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The local labour market effects of earthquakes

Roberto Basile[a], Luisa Giallonardo[a], Pasquale Lelio Iapadre[a,b], Maria Gabriela Ladu[a] and Riccardo Persio[c]

ABSTRACT

Using a balanced panel of local labour market areas (LLMAs) and adopting a new difference-in-differences approach with multiple time periods and multiple groups, this paper assesses the causal effects on local labour market outcomes of the earthquakes that occurred in Italy in 2009, 2012 and 2016. The results show a strong heterogeneity: the 2009 event had significant negative and persistent impacts on the employment rate of the LLMAs involved, while there were no adverse effects for the LLMAs affected by the earthquakes in 2012 and 2016. We also extend the analysis at the industry level in order to highlight the sectoral shifts that typically characterise the aftermath of these natural disasters.

KEYWORDS
natural disasters; labour market; counterfactual analysis; difference-in-differences approach

JEL C32, J61, Q54
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1. INTRODUCTION

A quite large body of research examines the effects of earthquakes and other natural disasters on local labour market outcomes (Belasen & Polachek, 2008, 2009; Di Pietro & Mora, 2015; Kirchberger, 2017; Mendoza et al., 2020; Mendoza & Jara, 2020; Porcelli & Trezzi, 2019; Wu et al., 2017; Yamasaki et al., 2016; Zhou & Botzen, 2021). Most of them focus on Asian countries and America, while only a few concern European economies. Studies of the experiences of other countries and continents can certainly be instructive, but we cannot make inferences based exclusively on them. The effects of natural disasters are indeed quite heterogeneous both between countries and within a single country, as they may vary according to their type, intensity, and the level of economic development and institutional quality of the affected region. A recent survey of the analytical models and empirical strategies used to study the economic effects of disasters by Botzen et al. (2019) distinguished the direct impact of disasters in terms of casualties and loss of assets from their indirect effects on economic activities in the short term and over time. The overarching idea is that a disaster can be thought of as a sudden loss of production factors and its subsequent indirect effects describe how the affected area returns to its former equilibrium or moves into a new one. For a given level of disaster intensity, its direct impact depends mainly on the population density of the affected area and the vulnerability of its buildings and infrastructure. On the other hand, what matters most for the indirect economic effects of the disaster are the quality of the economic and institutional structure of the region, which affects its resilience to catastrophic shocks (Imenez & Romero-Jaren, 2020), and the amount of domestic and external resources allocated to reconstruction activities. In the aftermath of a destructive earthquake, the normal functioning of local labour markets is disrupted both on the demand side, as many firms and production chains are unable to maintain their normal activities, and on the supply side, as many people are displaced and cannot return to their jobs immediately. Therefore, significant reductions in employment and earnings can be observed in the short term. Over time, however, different trends can emerge: the level, quality and structure of employment are influenced by the ability of firms to replace labour with capital and by the rate of technological progress and investment in human capital (Crespo Cuaresma, 2010), as well as by inflows and outflows of workers between the seismic area and other regions or countries. An important factor is the reconstruction process, which stimulates the demand for labour in the building industry, attracting workers from other sectors and/or territories. In the best cases, the reconstruction process can be an opportunity to improve the structure of the economy (*build back better* hypothesis), paving the way for long-term employment growth, even after the end of reconstruction

CONTACT Maria Gabriela Ladu mariagabriela.ladu@univaq.it
[a] Department of Industrial and Information Engineering and Economics, University of L'Aquila, L'Aquila, Italy
[b] United Nations University Institute on Comparative Integration Studies (UNU-CRIS), Bruges, Belgium
[c] Department of Economics and Law, Kore University, Enna, Italy
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activities (Klomp & Valckx, 2014). In other cases, the recovery generated by these activities can only temporarily mask the structural problems that trap development in disaster-stricken areas and may be exacerbated by subsequent depopulation.

In this paper, we assess the causal effects on different local labour market outcomes of the main earthquakes occurred in Italy over the last 15 years.

An important starting point for this analysis is the theoretical contribution of Kirchberger (2017), who develops a model in which an unpredictable event destroys capital assets and infrastructure, causing an increase in demand for the construction sector. In the local labour market, construction firms hire new workers, who move from other sectors or regions (e.g., higher labour demand in the construction sector may attract workers from abroad or from other parts of the country). Kirchberger also uses this framework to carry out an empirical investigation of the effects of earthquakes on local labour markets in Indonesia, applying quantile regression methods. The data confirm the sectoral reallocation of workers predicted by the theoretical model: while employment in the construction sector increases significantly, in the agriculture sector it decreases in the two years following the earthquake. Similar results are obtained by Porcelli and Trezzi (2019), who use instrumental variables regression methods to analyse the impact of 22 seismic events that occurred in 95 Italian provinces from 1986 to 2011 and find a weak negative effect on production and employment. However, in some cases they find a net positive effect of earthquakes on outcome variables thanks to reconstruction activities.

Most of the aforementioned empirical studies base their analyses on descriptive or traditional regression methods, while some carry out a counterfactual analysis, adopting either a difference-in-differences (DID) approach or a synthetic control method (SCM) (e.g., Barone & Mocetti, 2014). For example, using a DID approach, Mendoza and Jara (2020) show that workers in areas hit by an earthquake have a higher probability of becoming part of the informal sector. Di Pietro and Mora (2015) analyse the effect of the L'Aquila earthquake on labour market outcomes by comparing L'Aquila's residents with those of a control area before and after the earthquake. Specifically, they find that the probability of employment decreased in L'Aquila in the quarter immediately after the event, while it increased in the following four quarters.

A few studies analyse and compare the economic effects of more than one natural disaster. For example, Mendoza et al. (2020) compare the impacts of three different massive earthquakes (Italy in 2009, Chile in 2010 and Ecuador in 2016) on labour markets outcomes using a DID approach. They find positive effects on wages and hours worked in Ecuador, positive effects on hours worked only for women in Italy, maybe due to a reduction in the reservation wage for women after the earthquake, and no significant impact in Chile.

