTAT, dataset disclosed for research purposes
	Firms Index	Authors elaboration based on ISTAT, dataset disclosed for research purposes
	Income per capita index	Authors elaboration based on ISTAT
	FK Index	Authors elaboration based on ISTAT, dataset disclosed for research purposes
Control Covariates	Population	ISTAT
	Population density	**ISTAT**
	Foreign Population	ISTAT
	Active Population	ISTAT
	Percentage of municipalities that are coastal areas	**ISTAT**
	Percentage of municipalities that are classified as inner areas	**ISTAT**
	Employment rate	**ISTAT**
	Vehicles	ISTAT

$$Income\ per\ capita\ index_{it} = \frac{Income\ per\ capita_{it}}{Income\ per\ capita_{i,2006}} \tag{13}$$

The second indicator is the Finger-Kreinin (FK) index, that provides an insight into the sector diversification level of L'Aquila with respect to other LMAs in Abruzzo (Finger and Kreinin, 1979). Since a strong degree of dissimilarity with respect to the counterfactual may expose the area to a stronger risk of an idiosyncratic shock targeting the specific sectors where L'Aquila concentrates its competitive advantage, we use this indicator to assess the extent to which the earthquake affected the vulnerability of the local economic structure.

In particular, we compute the FK variable as follows:

$$FK_{it} = 0.5 * \sum_k \left| \frac{Employees_{ikt}}{Employees_{it}} - \left[\frac{Employees_{A,k,t} - Employees_{ikt}}{Employees_{A,t} - Employees_{i,t}} \right] \right| \tag{14}$$

where $Employees_{ikt}$ is the number of employees in LMA i in sector k in year t, $Employees_{it}$ is the total number of employees in LMA i in year t, $Employees_{A,k,t}$ is the number of employees in Italy in sector k in year t, and $Employees_{A,t}$ is the total number of employees in Italy in year t. A larger value of such indicator (ranging between 0 and 1) thus means a higher sector dissimilarity of LMA i with respect to other Italian LMAs. Also in this case, we assess differences of sector diversification over time computing the FK index with reference to year 2006 as follows:

$$FK\ index_{it} = \frac{FK_{it}}{FK_{i,2006}} \tag{15}$$

On the other hand, in terms of covariates $X_{i,t}$, we consider the number of residents (*population*) in each LMA to control for the size of units. Moreover, we include the population density as an additional demographic variable. We consider the percentage of foreign people to account for heterogeneity in the local socio-demographic structure (*foreign people*). We also plug in our model the portion of active population (*active population*), defined as the percentage of population aged between 15 and 64. By doing so, we control for potential differences in the local economic structure due to the presence of cohorts with diverse age classes. In line with Dube et al. (Dube et al., 2010) and Gobillon and Magnac (Gobillon and Magnac, 2016), we also considered the income per capita and the employment rate to account for other relevant economic variables and labour market factors. We encompass the number of vehicles (*Vehicles*) as a proxy of the availability of transportation

Table 2
We show descriptive statistics for our dependent and control variables. Data refer to the entire analysed period (2004–2013).

Variable	Q1	Median	Mean	Q3	Std.dev
Employment Index	0.967	1.00	1.01	1.034	0.058
Firm Index	0.953	0.983	0.974	1.000	0.067
Income pc	1.304	1.436	1.481	1.641	0.301
FK index	0.955	1.000	1.010	1.050	0.106
Population	21,498	46,938	107,602	94,854	282,391
Population density	68.350	138.169	263.438	304.086	385.65
Foreign Population	0.014	0.033	0.040	0.061	0.301
Active Population	0.664	0.650	0.648	0.633	0.023
Percentage of municipalities that are coastal areas	0.000	0.183	0.201	0.354	0.208
Percentage of municipalities that are classified as inner areas	0.067	0.215	0.226	0.615	0.395
Employment rate	0.362	0.437	0.426	0.486	0.075
Vehicles	16,570	36,858	87,327	78,523	235,139

Table 3
We show average values of our dependent and control variables for the treated unit (L'Aquila LMA) and control units observed during the pre-treatment period (2004–2008).

Variable	L'Aquila LMA [mean]	Other LMAs [mean]
Employment Index	0.983	0.974
Firm Index	0.887	1.001
Income pc	1.322	1.481
FK index	1.244	1.010
Population	98,016	107,622
Population density	61.805	264.003
Foreign Population	0.041	0.040
Active Population	0.663	0.648
Percentage of municipalities that are coastal areas	0.000	0.156
Percentage of municipalities that are classified as inner areas	1.000	0.412
Employment rate	44.038	42.610
Vehicles	85,753	87,330

infrastructures. Finally, we include the percentage of municipalities within the LMAs that are classified as coastal areas and as inner areas to account for potential alternative development patterns.[11] All control variables are made publicly available by ISTAT.[12]

Table 2 shows descriptive statistics for our dependent and control variables. Table 3 highlights the average values of such variables for our treated unit and the donor pool.

4. Empirical evidence

In this section, we discuss the results of the empirical analysis described in Section 3.1. In particular, Section 4.1 analyses the impact of the 2009 earthquake at the aggregate sectoral level in terms of firms, employment, income per capita and sector dissimilarity. Then, Section 4.2 further investigates such results by disaggregating previous evidence between the manufacturing and service sectors. Finally, sub-Sections 4.2.1 and 4.2.2 show how such evidence is driven at a high granular level by the manufacturing sub-sectors and the service sectors. This progressively increasing sectoral disaggregation in the analysis enables to identify the sectors that mostly suffered the impact of the event and those that are driving the economic recovery, thus providing evidence for policymakers to improve strategies aimed at strengthening territorial resilience.

4.1. All sectors aggregated

In a first step, we analyse the impact of the 2009 earthquake on L'Aquila's LMA considering all aggregated economic sectors. In Table 4, we show the ATT estimates at 1- and 5-years distance from the event to disentangle its short- and medium-term effects. We show our results in terms of the number of firms, number of employees, income per capita, and sector diversification.

Overall, we highlight that the earthquake significantly disrupted the L'Aquila's LMA in terms of number of firms and employees. One year after the earthquake, the number of firms was 38.2 % lower than that observed in the counterfactual (see also Fig. 3). Similarly, employment experienced a significant reduction compared to the synthetic control (-27.3 %), even though showing a lower magnitude with respect to the number of firms (see also Fig. 4). These estimates should isolate the impact of the earthquake since reconstruction policies had not been implemented yet. Interestingly, we find that such effects are transitory and not persistent, since the penalization in terms of number of firms and employees is not significant 5 years after the earthquake.

Table 4
We show the results of the SDID analysis described in Section 3.1. The table reports the ATT estimates over the periods 2004–2009 and 2004–2013, thus disentangling the earthquake impact at 1- and 5- years distance from the event in order to highlight short- and medium-term effects. We show the impact in terms of number of firms, employment, income per capita and sector diversification when we consider all sectors aggregated.

Variable	1 year	5 years
Firms	−0.382***	0.023
	(0.014)	(0.025)
Employees	−0.273***	0.045
	(0.035)	(0.042)
Income pc	−0.043	0.030
	(0.039)	(0.054)
FK	0.162**	0.187**
	(0.069)	(0.080)

Note: *** p-value < 0.01; ** p-value < 0.05; * p-value < 0.10

We also perform a set of robustness checks to assess the validity of our findings. First, we employ a time placebo test, where we consider the year 2010 as the beginning of the treatment period (rather than 2008). Panel B in Figs. 3 and 4 highlights that the discontinuity between the treated unit and the synthetic control starts in 2009 in correspondence with the earthquake, thus suggesting that the measured effect is not due to other events occurred in the following years. Second, we perform a leave-one-out placebo test, where we exclude from the donor pool, one at a time, the 5 units in the control group receiving the highest units' weights $\widehat{w}_i^{sdid}$. Also in this case, Panel C in Figs. 3 and 4 shows that the measured ATT is not due to the specific set of units included in the synthetic control. Indeed, the results are stable even when considering alternative combinations of units included in the donor pool to build the counterfactual. Finally, we do a space placebo test, where we virtually consider as treated all the other LMAs in Abruzzo. By doing so, we also estimate a synthetic control for each LMA in Abruzzo that did not directly experience the earthquake. Panel D in Figs. 3 and 4 displays the difference between the outcome variable for the treated unit and the synthetic control for L'Aquila and the other LMAs of Abruzzo. This allows us to offer further evidence of the economic penalization faced by L'Aquila since, especially in the years 2009 and 2010, it experienced a significantly larger gap with respect to other LMAs in Abruzzo, due to the earthquake. We also confirm how such effects in terms of both number of employees and firms are not anymore significant in a

[11] The adopted methodology exploits also the historical values of the outcome of interest, as proposed by Abadie et al (Abadie et al., 2015). to build the synthetic control.

[12] The ISTAT dataset is publicly available at the following link: http://dati.istat.it/?lang=en.

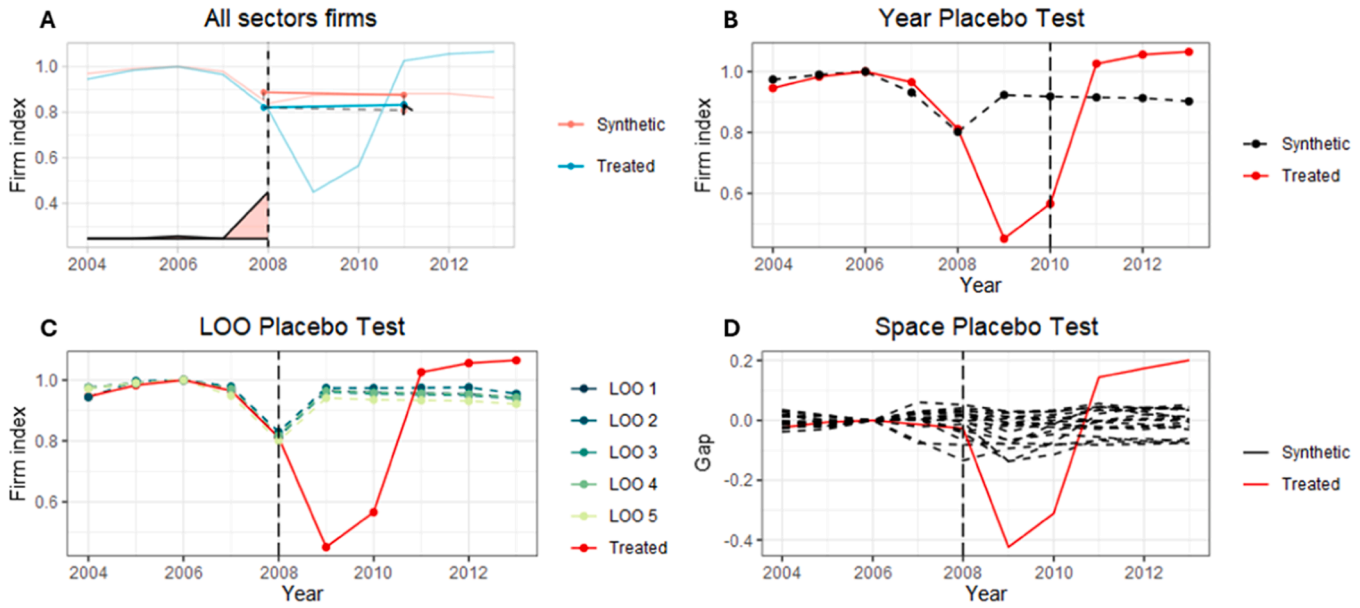


Fig. 3. Panel A shows the trend of the firm index for the treated LMA of L'Aquila and the synthetic control over the time frame 2004–2013. The arrow highlights the ATT estimated through the SDID introduced by Arkhangelsky et al. (Arkhangelsky et al., 2021) as described in Section 3.1. Estimates refer to the impact of the earthquake in terms of number of firms. Panels B, C, and D show the results of a time, leave-one-out, and space placebo tests.

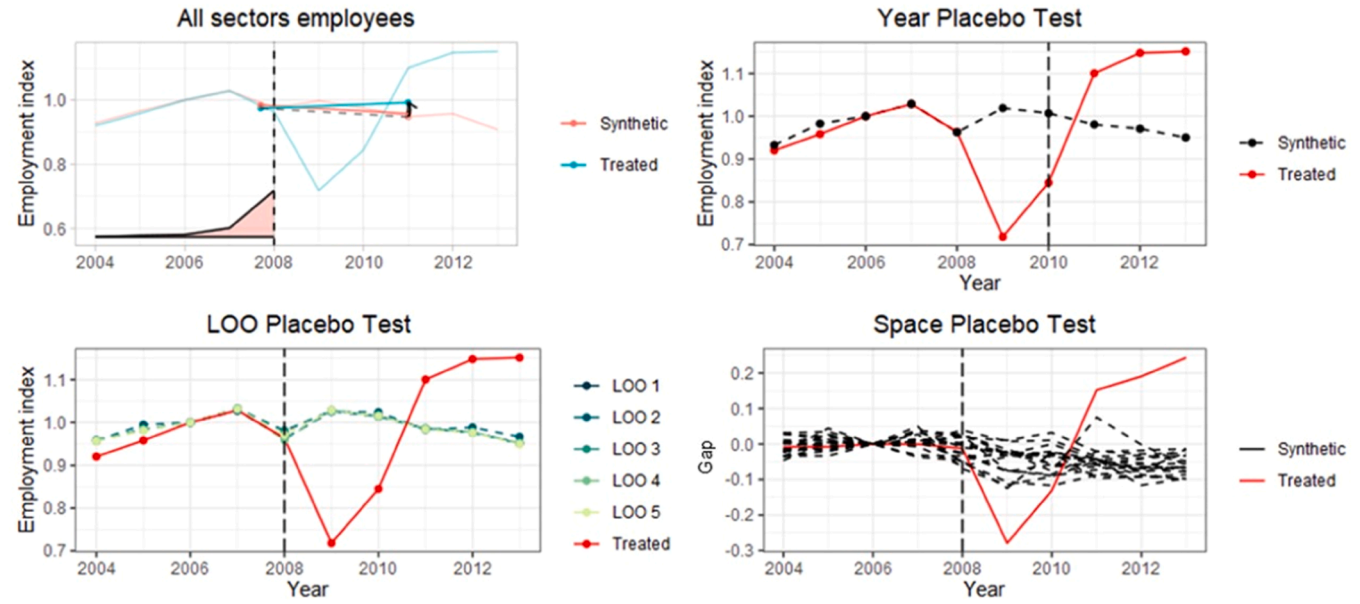


Fig. 4. Panel A shows the trend of the employment index for the treated LMA of L'Aquila and the synthetic control over the time frame 2004–2013. The arrow highlights the ATT estimated through the SDID introduced by Arkhangelsky et al. (Arkhangelsky et al., 2021) as described in Section 3.1. Estimates refer to the impact of the earthquake in terms of number of employees. Panels B, C, and D show the results of a time, leave-one-out, and space placebo tests.

medium-term perspective.