However, the traditional DID approach faces two important problems: the choice of an appropriate control group and the necessity to carry out the analysis on a single experimental group. Belasen and Polachek (2008, 2009) propose a generalised difference-in-differences method (GDID) to analyse multiple disasters and multiple time periods in order to overcome the shortcomings mentioned above. Compared with the standard DID analysis, GDID is based on many experimental groups as well as many control groups. In particular, the authors apply this new method to study the impact of hurricanes on the Florida job market. Unfortunately, the GDID approach also suffers from an important shortcoming, as already-treated units could act as controls in subsequent events, and changes in a portion of their treatment effect over time are subtracted from the DID estimates, because their estimators could enter the average with negative weights. The average treatment of the treated can thus be underestimated.

An alternative DID approach for multiple events analysis, which overcomes the latter shortcoming, is the method recently proposed by Callaway and Sant'Anna (2021) and implemented in the open-source software *R* (library did). In this paper, we adopt this approach to assess the causal effects of the three main earthquakes that have hit Italy in the past 15 years on local labour market outcomes: the earthquake in Abruzzo in April 2009; the earthquake in Emilia-Romagna in May 2012; and the earthquake in Central Italy (Abruzzo, Lazio, Marche and Umbria) in August 2016. Analysing the multiple events that occurred in the same country (Italy) over a long period of time allows us to answer questions, such as:

- Are the effects heterogeneous depending on when earthquake occurs?
- Does the effect of the natural disaster increase over time?
- Are short-run effects more pronounced than long-run effects?

We explore these issues using a balanced panel of 208 local labour market areas (LLMAs) belonging to the Italian NUTS-2 regions hit by the earthquakes. The outcome variable is the *local employment rate*. The treatment variable is the occurrence of a *destructive earthquake*. The period of the analysis is 2006–18. The three groups of LLMAs involved in these natural disasters represent our groups of treated. The other LLMAs, belonging to the same regions as those treated but not affected by any earthquake, constitute the untreated groups. This set-up allows us to compare the effect of more than one event, also considering their dynamics over time.

The results of the analysis show a strong heterogeneity in the earthquake effects: the 2009 event had a significant and persistent negative impact on the employment rate of the affected LLMAs, while we find no negative effect of the 2012 and 2016 earthquakes on the aggregate labour market outcomes of the affected areas. Extending the

Table 1. The three earthquakes.

Variables	Treated areas		
	L'Aquila, 2009	Emilia-Romagna, 2012	Central Italy, 2016
1. Moment magnitude	6.3	5.9	6.5
2. Mercalli Scale	IX–X	VII–VIII	X
3. Number of victims	309	27	306
4. Estimated number of damaged buildings (thousands)	73	39	80
5. Surface (km^2)	7131	9197	13,218
6. Population (thousands)	592	2588	1226
7. Population density (number of individuals per km^2)	83	281	93
8. Employment density[a]	30	59	9
9. Correlation between (1) and (8)[b]	0.44	0.53	–0.22
10. Number of local labour market areas (LLMAs)	7	12	18
11. Main specialisation sectors	(Wholesale; construction)	(Med-high tech)	(Textile-clothing)
12. Public funds allocated for reconstruction (€ millions)	17,458	8171	13,163
(a) Funds actually granted	10,842	5885	8369
(b) Funds actually used	7823	5094	5069
13. Degree of utilisation (b/a %)	72.2%	86.6%	60.6%

Note: [a]Employees/km^2 in the municipalities where the Mercalli grade of the earthquake was above VI.
[b]Spearman correlation index.
The reference year is that of the earthquake for all variables, but for public funds, for which the reference year is 2022.
Sources: INGV, Protezione Civile, ISTAT, OpenData Ricostruzione GSSI and OpenData Ricostruzione Emilia-Romagna, Struttura Commissariale Sisma 2016.

analysis to the sector level, we find a positive impact of earthquakes on the construction sector's share of employment in the 2009 and 2012 events and a negative impact on the manufacturing sector's share of employment in the same events and on the accommodation sector's share of employment in the 2009 event.

The rest of the paper is organised as follows. Section 2 describes the three catastrophic events and their aftermaths. Section 3 describes the DID method adopted in our empirical analysis. Section 4 reports and discusses the main evidence obtained. Section 5 concludes.

2. THE LATEST MAJOR EARTHQUAKES IN ITALY AND THEIR AFTERMATH

This section describes the last three major earthquakes occurred in Italy (L'Aquila in 2009, Emilia-Romagna in 2012 and Central Italy in 2016) and their consequences. The focus is on the magnitude of the seismic events and related damage, the main geographical and economic characteristics of the affected areas, and government spending on reconstruction.

The indicators considered for the strength of earthquakes are: (1) the moment magnitude (Mw), measured at the epicentre of each of the three seismic events; (2) the Mercalli Scale, also identified as the Mercalli–Cancani–Sieberg (MCS) scale; (3) the number of victims; and (4) the number of buildings damaged. The Mw indicator measures (on a logarithmic scale) the amount of energy released by the earthquake more accurately than the Richter scale, while the Mercalli Scale measures the extent of the damage caused by the quake in a range between I and XII (see Porcelli & Trezzi, 2019, for more details). The different size of the areas hit by the earthquakes is shown in terms of surface, population and number of affected LLMAs. However, the economic relevance of the areas involved is better measured in terms of employment density, that is, the number of employees/km^2 in the hardest-hit municipalities.[1] This indicator proves to be very important for understanding the economic impact of the three earthquakes. We also consider government grants given to earthquake areas to finance the reconstruction of buildings and economic activities and their degree of utilisation. Efficiency in the management of these funds influences the dynamics of recovery in disaster-stricken areas. As we shall see, the interaction between all these variables is of primary importance in explaining the heterogeneous economic impact of similar seismic events. Table 1 summarises these variables for the three areas officially identified as 'earthquake zones'.

The earthquake of 6 April 2009 hit a wide area of the Abruzzo hinterland, affecting 57 municipalities and seven LLMAs, located mainly in the province of L'Aquila. Its epicentre was very close to the city of L'Aquila, and its intensity, recorded by the National Institute of Geophysics and Volcanology (INGV), was 6.3 in terms of Mw and between the IX and X grades of the Mercalli Scale. The earthquake killed 309 victims and damaged 73,000 buildings. Government funds allocated for reconstruction amount to €17.5 billion, but their degree of utilisation is still relatively low, and 13 years after the event the reconstruction process has reached a good level of completion only for private buildings and the city of L'Aquila. When the earthquake occurred, the area's economy was characterised by a significant presence of wholesale and retail trade activities concentrated mainly in the city centre of L'Aquila and many small firms operating in the construction sector. In addition, there were also a small number of major high-tech manufacturing plants in the pharmaceutical and information and communication technology (ICT) sectors.

The 2012 event hit 12 LLMAs located in northern Emilia-Romagna and in neighbouring regions. These LLMAs are characterised by a high population density, being inhabited by about 2.6 million people who are relatively younger than the rest of the country. The earthquake caused 29 deaths, displaced 5000 persons and damaged over 39,000 buildings, including many factories. Government funding for reconstruction amounts to €8 billion, and the process is at a relatively advanced stage for both private and public buildings. Compared with the 2009 earthquake, the 2012 earthquake was less devastating, mainly for two reasons. The first is the different geological structure of the areas involved: while the 2012 event hit the Po Valley (a flat area), the 2009 event hit a mountainous area, where seismic propagation waves can be amplified (Lee et al., 2009; Zaalishvili, 2021; Zaalishvili et al., 2016). The second difference is in the intensity of the two earthquakes: in the case of 2012, the intensity recorded by INGV was 5.9 in terms of Mw compared with 6.3 recorded for 2009, and since Mw is measured on a logarithmic scale, the 2009 earthquake appears much stronger than that in Emilia-Romagna. As for the Mercalli Scale, INGV recorded a grade between VII and VIII for Emilia-Romagna versus IX–X for L'Aquila. Accordingly, we can identify the 2009 event as 'disastrous', in that it was characterised by the collapse of many buildings, a large number of casualties and noticeable fractures in the ground, while the 2012 event can be classified as 'very strong', in that it was characterised by the partial ruin of some buildings, with few collapses and a limited number of casualties. A strong difference between the two events also emerges with regard to efficiency in the management of public funds for the reconstruction and restoration of economic activities. Specifically, 10 years after the Emilia-Romagna earthquake, local institutions have managed to use 86.61% of the funds dedicated to public and private reconstruction, ensuring both faster reconstruction and a more rapid recovery of the economy. On the other hand, 13 years after the 2009 earthquake, only 72.2% of the public resources earmarked for reconstruction have been used, and the process is still far from complete.

The seismic event of Central Italy (which started in August 2016 and ended in January 2017) shows more similarities with the L'Aquila earthquake in terms of intensity (Mw = 6.5 and Mercalli Scale = X) and number of victims (306). Civil Protection has estimated the damage at around €13 billion, and only 20% of the private projects already submitted and approved have been completed, while the public ones are still around 8%. However, there is a fundamental difference between the two: the 2009 earthquake hit an area with a higher employment density than the 2016 seismic area. Figures A1–A3 in Appendix A in the supplemental data online show the spatial distribution of the Mercalli Scale and of the number of employees/km^2 for the three events. The correlation between the Mercalli Scale and employment density turns out to be positive in the case of L'Aquila and negative in the case of Central Italy (Table 1). Definitely, it is possible to say that while the L'Aquila earthquake hit a densely populated regional capital, the 2016 seismic sequence mainly affected a mountainous area, sparsely inhabited and quite distant from the business centres of the LLMAs involved.

3. METHODOLOGY

Difference-in-differences (DID) is one of the most popular techniques used to evaluate causal treatment effects. In the canonical DID set-up, there are two time periods (say $t-1$ and t) and two groups: no one is treated in $t-1$, while in period t some units are treated (the treated group) and some units are not (the control group). If, in the absence of treatment, the average outcomes for treated and control groups would have followed parallel paths over time (*parallel trends assumption*), one can estimate the average treatment effect for the treated subpopulation (*ATT*) by comparing the average change in outcomes experienced by the treated group with the average change in outcomes experienced by the control group. In this standard approach, *ATT* can be estimated by using a two-way fixed effects (TWFE) estimator (Imbens & Wooldridge, 2009):

$$Y_{it} = \alpha_t + \alpha_i + \beta D_{it} + v_{it}$$

where D_{it} is a treatment dummy variable equal to 1 if unit i is treated in period t, and 0 otherwise; and β is the treatment parameter.

With multiple groups, β is a weighted average of individual two-group/two-period DID estimators with the weights proportional to the group size. However, when different groups are treated in different time periods, some of the 2 × 2 estimates enter the average with negative weights. The reason is that already-treated units act as controls, and changes in a portion of their treatment effect over time are subtracted from the DID estimates. In these cases, the TWFE can generate biased estimates of *ATT*.

A natural way to solve this problem with multiple periods and multiple groups is to compute the group–time average treatment effect. Following Callaway and Sant'Anna (2021), we define G as the time period of the first treatment of each unit (2009, 2012 and 2016 in our case), which also identifies the group to which it belongs. Therefore, the average effect of participating in the treatment for individuals in group g at time t is given by:

$$ATT(g, t) = \mathbb{E}\left[Y_t(g) - Y_t(0) | G_g = 1\right] \quad (1)$$

where Gg is a binary variable equal to 1 if a unit is first treated in period g. Callaway and Sant'Anna propose a methodology to identify, estimate and make inference about $ATT(g, t)$ when the parallel trends assumption holds potentially only after conditioning on observed pre-treatment covariates (X). Specifically, the group–time ATT for group g in period t is non-parametrically identified and given by:

$$ATT(g, t) = \mathbb{E}\left[\left(\frac{G_g}{\mathbb{E}[G_g]} - \frac{\frac{p_g(X)C}{1 - p_g(X)}}{\mathbb{E}\left[\frac{p_g(X)C}{1 - p_g(X)}\right]}\right)(Y_t - Y_{g-1} - m_{g,t}(X))\right] \quad (2)$$

where $p_g(X)$ is the generalised propensity score (GPS), with $C = 1$ for never treated units, Y_t is the potential outcome at time t, Y_{g-1} is the potential outcome in the period $g - 1$, and $m_{g,t}(X) = \mathbb{E}[Y_t - Y_{g-1} | X, C = 1]$ is the population outcome regression for the 'never-treated' group. This is a weighted average of the 'long difference' of the outcome variable, with the weights depending on the propensity score. Therefore, the algorithm uses observations from the control group and group g, omitting other groups, and assigns more weight to observations from the control group that have characteristics similar to those frequently found in group g.