Conversely, we do not find a short- nor a medium-term contraction of income per capita as shown in Panel A of Fig. 5. Such evidence is corroborated by our time, "leave one out", and space placebo tests (see Panels B, C and D in Fig. 5). Indeed, all these further analyses confirm the absence of significant results in terms of income per capita variation in L'Aquila with respect to alternative counterfactuals and other LMAs in Abruzzo, meaning that the local level of wealth did not seem to decrease. Other analyses focusing on the effect of disasters on income per capita obtain heterogeneous results depending on the geographical area and the type of event under scrutiny. Nonetheless, they generally find that high income countries, like Italy is, show no (Cavallo et al., 2013) or little negative effects (Strobl, 2011; Felbermayr and Gröschl, 2014). The reasons highlighted are variegated: (i) financial aid provided to hit areas attenuates the negative effects of physical damage, as Trezzi and Porcelli (Trezzi and Porcelli, 2014) documented regarding L'Aquila in the very short run. This was confirmed also regarding GDP per capita by Barone and Mocetti (Barone and Mocetti, 2014) and regarding wages by Kirchberger (Kirchberger, 2017) and Mendoza et al (Mendoza et al., 2020).; (ii) high institutional quality at local and state level (Barone and Mocetti, 2014; Felbermayr and Gröschl, 2014; Mendoza et al., 2020) combined with a developed national economy (Kahn, 2005) also matter, as they provide implicit insurance against shocks; (iii) when a reduction in income per capita is observed, outward migrations is identified as a

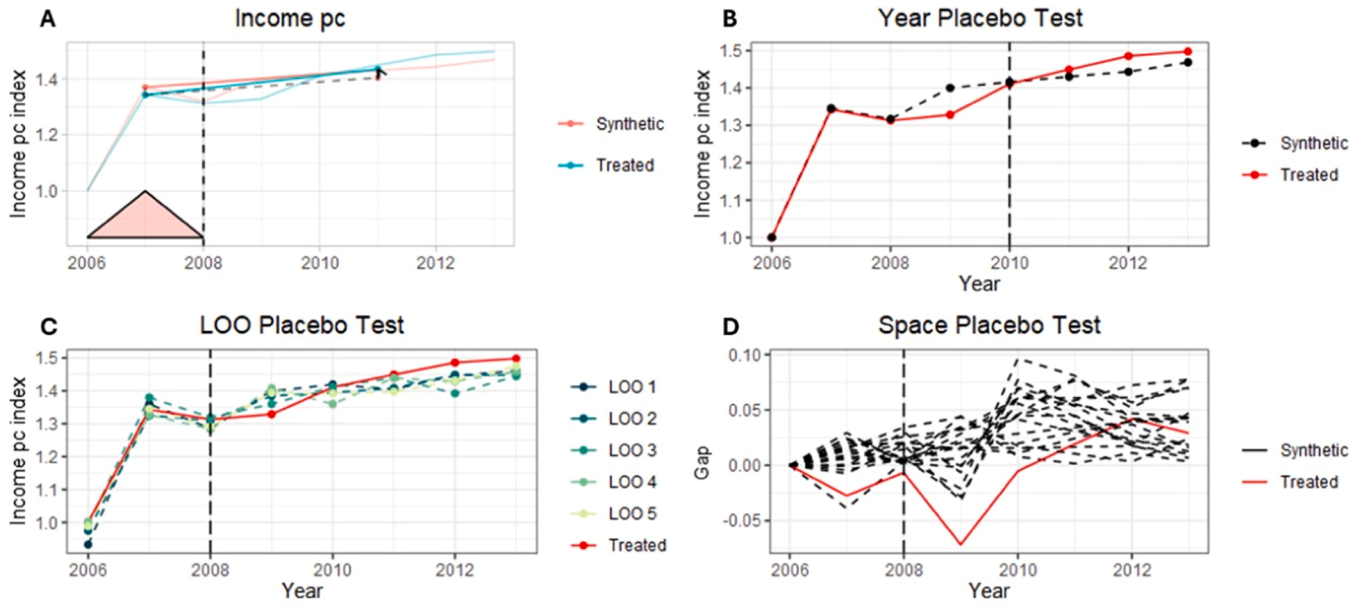


Fig. 5. Panel A shows the trend of the income per capita index for the treated LMA of L'Aquila and the synthetic control over the time frame 2004–2013. The arrow highlights the ATT estimated through the SDID introduced by Arkhangelsky et al. (Arkhangelsky et al., 2021) as described in Section 3.1. Estimates refer to the impact of the earthquake in terms of income per capita. Panels B, C, and D show the results of a time, leave-one-out, and space placebo tests.

reason, as Strobl (Strobl, 2011) finds when analysing hurricanes effects in the U.S. This is not the case of L'Aquila, where the earthquake did not foster locals to move away (Basile et al., 2024).

Finally, we observe significant coefficients when we account for sector diversification both in a short- and medium-term perspective. Indeed, the ATT of FK is positive and significant ($\hat{\tau} = 0.16$ and 0.19, respectively), thus meaning that the earthquake induced a pattern of sector dissimilarity that structurally changed the local economic structure of L'Aquila with respect to other LMAs (see Panel A in Fig. 6). Panel B in Fig. 6 highlights that the pattern of economic diversification of L'Aquila economy started in 2008 in correspondence with the earthquake and was not due to other events. Panel C in Fig. 6 shows that the growth in the FK index is robust to the selection of alternative control units for the construction of the synthetic control. Finally, Panel D in Fig. 6 suggests that the economy diversification observed in L'Aquila is stronger than that experienced by other LMAs in Abruzzo during the analysed period.

4.2. Manufacturing and service sectors

In this section we discuss the heterogeneity of the earthquake impact across the manufacturing and service sectors. By manufacturing sector werefer to business activities that are classified under letter "C" in the NACE rev.2 classification. By service sector we refer to all economic activities that are not included in the primary or secondary sectors,[13] thus encompassing all sectors with a NACE sector code classified under the letters from "D" to "S", with the excluding letter O.[14]

Table 5 focuses on the manufacturing sector and shows evidence of a strong reduction of activities as a consequence of the earthquake. Indeed, L'Aquila's LMA experienced an immediate drop in the number of firms 1 year after the disaster that is 35.6 % larger than that observed in the synthetic control. Similar evidence holds in terms of number of employees (-19.9 %). Contrarily when we consider all aggregate sectors, we find that the disruption of the local business was prolonged with significant effects even 5 years after the event ($\hat{\tau} = -14.7\%$ and -10.4%, see also Panel A in Figs. 7 and 8).

These impacts are robust to a set of alternative placebo tests. The time placebo test shows that the discontinuity between L'Aquila and the synthetic control occurs in 2009 when the earthquake took place and not in correspondence of other events (see Panel B in Figs. 7 and 8). Furthermore, the "leave one out" placebo test highlights that the contraction in the manufacturing sector is not due to the specific units included in the synthetic control, since the result is stable even by slightly changing the counterfactual (see Panel C in Figs. 7 and 8). Moreover, the reduction of employment and number of firms in the manufacturing sector in L'Aquila is significantly larger than that observed in other LMAs in Abruzzo that did not experience the earthquake (see Panel D in Figs. 7 and 8).

The seismic event fostered a dynamic of manufacturing sub-sectors diversification. Such pattern did not vanish in a medium-term horizon, since the ATT at 5-years distance ($\hat{\tau} = 0.09$) is even larger if compared to 1-year distance ($\hat{\tau} = 0.06$,see also Panel A in Fig. 9). Time, "leave one out" and space placebo tests corroborate these findings (see Panels B,C and D in Fig. 9).

Table 6 enables to detect that the earthquake impact at aggregate level was the result of heterogeneous dynamics between the manufacturing and service sectors. Also the latter, indeed, showed a negative short-term effect in terms of both number of firms and employment ($\hat{\tau} = -39.0\%$ and -26.1%, see also Panel A in Figs. 10 and 11). Nonetheless, the 5-years ATT is positive and not significant in terms of number of firms ($\hat{\tau} = 2.2\%$) and employees ($\hat{\tau} = 6.6\%$), thus meaning that the service sector experienced a relevant rebound after the event allowing to achieve levels of activities that are comparable with the pre-treatment period and that are not significantly different from those observed in the counterfactual. These patterns are confirmed also by our placebo tests. Indeed, we observe that the strong contraction of the services sectors started in 2009 in correspondence with the earthquake and not in the following years (see Panel B in Figs. 10 and 11). The "leave one out" placebo test confirms that the immediate reduction in the number of firms and employees, as well as the recovery in the medium term, were not due to the specific control units included in the

[13] By "primary sector" we refer to NACE sector codes A ("agriculture, forestry and fishing") and B ("mining and quarrying"). With the term Secondary sector, we refer to NACE sector code C ("manufacturing").

[14] Letter "O" refers to the public administration sector, whose data availability does not match our time frame.