The estimate of $ATT(g, t)$ is obtained by using a two-step strategy. In the first step, one estimates the nuisance functions for each group g and time t, $p_{g,t}(X)$ and mg, t *(X)*. In the second step, one plugs the fitted values of these estimated functions into the sample analogue of $ATT(g, t)$ in (2) to obtain estimates of the group–time average treatment effect. In order to conduct asymptotically valid inference, Callaway and Sant'Anna (2021) also propose using a computationally convenient multiplier-type bootstrap procedure to obtain simultaneous confidence bands for the group–time average treatment effects.

Group–time average treatment effects *ATT(g, t)* can be directly used for learning about treatment effects heterogeneity (i.e., they allow us to consider how the effect of treatment varies by group and time) and/or to construct aggregate causal effect parameters. The simplest way of combining $ATT(g, t)$ across g and t is the weighted average of $ATT(g, t)$ putting more weight on with larger group sizes:

$$\theta_W^O = \frac{1}{k} \sum_{g \in \mathbb{G}} \sum_{t=2}^{T} 1\{g \leq t\} ATT(g, t) P(G = g | G \leq T) \quad (3).$$

with $k = \sum_{g \in \mathbb{G}} \sum_{t=2}^{T} 1\{g \leq t\} P(G = g | G \leq T)$. Unlike β in the TWFE regression specification (1), this simple combination of the $ATT(g, t)$'s immediately rules out troubling issues due to negative weights.

Another aggregate measure which may be of interest in our analysis is the average group-specific treatment effect:

$$\theta_{sel}(g) = \frac{1}{T - g + 1} \sum_{t=g}^{T} \sum ATT(g, t) \quad (4)$$

Note that $\theta_{sel}(g)$ is the average effect of participating in the treatment among units in group g, across all their post-treatment periods. We can also consider an average across groups of $\theta_{sel}(g)$ as an overall measure of treatment effect in place of θ_W^O:

$$\theta_{sel}^O = \sum_{g \in \mathbb{G}} \theta_{sel}(g) P(G = g | G \leq T) \quad (5)$$

This alternative measure has the advantage of not putting more weights on groups that participate in the treatment for longer.

4. THE IMPACT OF EARTHQUAKES ON LOCAL LABOUR MARKET OUTCOMES IN ITALY: EVIDENCE

In this section we report the results of the DID analysis of the effect of the three earthquakes on local labour markets. First, we define the outcome variables and describe the spatial units of analysis (subsection 4.1). Second, we describe the analysis set-up (subsection 4.2). Finally, we discuss the evidence obtained (subsections 4.3 and 4.4).

4.1. Labour market outcomes and spatial units of analysis

We use the following labour market outcomes computed at the LLMA level for the period from 2006 to 2018: the employment rate and sectoral employment shares. The LLMAs are highly integrated clusters of contiguous municipalities and their borders are identified on the basis of the self-containment of commuting flows (ISTAT, 2015). In other words, LLMA are subregional geographical areas where the bulk of the workforce lives and works, and where enterprises can find most of the required workforce. Their features meet the need for meaningfully comparable subregional labour market statistical units. According to the most recent map drawn up by ISTAT in 2011, the national territory can be broken down into 611 LLMAs.[2]

LLMAs, unlike administrative areas, can change as a consequence of complex socio-economic factors. From a technical point of view, they are functional regions built through the aggregation of two or more municipalities, maximising their spatial horizontal interaction. As mentioned above, in the case of LLMAs these horizontal links are identified through commuting flows, which allow one to evaluate the degree of integration between different areas (municipalities in the case of Italy). To define them, Eurostat and several national statistical institutes have implemented a specific algorithm that works with a set of four parameters (minimum and target size of employment, and minimum and target levels of self-containment). From the supply side, self-containment is measured as the number of people living and working in an area divided by the number of workers living in the area. From the demand side, self-containment is measured as the number of people living and working in an area divided by the number of jobs in the area.

4.2. Analysis set-up

We want to assess the causal effects on the local labour market of the three major earthquakes that occurred over the period 2006–18, assumed to be exogenous events,[3] and try to answer the following questions:

- Are these effects heterogeneous by time of earthquake occurrence?
- Does the effect of the treatment increase over time?
- Are short-run effects more pronounced than long-run effects?

We use the estimated $ATT(g, t)$ described in section 3 to answer these questions. Furthermore, for LLMAs that experienced an earthquake in later periods, we can pre-test the conditional parallel trends assumption that serves as a check of the internal consistency of the model used to identify the treatment effects. The estimates are computed using the open-source software *R* (library did).[4]

As discussed above, the methodology is based on a first-step estimation of the generalised propensity score (GPS). For each GPS, we estimate a logit model that includes the characteristics of each LLMA. Specifically, we consider the following LLMAs' characteristics: (1) the log of population density in 2006, (2) a polytomous variable indicating the level of average labour cost,[5] (3) a polytomous variable indicating the degree of trade openness,[-6]. (4) a polytomous variable indicating the functional and industrial specialisation of each LLMA, as described in Appendix B in the supplemental data online, (5) a polytomous variable indicating the LLMA's socio-demographic characteristics, as also described in Appendix B online, and (6) the spatial lags of (3)[7] and (5).

By default, the DID package uses the group of units that never participate in the treatment as the control group. We used this option, while the alternative ('not yet treated') option includes the never-treated units as well as those units that, at a given time, have not yet been treated (although they eventually become treated).[8] This group is at least as large as the never-treated group, although it changes over time.