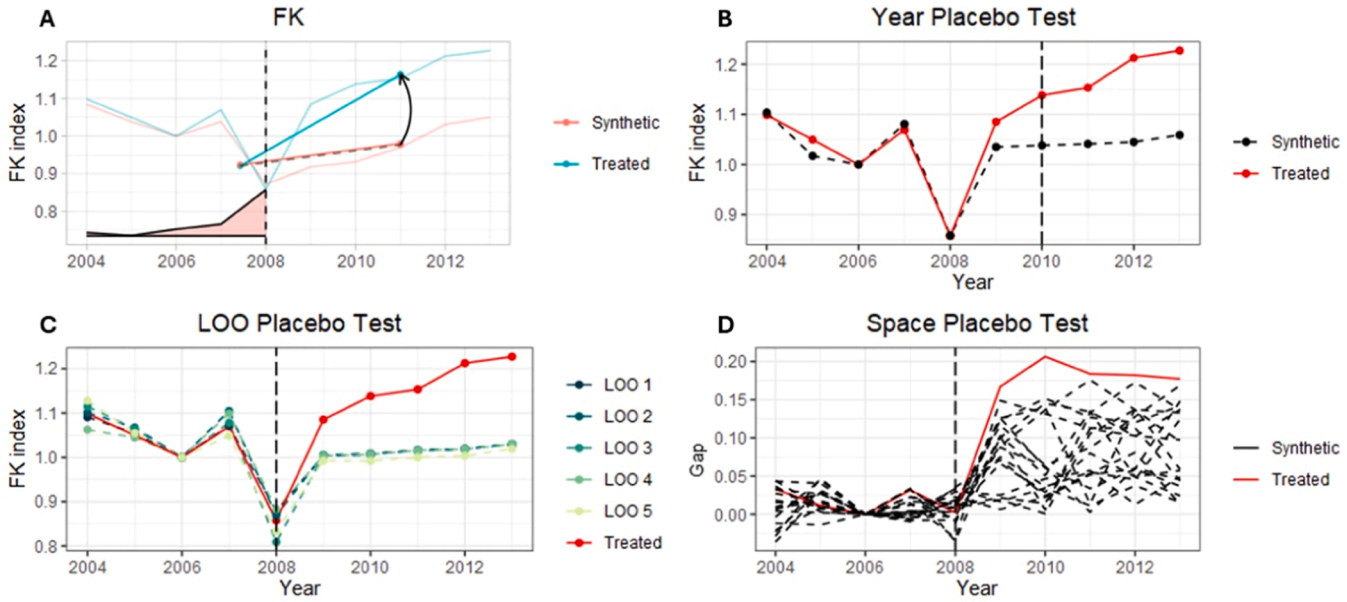


Fig. 6. Panel A shows the trend of the FK index for the treated LMA of L'Aquila and the synthetic control over the time frame 2004–2013. The arrow highlights the ATT estimated through the SDID introduced by Arkhangelsky et al. (Arkhangelsky et al., 2021) as described in Section 3.1. Estimates refer to the impact of the earthquake in terms of FK index. Panels B, C, and D show the results of a time, leave-one-out, and space placebo tests.

Table 5
We show the results of the SDID analysis described in Section 3.1. The table reports the ATT estimates over the periods 2004–2009 and 2004–2013, thus disentangling the earthquake impact 1- and 5-years after it took place, in order to highlight short- and medium-term effects. We show the impact in terms of number of firms, employment, and sector diversification focusing on the manufacturing sector.

Variable	1 year	5 years
Firms	−0.356***	−0.147***
	(0.021)	(0.034)
Employees	−0.199***	−0.104***
	(0.021)	(0.024)
FK	0.059*	0.085***
	(0.032)	(0.032)

synthetic control (see Panel C in Figs. 10 and 11). Finally, the space placebo test demonstrates that such patterns are stronger in L'Aquila than in other LMAs of Abruzzo (see Panel D in Figs. 10 and 11).

Also in this case, Panel A in Fig. 12 shows that L'Aquila increased its sector diversification across service activities, with a medium-term transformation of the local economic structure (5 years $\widehat{\tau} = 0.12$). These results are confirmed by the time, "leave one out", and space placebo tests (see Panels B, C and D in Fig. 12).

4.2.1. *Manufacturing sub-sectors*

In this section, we analyse the impact of the earthquake across 12 manufacturing sub-sectors in terms of employment.

Table 7 provides consistent results with respect to those displayed in Section 4.2, highlighting that also most manufacturing sub-sectors experienced a significant immediate downturn considering employment. The most hardly penalized sub-sector in the short term is the "food" industry with a reduction in the number of employees compared to the synthetic control equal to −43.3 %. Other sectors displaying a negative 5-years ATT larger than 10 % (in absolute values) are "electronics" (-36.9 %), "other manufacturing" (-29.4 %), and "wood-paper" (-13.9 %). It is worth noticing that such disruption affects sectors accounting for almost half of the total employment across manufacturing sub-sectors (40 %) during the pre-treatment period, as shown in Table B2 in Appendix B. The fall in the "electronics" subsector mirrors a profound crisis that hit the so called "Electronic Hub" of L'Aquila, an agglomeration of firms specialized in electronics that was set up in the 1960s within a development plan for southern Italy ("Cassa per il Mezzogiorno"), entered into crisis in the 1980s and eventually faded after the earthquake (Iapadre, 2013). In absolute terms, the subsector "electronics" used to employ 2285 workers in 2001, 577 in 2008, 262 in 2013, and 107 in 2021. In 2001, it accounted for 37 % of employment among the manufacturing subsectors; in 2021, such a value dropped to 4 %. "Electronics" was one of the industries that received financial aid after the earthquake through a resolution (Delibera Cipe 135/2012)[15] that allocated 55 million euros to help targeted industrial districts recover; apparently, it could not alleviate the crisis the sector was already experiencing.

Nonetheless, we also find that a few manufacturing sub-sectors show a positive ATT. Some examples are represented by the "chemicals" (30.8 %), "electrical components" (19.1 %), "metallurgy" (21.1 %), and "transport" (8.3 %). However, these sub-sectors only account for around 25 % of the total employment in the manufacturing sector. Transportation manufacturing was another sector that received aid through the mentioned resolution; the area is specifically specialized in aerospace engineering. Two big companies (Thales Alenia Space and Leonardo) set up a new joint plant in L'Aquila after being temporarily moved out of the region due to physical damage on their buildings.[16] Even if looking at more recent data provided by ISTAT on 2021, it emerges that employment in this subsector is 11 % higher than in 2008, compared to a drop by −15 % in Abruzzo overall and a drop by −8 % in Italy overall.

Finally, in our analysis we find that "machineries", "pharmaceuticals", "rubber and plastics", as well as "textile" do not show statistically significant variations of employment. "Pharmaceuticals" is another sector where funds were allocated in 2012. Three plants (Dompé, Sanofi Aventis and Menarini) were established in the area in the 1990s as a last step of the "Cassa per il Mezzogiorno" plan; the purpose was to absorb

[15] The text of the resolution is available at the following link: https://ricerca-delibere.programmazioneeconomica.gov.it/media/docs/2012/E120135.pdf

[16] For more details, see: www.leonardo.com/en/press-release-detail/-/detail/leonardo-inaugurates-its-new-airborne-systems-facility-in-l-aquila-making-the-abruzzo-region-a-hub-for-leonardo-s-high-tech-production.

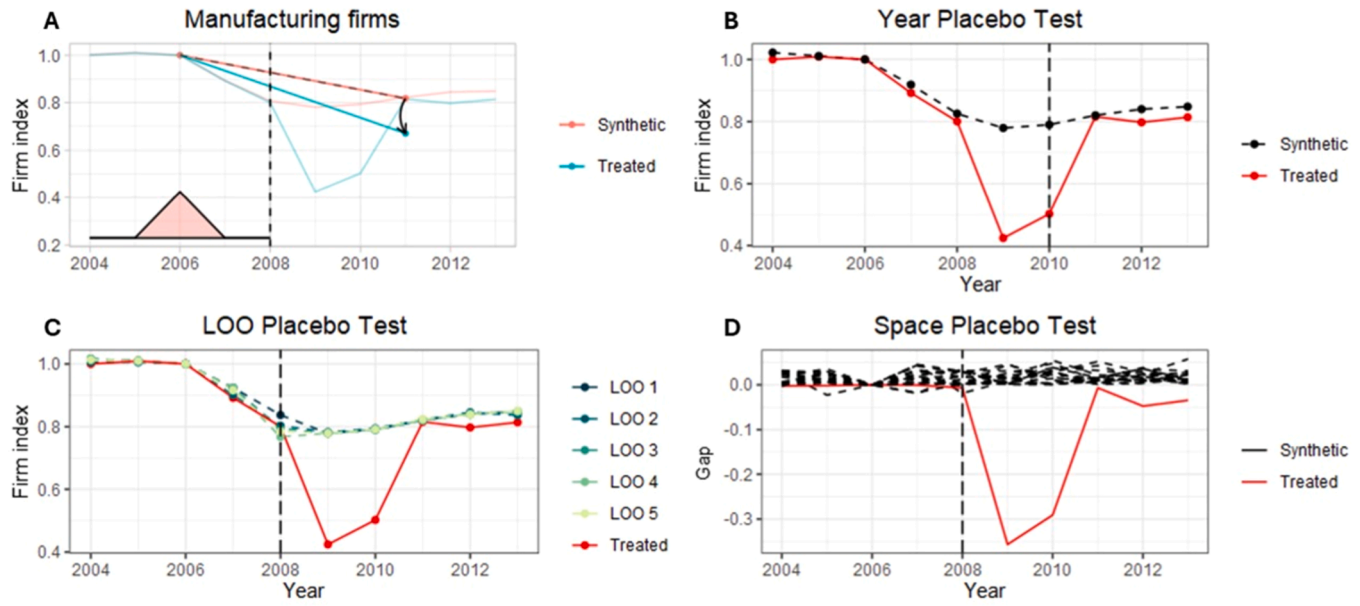


Fig. 7. Panel A shows the trend of the firm index for the treated LMA of L'Aquila and the synthetic control over the time frame 2004–2013. The arrow highlights the ATT estimated through the SDID introduced by Arkhangelsky et al. (Arkhangelsky et al., 2021) as described in Section 3.1. Estimates refer to the impact of the earthquake in terms of the number of firms in the manufacturing sector. Panels B, C, and D show the results of a time, leave-one-out, and space placebo tests.

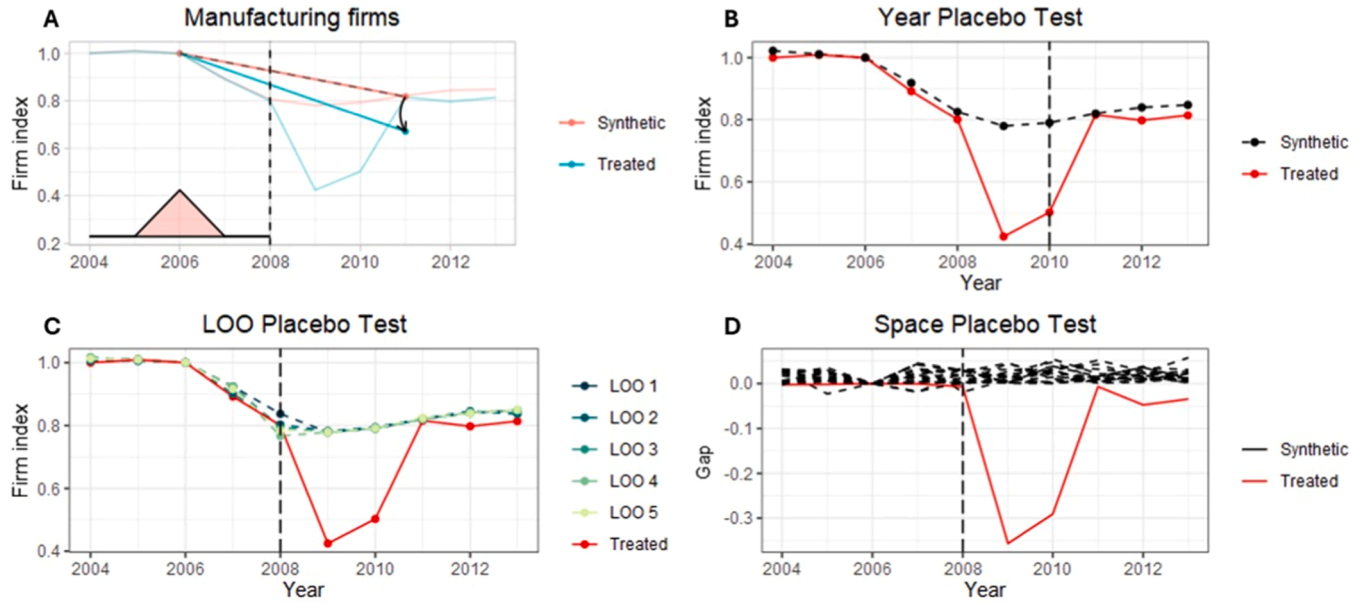


Fig. 8. Panel A shows the trend of the employment index for the treated LMA of L'Aquila and the synthetic control over the time frame 2004–2013. The arrow highlights the ATT estimated through the SDID introduced by Arkhangelsky et al. (Arkhangelsky et al., 2021) as described in Section 3.1. Estimates refer to the impact of the earthquake in terms of the number of employees in the manufacturing sector. Panels B, C, and D show the results of a time, leave-one-out, and space placebo tests.

part of the unemployment the "Elecronic Hub" crisis generated a few years before. This subsector seemed to survive the earthquake with almost no changes in employment both thanks to public aid and private investments (Fortune, 2023). According to the last available data from ISTAT (2021), it has now become the manufacturing subsector with the highest employment share (19 %) in the L'Aquila's LMA.

These results, combined with the previous evidence of a positive FK, allow us to explain the main dynamics behind the sector diversification of L'Aquila's manufacturing sector. This finding is indeed the effect of a strong employment reduction in specific sectors such as "food" and "other manufacturing", and an increase in the relevance of other activities such as the metallurgy sector (long-term $\tau = 7.1\%$).

4.2.2. *Service sub-sectors*

In this section, we disaggregate our analysis on the service sectors, disentangling the impact of the earthquake across relevant sub-sectors.

Table 8 highlights that some activities in the service sectors do experience a positive and significant medium-term ATT. Such evidence holds for the "construction" and the "real estate" sectors concerning the number of employees (+48.9 % and +12.2 %, respectively). This pattern coincides with the start of the reconstruction activities, that boosted these activities. We also observe how the Construction sector