Furthermore, of the 611 Italian LLMAs, we selected only 208 belonging to the seven NUTS-2 regions affected by an earthquake during the sample period (see Figure B1 in Appendix B in the supplemental data online): 174 of them have never been affected by an earthquake in the period 2006–18, seven belong to the '2009' group and are all located in the region of Abruzzo,[9] 12 belong to the '2012' group and are located in Emilia-Romagna and Lombardia, and 15 belong to the '2016' group and are located in Lazio, Marche and Umbria.[10] The decision to restrict the sample of control units to the LLMAs belonging to the same regions as the treated units was based on the consideration of using a spatially homogeneous sample within which the main difference is represented by the treatment, as in a spatial regression discontinuity design. This decision was also guided by the results of the pretest of the conditional parallel trends assumption. Using the whole set of territorial units, in fact, this assumption is never satisfied, while with the selected subsample the conditional parallel test assumption is strongly satisfied.

Summary statistics for the characteristics of LLMAs are provided in Table 2. Data refer to the period between 2007 and 2009. Treated LLMAs have on average significantly lower population density. In terms of socio-demographic characteristics, treated units are more likely to be in the groups S-A (Cities of the Centre–North), S-C (Green heart) and S-F (Inner South), while they are less likely to be in the group S-B (Widespread cities). In terms of specialisation, treated units are more likely to be non-specialised (A), urban areas (BA), and manufacturing areas specialised in textile, clothing and leather goods; whereas treated units are less likely to be tourist and rural areas (BB), manufacturing local areas specialised in other Made in Italy activities (CB), and heavy-manufacturing local labour systems (D). There are also significant differences in labour cost and in trade openness between treated and untreated units.

4.3. The impact of earthquakes on the employment rate

We first estimate the effect of the three earthquakes on the employment rate. The results for the aggregate average treatment effects are reported in Table 3.[11] A weighted average of all group–time average treatment effects (ATT), with weights proportional to group size, indicates that the occurrence of earthquakes leads to a reduction in the employment rate by 0.9% and this effect is strongly statistically significant (Table 3). Thus, this simple evidence provides support for the view that earthquakes lead to a reduction in employment. Nevertheless, this average impact masks a strong heterogeneity in treatment effects between different groups in different time periods. By computing the aggregate ATT for each of the three groups, in fact, a significantly negative impact on the employment rate (−1.7%) emerges only for the LLMAs group hit by the 2009 earthquake in L'Aquila. It is worth noting that the weighted average effect (−0.7%) computed using these three overall group-specific parameters is lower than the weighted average reported above (−0.9%), as the latter gives more weights to effects with a longer length. Finally, Table 3 reports the p-value of a Wald pre-test of the conditional parallel trends assumption, which appears not be rejected at conventional significance levels. In other words, the parallel trends assumption holds for all pre-treatment periods and for all groups.

Figure 1 contains separate plots of group–time average treatment effects for each of the three groups from

Table 2. Summary statistics on local labour market area (LLMA) characteristics for treated and untreated LLMAs.

	Treated LLMAs	Untreated LLMAs	Difference	*P*-value difference
log Population density in 2006	4.80	4.95	−0.15	0.000
Socio-demographic characteristics				
S-A (Cities of the Centre–North)	15.91	7.92	7.98	0.0
S-B (Widespread cities)	22.73	39.02	−16.30	0.0
S-C (Green heart)	54.54	47.56	6.98	0.03
S-D (Southern urban centres)	–	–	–	–
S-E (Southern hardship territories)	–	–	–	–
S-F (Inner South)	4.54	2.44	2.11	0.24
S-G (The other South)	2.27	3.04	−0.78	0.286
Specialisation type				
A (non-specialised local areas)	2.27	0.61	1.66	0.10
BA (urban areas)	18.18	9.75	8.43	0.0
BB (tourism and rural activities)	6.82	14.63	−7.82	0.0
(textile, clothing and leather goods)	29.54	14.63	14.91	0.0
CB (other Made in Italy activities)	31.81	36.58	−4.77	0.31
(heavy-manufacturing)	11.36	23.78	−12.42	0.000
Labour cost[a]				
*LC*1	0.00	2.44	−2.44	0.0
*LC*2	40.91	34.15	6.76	0.03
*LC*3	36.36	32.92	3.44	0.128
–	15.91	25.61	−9.70	0.000
–	6.82	5.87	1.94	0.192
Trade openness[b]				
*Q*1	4.54	7.32	−2.77	0.08
*Q*2	13.64	13.41	0.22	0.891
*Q*3	43.18	32.31	10.86	0.0
*Q*4	38.64	46.95	−8.31	0.000

Note: Authors' elaborations on ISTAT data.
[a]Five categories are considered based on the level of labour cost (€ thousands): (1) up to 24.2 (*LC*1); (2) between 24.3 and 31.2 (*LC*2); (3) between 31.3 and 34.6 (*LC*3); (4) between 34.7 and 38.1 (*LC*4); and (5) more than 38.2 (*LC*5).
[b]Four categories are identified based on the quartile distribution of the ratio between imports plus exports (€ thousands) and the number of employees: (1) up to 2.3 (*Q*1), (2) between 2.4 and 10.3 (*Q*2), (3) between 10.4 and 31.6 (*Q*3), and between 31.7 and 40.1 (*Q*4). For polytomous variables, we report the percentage of LLMAs in each category. Data refer to the period between 2007 and 2009. Number of treated units: 34; and number of untreated units: 174.

2007 to 2018, along with a uniform 95% confidence band. The light grey dots are pre-treatment pseudo group–time average treatment effects and are most useful for pre-testing the parallel trends assumption. Here they are provided with 95% simultaneous confidence intervals. The dark grey dots are post-treatment group–time average treatment effects. Under the parallel trends assumption, these can be interpreted as the average effects of earthquakes for units in a particular group at a particular point in time. All inference procedures use clustered bootstrap standard errors at the LLMA level. By looking at the uniform confidence bands for the $ATT(g, t)$, we can see that they all cover zero in all pre-treatment periods. Therefore, we cannot reject the null hypothesis that ATT is equal to zero in all pre-treatment periods.

Both instantaneous and long-lasting effects of the 2009 L'Aquila earthquake emerge on the employment rate: a negative impact occurs in 2009 and the years following exposure to the event. For all post-treatment group–time average treatment effects in the 2009 group there is, in fact, a statistically significant negative effect on employment. The employment rate is 1.2% lower in 2009 than it would have been in the absence of the earthquake. The impact remains stable in the subsequent year. In 2011 and 2012, the negative impact of the earthquake apparently disappeared. However, from 2013 to 2015, the negative effect emerged again with

Table 3. Estimates of the average treatment effects of earthquakes.