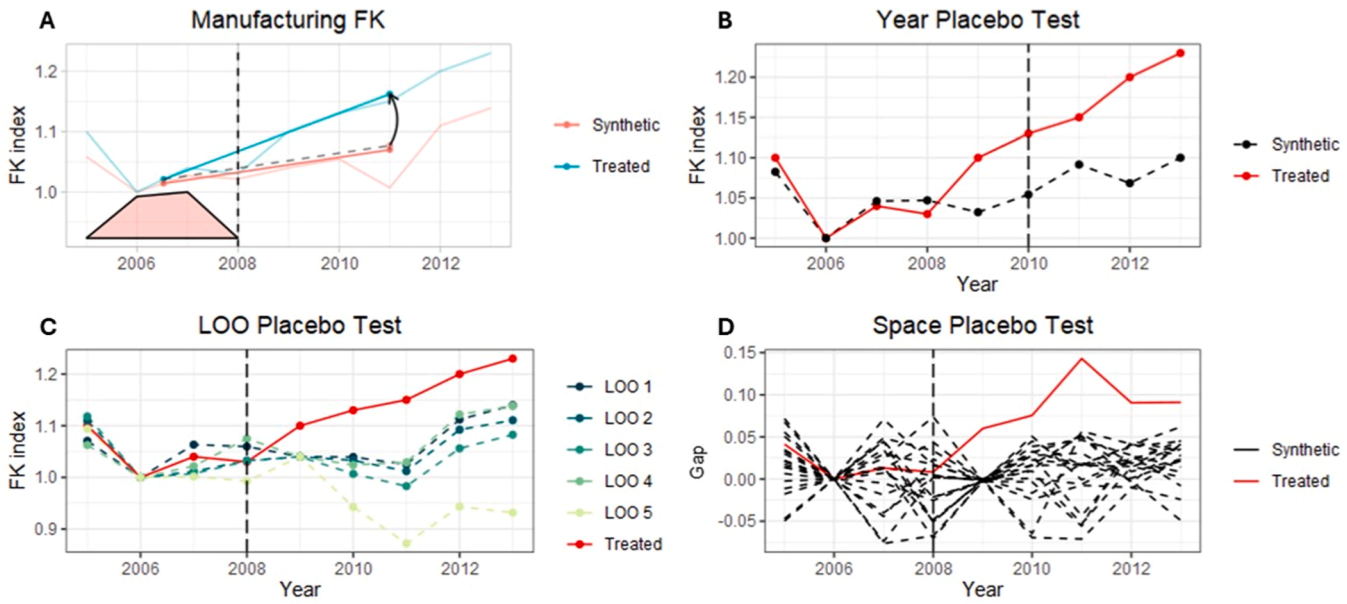


Fig. 9. Panel A shows the trend of the FK index for the treated LMA of L'Aquila and the synthetic control over the time frame 2004–2013. The arrow highlights the ATT estimated through the SDID introduced by Arkhangelsky et al. (Arkhangelsky et al., 2021) as described in Section 3.1. Estimates refer to the impact of the earthquake in terms of the FK index in the manufacturing sector. Panels B, C, and D show the results of a time, leave-one-out, and space placebo tests.

Table 6
We show the results of the SDID analysis described in Section 3.1. The table reports the ATT estimates over the periods 2004–2009 and 2004–2013, thus disentangling the earthquake impact 1- and 5-years after it took place, in order to highlight short- and medium-term effects. We show the impact in terms of number of firms, employment, and sector diversification focusing on the service sectors.

Variable	1 year	5 years
Firms	−0.390***	0.022
	(0.015)	(0.028)
Employees	−0.261***	0.066
	(0.037)	(0.046)
FK	0.082	0.123*
	(0.063)	(0.071)

significantly increased its relevance within the economy of the L'Aquila's LMA (see Table B3 in Appendix B), raising its weight by 6.1 % (from 18.3 % over the period 2004–2008–24.4 % over the period 2009–2013).

Consistently with the results showed in Section 4.2 for the service sectors, we find a large number of activities characterized by a negative and statistically significant 1-year ATT. Notable examples are the "ICT" (-51.9 %), "Restaurants and Accommodation" (-50.4 %), "other services" (-50.3 %), "real estate" (-45.1 %), "education" (-43.9 %), "healthcare" (-42.6 %), "entertainment" (-34.6 %), "wholesale trade" (-33.2 %), "professional activities" (-24.0 %), and "finance" (-16.2 %).

However, we find that employment in these activities experience a significant rebound, since most sub-sectors reduce the intensity of the ATT in a long-term perspective; some of them lose the statistical significance or even show a positive coefficient (like "construction", "restaurants and accommodation", "real estate", "ICT", "professional activities", "education", "healthcare", "support services", and "entertainment").

The combined evidence of such dynamics at service sub-sectors level with the positive ATT for the FK variable highlighted in Section 4.2 suggests that L'Aquila's LMA was subject to a strong diversification across service activities. This is due to the development of a strong competitive advantage in the "construction", and "support services" activities, who raised their percentage weight in terms of employees after the earthquake. Such pattern was also determined by the contemporary loss of relevance for the "wholesale and trade" sub-sector, characterized by a negative ATT equal to −8.5 % 5 years after the earthquake.

5. Conclusions

In this paper, we analysed the impact of the 2009 earthquake on the L'Aquila's LMA in terms of number of employees and firms, income per capita and sector diversification. Furthermore, we investigated how such effects can be declined across different economic sectors.

The empirical evidence suggests that the natural event immediately disrupted the local economy both in terms of employment and number of firms, with effects equal to −27.3 % and −38.2 % 1 year after the earthquake. We also showed how these results are transient, since they do not hold 5 years after the event. Moreover, we found that the area did not experience a significant reduction in terms of income per capita; we also highlighted a strong pattern of sector diversification of L'Aquila with respect to other LMAs in Abruzzo over the time analysed.

In addition, we disentangled how such findings are the combined evidence resulting from heterogeneous dynamics characterizing the manufacturing and service sectors. Although both experienced a significant contraction in terms of number of employees and firms in the shortterm, the former was subject to persistent effects (5-years ATT equal to −10.4 % and −14.7 %), and the latter showed a strong recovery of underlying activities leading to not significant 5-years ATT coefficients. Interestingly, we obtain a stronger penalization in terms of number of firms rather than employees both when we consider all sectors aggregated and when we focus either on the manufacturing or service sectors. Such findings highlight the importance of studying the impact of the natural event across different outcome variables, suggesting that L'Aquila's LMA was more resilient in terms of capacity to attract labour force, and less attractive for opening new firms.

In a study elaborated soon after the earthquake, the OECD (OECD, 2013) already highlighted that an observed decrease in the manufacturing sector was representing a threat to the economy of the Abruzzo region62–64 (OECD, 2013, p. 62-64), suggesting that a regional innovation strategy to strengthen the manufacturing sector was urgently needed (OECD, 2013, p. 109-147). Our results highlight that policy-making should still concentrate on this, especially in the L'Aquila area.

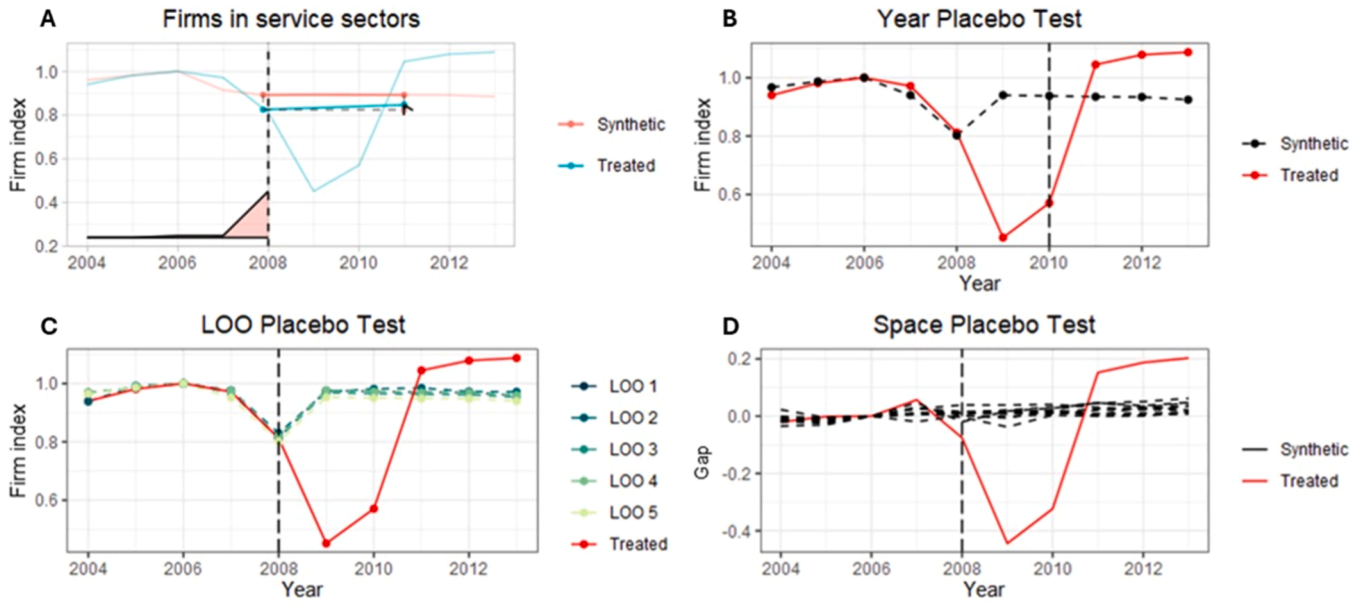


Fig. 10. Panel A shows the trend of the firm index for the treated LMA of L'Aquila and the synthetic control over the time frame 2004–2013. The arrow highlights the ATT estimated through the SDID introduced by Arkhangelsky et al. (Arkhangelsky et al., 2021) as described in Section 3.1. Estimates refer to the impact of the earthquake in terms of the number of firms in service sectors. Panels B, C, and D show the results of a time, leave-one-out, and space placebo tests.