	Employment rate
Weighted average of group–time ATT	−0.902*
	(0.409)
Weighted average of group-specific effects	−0.730*
	(0.289)
Group-specific effect, 2009	−1.668*
	(0.577)
Group-specific effect, 2012	−0.484
	(0.629)
Group-specific effect, 2016	−0.490
	(0.310)
P-value pre-test DID assumption	0.231

Note: Reported are aggregated treatment effect parameters under the conditional parallel trends assumption and with clustering at the local labour market area (LLMA) level. The first row reports the weighted average (by group size) of all available group–time average treatment effects (ATT_W^O), as in equation (3). The second row reports the weighted average of the three group-specific average treatment effects (ATT_W^{Sel}), as in equation (5). The rows 'Group-specific effects' summarise average treatment effects by the timing of the earthquake. Standard errors are shown in parentheses. *Confidence band at the 95% significance level does not cover the zero. Balanced panel data: 208 LLMAs observed for 13 years (2704 observations).

an $ATT(g, t)$ parameter ranging between − 2.0% and −2.5%. Over time, however, the confidence interval increases, indicating a higher heterogeneity of the treatment effect across spatial units within this group. On the contrary, for LLMAs first treated in 2012 and in 2016 the employment effect of the earthquakes is never statistically significant.

In order to examine the heterogeneous impact of the three events across LLMAs, we have also applied a disaggregated version of the synthetic control method (SCM) originally proposed by Abadie et al. (2010). For each of the 34 treated LLMAs (seven in the first group, 12 in the second group and 15 in the third group), we have formed a synthetic control group as an optimally weighted average of the 174 control units, which are the LLMAs belonging to the same regions of the treated areas but never hit by an earthquake over the sample period (i.e., the same control group used in the DID analysis). Under the conditions of the SCM approach, we thus obtained an unbiased estimate of the earthquake effect on the employment rate for every LLMA in the three treatment areas. The details of this analysis are reported in Appendix C in the supplemental data online. In essence, it is important to note that the dynamics of the simple average of the LLMA-level effects in each treated area are qualitatively very similar to those reported in Figure 1. In particular, only for the group of LLMAs hit by the earthquake in 2009, the average effects over the post-earthquake periods are significantly negative, except in 2011, and become stronger and persistent over time. Encouraged by this robustness check, we also provide in Appendix C heat maps showing the spatial distribution of the disaggregated effects for the first and last post-treatment years.

Focusing on the LLMAs affected by the 2009 earthquake, most of the estimated effects are negative and some of them are strongly negative (see Figure C3 in Appendix C online). As expected, the inner LLMAs of Abruzzo (such as L'Aquila and Sulmona) were the most negatively affected immediately after the 2009 earthquake. These areas also recorded the main damage in terms of the Mercalli Scale (see Appendix A online). The map for the last sample year (2018) suggests that over time the negative effect of the earthquake has become stronger not only in L'Aquila and Sulmona, but also in the Chieti LLMA. However, in 2018 we can also observe a positive effect for Penne and Celano, confirming the aforementioned growing heterogeneity of the effects.

The heat map of the spatial distribution of the effects of the 2012 earthquake shows a negative impact on the employment rate in the central area of Emilia-Romagna (see Figure C4 in Appendix C online). In particular, the most affected LLMAs were those of Ferrara, Parma and Viadana, followed by Carpi and Mirandola, although the epicentres of the two main shocks were located in the municipalities of Finale Emilia (first shock) and Medolla (second shock), both belonging to the LLMA of Mirandola. A few weeks after the earthquake, the reconstruction process began and safety interventions were carried out on public and private buildings, especially in historic centres. The rapid start of the reconstruction process may have helped speed up the recovery of the involved areas. The heat map for the last sample year (2018) shows indeed an improvement for most of the LLMAs, but for Mirandola, Parma and Viadana.

Finally, the negative employment effects of the 2016 earthquake in Central Italy seem to be concentrated on the LLMAs of Norcia, Comunanza and San Benedetto del Tronto (see Figure C5 in Appendix C online). In the last sample year (2018) there was a partial recovery in the most involved areas, but also a spatial diffusion of the negative effects in some initially unaffected LLMAs (such as Fabriano and Matelica).

4.4. The impact of earthquakes on sectoral employment shares

We extend the analysis by estimating the impact of earthquakes on the sectoral distribution of employment. The outcome variable here is the employment share of the following six sectors: manufacturing; construction; accommodation and food service activity; wholesale and retail trade; other private services; and public utilities.

Table 4 shows that the overall effect of the earthquakes is significantly negative for manufacturing and significantly positive for construction. These results are in line with Kirchberger (2017) and Belasen and Polachek (2008). In particular, Kirchberger (2017) shows that in the aftermath of an earthquake there is a reallocation of