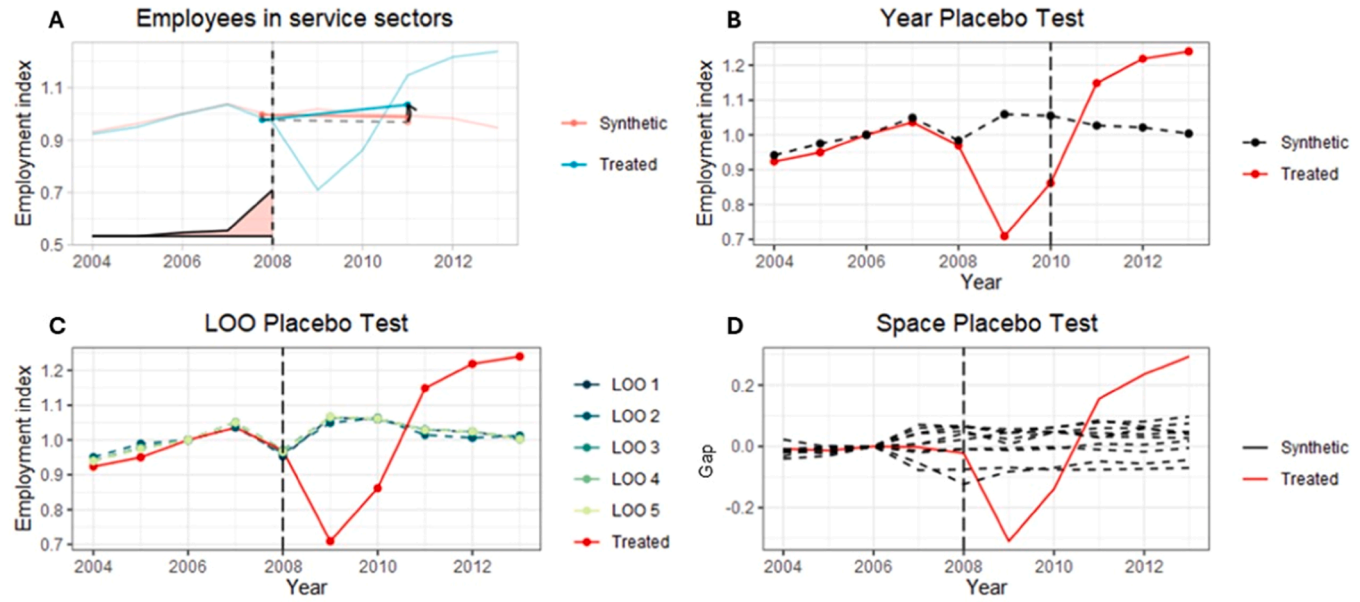


Fig. 11. Panel A shows the trend of the employment index for the treated LMA of L'Aquila and the synthetic control over the time frame 2004–2013. The arrow highlights the ATT estimated through the SDID introduced by Arkhangelsky et al. (Arkhangelsky et al., 2021) as described in Section 3.1. Estimates refer to the impact of the earthquake in terms of the number of employees in service sectors. Panels B, C, and D show the results of a time, leave-one-out, and space placebo tests.

Indeed, in absolute terms, considering the most recent data provided by ISTAT, employment in the manufacturing sector in the L'Aquila's LMA dropped by −34 % from 2008 to 2021, compared to −25 % overall in Abruzzo and −15 % overall in Italy. A shift of employment from tradeable to non-tradeable sectors as observed in L'Aquila also represents a threat according to a recent study by the OECD (OECD, 2018) on productivity and jobs, where authors recognize that European regions whose economies were more successful over the last years were those whose tradeable sectors increased their volumes. A positive annotation concerns the "transport" and "pharmaceuticals" industries, whose development can be crucial for the near future, since both areas are among those that are less prone to delocalize in lower income countries (Moretti, 2012). ISTAT data on L'Aquila's LMA foreign trade reveal that the "pharmaceuticals" sector increased the value (in euros) of its export by 488 % between 2017 and 2022 (first and last available data); the Covid-19 pandemic may have had a role in this, therefore understanding whether local firms are able to keep high values of export is a task for the future.

Finally, we documented a strong pattern of sector diversification, characterizing both manufacturing and service activities. In the former case, such dynamic can be justified by a strong reduction of the relevance of "food", "electronics" and "other manufacturing" sub-sectors, combined with a relevant growth in "metallurgy" activities. Apart from these few exceptions, the manufacturing sector, in aggregate terms,

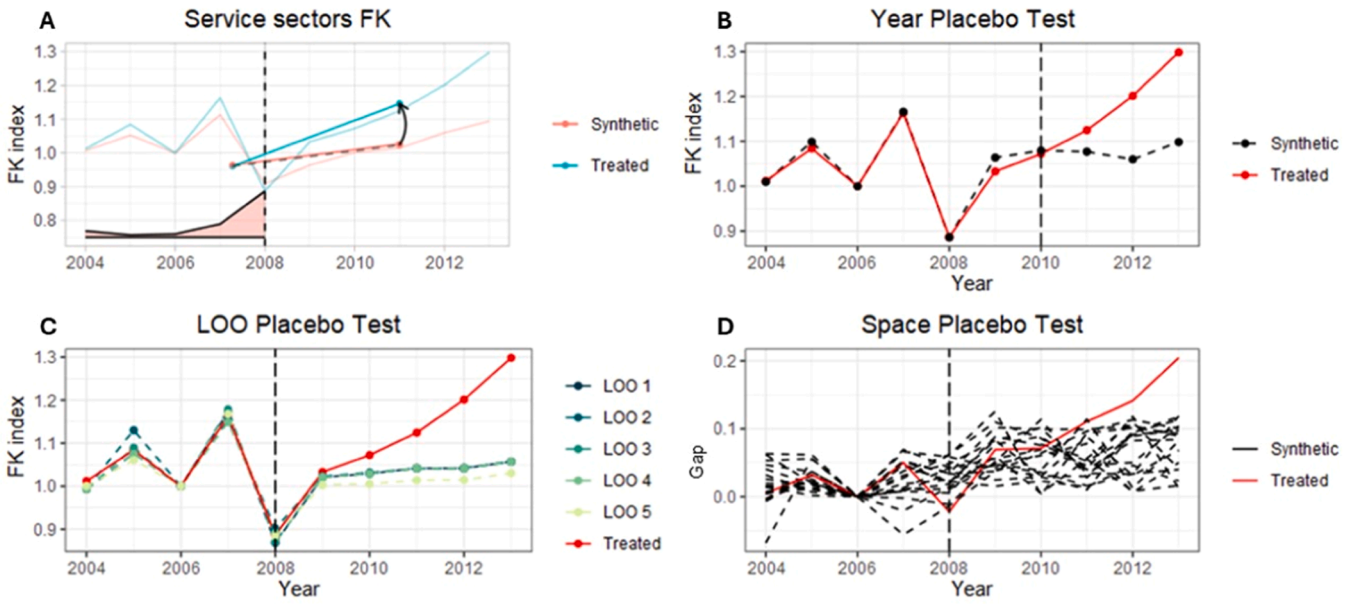


Fig. 12. Panel A shows the trend of the FK index for the treated LMA of L'Aquila and the synthetic control over the time frame 2004–2013. The arrow highlights the ATT estimated through the SDID introduced by Arkhangelsky et al. (Arkhangelsky et al., 2021) as described in Section 3.2. Estimates refer to the impact of the earthquake in terms of the FK index in service sectors. Panels B, C, and D show the results of a time, leave-one-out, and space placebo tests.

Table 7
We show the results of the SDID analysis described in Section 3.1. The table reports the ATT estimates over the periods 2004–2009 and 2004–2013, thus disentangling the earthquake impact 1- and 5-years after it took place, in order to highlight short- and medium-term effects. We show the impact in terms of employment focusing on 12 manufacturing sub-sectors.

Sub-sector	1 year	5 years
Chemicals	0.209	0.308**
	(0.178)	(0.124)
Electrical components	−0.143*	0.191***
	(0.079)	(0.062)
Electronics	−0.412***	−0.369***
	(0.109)	(0.126)
Food	−0.433***	−0.275***
	(0.045)	(0.055)
Machineries	0.076	0.127
	(0.115)	(0.093)
Metallurgy	0.011	0.211**
	(0.151)	(0.102)
Other manufacturing	−0.332**	−0.294***
	(0.121)	(0.105)
Pharmaceuticals	0.051*	0.020
	(0.027)	(0.046)
Rubber and other plastics	−0.054	0.091
	(0.037)	(0.114)
Textile	−0.062*	−0.018
	(0.036)	(0.122)
Transport	0.032	0.083***
	(0.035)	(0.031)
Wood-paper	−0.376***	−0.139*
	(0.088)	(0.068)

Table 8
We show the results of the SDID analysis described in Section 3.1. The table reports the ATT estimates over the periods 2004–2009 and 2004–2013, thus disentangling the earthquake impact 1- and 5-years after it took place, to highlight short- and medium-term effects. We show the impact in terms of employment focusing on 15 service sub-sectors.

Sub-sector	1 year	5 years
Construction	−0.086	0.489***
	(0.076)	(0.112)
Restaurants and accommodation	−0.504***	−0.057
	(0.088)	(0.087)
Real estate	−0.451**	0.122*
	(0.221)	(0.067)
Utilities	−0.070	−0.167**
	(0.093)	(0.152)
Water supply	−0.032	−0.176
	(0.065)	(0.139)
Wholesale & trade	−0.332***	−0.085*
	(0.057)	(0.046)
Transportation	−0.216	−0.150
	(0.164)	(0.147)
ICT	−0.519***	−0.021
	(0.173)	(0.196)
Finance	−0.162*	−0.136***
	(0.084)	(0.049)
Professional activities	−0.240***	0.063
	(0.091)	(0.111)
Support services	−0.295	0.125*
	(0.211)	(0.069)
Education	−0.439*	−0.435
	(0.221)	(0.359)
Healthcare	−0.426**	0.039
	(0.176)	(0.098)
Entertainment	−0.346***	−0.098
	(0.138)	(0.119)
Other services	−0.503***	−0.276**
	(0.086)	(0.126)

has not proven to be resilient so far in terms of adapting to new conditions; even though negative trends are found in our counterfactuals too, its decrease in L'Aquila is evidently more pronounced.

The service sector, instead, shows some form of resilience as compared to our counterfactuals, since the employees' curve significantly grew in the medium term; such area of economic activity seems to have found a new equilibrium, with the slope regarding employees being even more marked than it was before the event. This rebound in the service sector is due in particular to those activities associated with the reconstruction phase, such as "construction", "real estate" and "support services", that significantly rose their relevance within the local economic structure. On a report on L'Aquila elaborated soon after the event, the Ministry for Territorial Cohesion (Ministero per la Coesione Territoriale, 2012, p. 7-8) already warned that an increased employment in these sub-sectors would probably only last until

reconstruction activities are needed. Afterwards, employment in sub-sectors directly and indirectly linked to reconstruction activities will probably experience a decrease in its weight, therefore urging to find alternative long-lasting economic areas where to foster development, unless firms related to these activities specialize in tradeable goods and services and export know-how, a possibility highlighted by Formez PA (Formez, 2011, p. 77). This equilibrium risks to be precarious, and therefore needs to be kept under attention.

Eventually, in aggregate terms, analysing how the number of firms and employees evolved throughout the considered span of time, we can say that L'Aquila's LMA experienced a rather quick rebound after the event, coinciding with the beginning of the reconstruction activities, and then entered a new optimal equilibrium in the medium run; indeed, the two curves reached larger values than those describing number of firms and employees in our counterfactuals. However, the basis of such equilibrium may not be strong enough to withstand the end of extraordinary public financing for reconstruction, with the risk that a situation similar to that mentioned regarding the 1990s will arise.

Overall, our work sheds light on the effects generated by the 2009 earthquake on the L'Aquila's LMA providing a comprehensive overview of the impact across alternative variables of interest and different economic sectors. The high granularity of our analysis may provide a detailed comprehension of the dynamics that lay behind more aggregate evidence of previous studies, thus supporting policy makers in further refining recovery strategies to increase the resilience of the territory, since the reconstruction process is still ongoing.

CRediT authorship contribution statement

Giovanni Baiocchetti: Writing – original draft, Validation, Project administration, Investigation, Data curation, Conceptualization. **Pasquale Lelio Iapadre:** Writing – review & editing, Validation, Supervision, Methodology. **Francesco Scotti:** Writing – original draft, Validation, Software, Methodology, Investigation, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Figure A1 reports the geographical distribution of the treated unit (L'Aquila, in red) and the donor pool (in green). We also highlight (in grey) the LMAs excluded from the control units as they were subject to the Emilia-Romagna earthquake in May 2012.

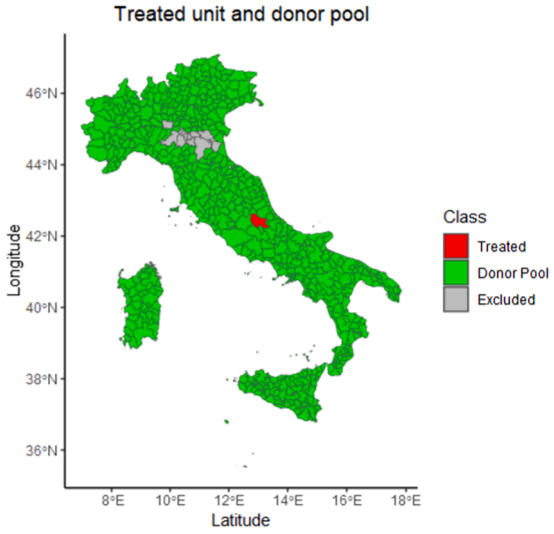


Figure A1. The geographical distribution of the treated unit (L'Aquila, in red) and the donor pool (in green). We also highlight the LMAs excluded from the control units as they were subject to the Emilia-Romagna earthquake in May 2012.

Appendix B

In this section, we report the number of employees' weight of alternative sectors combinations in L'Aquila's LMA at different time horizons. In particular, Table B1 focuses on the manufacturing and service sectors. Table B2 considers the weights of manufacturing sub-sectors, whereas Table B3 shows the relevance of service sub-sectors.

Table B1
Sector weights in terms of number of employees with respect to total employees in the analysed sectors in L'Aquila's LMA. We focus on manufacturing and service sectors, excluding those economic activities on which no data were available (e.g. agriculture). The table reports average values over the considered time periods.

	2004–2008	2009–2013
Manufacturing	0.185	0.151
Service sectors	0.815	0.849

Table B2
Sector weights in terms of number of employees with respect to total employees in manufacturing sub-sectors in L'Aquila's LMA. The table reports average values over the considered time periods.

	2007–2008	2009–2013
Chemicals	1.18	1.11
Electrical components	3.75	4.87
Electronics	16.57	8.05
Food	11.88	11.50
Machineries	0.93	0.90
Metallurgy	14.27	15.87
Other manufacturing	5.96	5.45
Pharmaceuticals	13.14	16.43
Rubber and other plastics	18.23	18.14
Textile	1.89	1.57
Transport	6.51	8.37
Wood-paper	5.69	7.74

Table B3
Sector weights in terms of number of employees with respect to total employees in service sectors in L'Aquila's LMA. The table reports average values over the considered time periods.

	2004–2008	2009–2013
Utilities	0.95 %	1.09 %
Water supply	1.35 %	1.83 %
Construction	18.31 %	24.41 %
Wholesale & trade	23.44 %	20.07 %
Transportation	6.25 %	5.80 %
Restaurants and accommodation	10.33 %	9.80 %
ICT	2.34 %	1.98 %
Finance	4.15 %	3.73 %
Real estate	0.88 %	0.72 %
Professional activities	9.97 %	9.56 %
Support services	10.75 %	11.58 %
Education	0.77 %	0.59 %
Healthcare	5.38 %	5.35 %
Entertainment	1.38 %	0.93 %
Other services	3.75 %	2.56 %

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