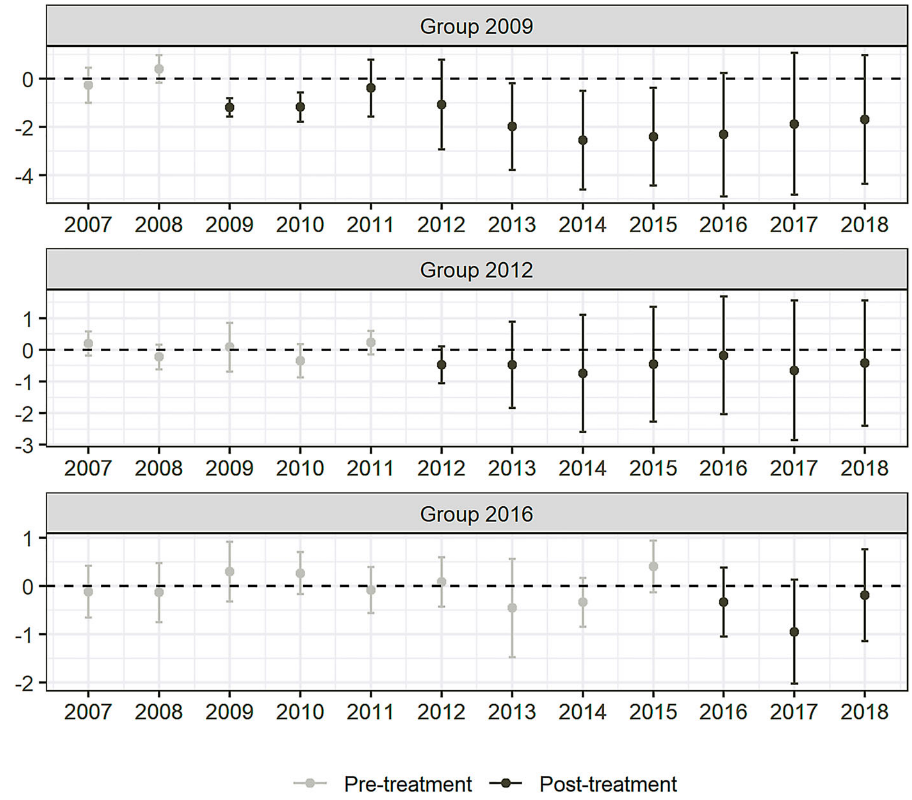

Figure 1. Effect of earthquakes on the employment rate.
Note: The effects of earthquakes are estimated under the conditional parallel trends assumption. Light grey lines give point estimates and uniform 95% confidence bands for pre-treatment periods ($g > t$) allowing for clustering at the local labour market area (LLMA) level. Under the null hypothesis of the conditional parallel trends assumption holding in all periods, these should be equal to zero. Dark grey lines provide point estimates and uniform 95% confidence bands for the treatment effect of earthquakes (for the post-treatment periods $g \leq t$) allowing for clustering at the LLMA level. The top panel includes LLMAs of the Abruzzo region that were involved in the 2009 earthquake, the middle panel includes LLMAs involved in the 2012 earthquake, and the bottom panel includes LLMAs involved in the 2016 earthquake in Italy. No LLMAs experienced earthquakes in other years before 2009.

employment and wage premia between sectors producing tradable and non-tradable goods. Indeed, an unpredictable natural disaster, which destroys capital assets and infrastructure, causes an increase in the demand for construction. By analysing the effects of hurricanes on the sectoral composition of the labour market in Florida's counties, Belasen and Polachek (2008) find similar results.

However, aggregate results hide a remarkable heterogeneity in treatment effects between different groups of treated in different time periods (Table 4 and Figures 2 and 3) (see also Appendix D in the supplemental data online). In particular, a significantly negative impact of the earthquake on the manufacturing industry's employment share (−1.3%) emerges for the group of LLMAs hit by the 2009 earthquake in L'Aquila and for those hit by the earthquake in 2012. On the other hand, a strong and significant positive effect of the earthquake on the employment share of the construction sector is observable only for LLMAs belonging to the 2009 and 2012 treatment groups, while a negative and significant impact emerges on the employment share of accommodation services for the groups of LLMAs affected by the 2009 earthquake. Finally, there is no evidence of significant effects on the other three sectors under analysis.

5. DISCUSSION AND CONCLUSIONS

In this paper, we evaluated the causal effects of the three major earthquakes that hit Italy over the past 15 years (L'Aquila in 2009, Emilia-Romagna in 2012 and Central Italy in 2016) on local labour market outcomes. Evidence obtained through the application of a new DID approach suggests a sizeable heterogeneity in treatment effects between the three groups of LLMAs over different time periods. With this paper we contributed to the ongoing literature by exploring the reasons for this heterogeneity among different earthquakes, which are only apparently very similar. Specifically, we found that the average effect of earthquakes on the aggregate employment rate appears significantly negative over the entire time span only for the LLMAs hit by the 2009 earthquake. This result can be explained by the intensity of the earthquake (measured by the Mw and Mercalli Scale), as well as by the geological structure and employment density of the involved areas.

Table 4. Estimates of the average treatment effects of earthquakes.

	Manufacturing	Construction	Accommodation
Weighted average of group–time ATT	−1.320*	1.025*	−0.162
	(0.393)	(0.456)	(0.145)
Weighted average of group-specific effects	−1.011	0.789*	−0.181
	(0.325)	(0.257)	(0.112)
Group-specific effect, 2009	−1.701*	1.831*	−0.517*
	(0.739)	(0.905)	(0.232)
Group-specific effect, 2012	−1.370*	0.537*	0.227
	(0.608)	(0.298)	(0.173)
Group-specific effect, 2016	−0.402	0.503	−0.351
	(0.380)	(0.340)	(0.213)
P-value pre-test DID assumption	0.107	0.081	0.075
	Trade	**Other private services**	**Public utilities**
Weighted average of group–time ATT	−0.038	0.278	0.029
	(0.252)	(0.251)	(0.062)
Weighted average of group-specific effects	−0.060	0.275	0.073
	(0.177)	(0.228)	(0.083)
Group-specific effect, 2009	−0.323	0.108	0.013
	(0.546)	(0.415)	(0.148)
Group-specific effect, 2012	0.282	0.491	−0.015
	(0.218)	(0.387)	(0.039)
Group-specific effect, 2016	−0.210	0.165	0.171
	(0.281)	(0.402)	(0.194)
P-value pre-test DID assumption	0.175	0.112	0.242

Note: See the note to Table 3. Results are by sector.

In fact, as discussed, only the area affected by the 2009 earthquake was simultaneously characterised by a high intensity of the event, a high-propensity seismic waves propagation (given its mountainous nature) and a high employment density. The 2016 earthquake was also devastating, but the LLMAs affected have a much lower employment density. On the other hand, the 2012 event was much less intense than the other two.

The dynamics over time of the estimated effect of the 2009 event on the aggregate employment rate are also very interesting. The negative impact appeared indeed not only in the immediate post-event period, but also over the subsequent years, suggesting a strong persistence of the effect over time, although there was also an increasing heterogeneity of the treatment effect among the LLMAs belonging to the affected area. The negative impact in the aftermath of the event can be attributed to the initial effects of the earthquake on labour demand and supply. Its persistence can be explained by the complex multiplier mechanisms driving the space–time propagation of the shock.

Another important argument to explain the heterogeneous effect of natural disasters, suggested by the previous literature (Kirchberger, 2017; Trezzi & Porcelli, 2014), is the generation of a sectoral shift in employment, following an earthquake, with job destruction in tradable sectors and job creation in non-tradable sectors, mainly due to reconstruction activities. However, job losses in manufacturing or other tradable sectors are not always offset by job creation in the construction sector. This seems to be the case in the L'Aquila earthquake, where increased employment in the construction sector has only partially offset job reductions in other sectors (especially in manufacturing).

These sectoral results help understand the heterogeneous impact of the three earthquakes on the employment rate. Indeed, while in the case of Emilia-Romagna the positive effect of the reconstruction on labour demand counterbalanced the negative impact of the earthquake on other sectors, this compensation mechanism did not occur in the case of L'Aquila, where we observe a more severe negative impact on manufacturing employment. Furthermore, in Emilia-Romagna industrial buildings were restored immediately after the 2012 event, a reaction that mitigated the employment effect of the earthquake. On the other hand, the lack of a significant impact on manufacturing employment in Central Italy can be explained by the fact that most of its industrial activities are located far from the 2016 seismic zone (Dottori & Micucci, 2019).

An important role in the explanation of the heterogeneity of the three seismic events is also played by public

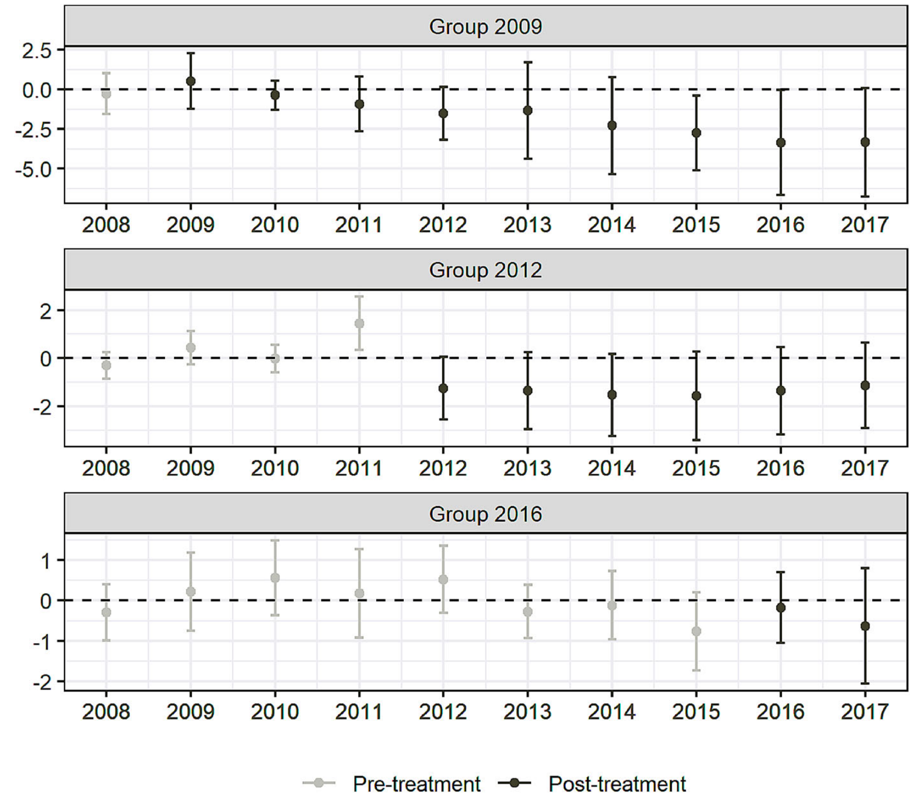

Figure 2. Effect of earthquakes on manufacturing employment.
Note: See the note to Figure 1.

expenditure for the reconstruction. As we have seen, substantial amounts of public grants have been used by the Italian government to help the recovery process of the areas affected by the three earthquakes. However, the impact of this aid has been very different across the three disasters. In particular, the recovery process appears to have been faster for the areas affected by the 2012 earthquake. We can explain this by considering mainly two factors: the different extent of the damage caused by the three events; and the level of efficiency of local authorities in the management of public funds, which is related to the different quality of the institutional setting, as discussed by Barone and Mocetti (2014).

Finally, all the arguments mentioned above can help explain why the effect we find for the group of LLMAs hit by the 2009 earthquake in L'Aquila is not only significant but also persistent. A very important difference with the other two events is that the epicentre of the 2009 earthquake was very close to the city of L'Aquila, the capital of the Abruzzo region, an area characterised by many economic activities. In particular, in the city of L'Aquila there were numerous wholesale and retail trade activities, a large number of small firms linked to the construction sector, and some important production plants in the pharmaceutical and ICT sectors. Therefore, the economic damage of the 2009 event was greater than the other two earthquakes (see section 2 and Appendix A in the supplemental data online for more details). Moreover, while the reconstruction process in the LLMA of L'Aquila has been managed by both national and local institutions, causing many delays in its completion, in the case of Emilia-Romagna the process was managed directly and more quickly by local institutions.

The policy implications of our analysis can be drawn straightforwardly by these sectoral findings and challenge the widespread idea that natural disasters can exert a positive influence on the long-run growth path of production and employment through the effects of reconstruction activities and the processes of 'Creative destruction' they can activate (Leiter et al., 2009). On the one hand, our results for the 2012 Emilia-Romagna earthquake seem to confirm the possibility that the direct and indirect upshots of the reconstruction activities offset the negative impact of the earthquake, so much so that its overall effect on the employment rate is estimated as not significant. On the other, the case of the 2009 L'Aquila earthquake clearly shows that policymakers should not rely too much on these counterbalancing effects. If local economies are characterised by structural weaknesses, including the poor quality of their institutions and exogenous disadvantages (location in inner areas), a destructive earthquake hitting an urban system with a high density of employment, such as that of L'Aquila in 2009, can have a significant and persistent adverse effect on local rates of employment. In these cases, the benefits of public expenditure for reconstruction may not be sufficient to compensate for the darkening of local growth and investment prospects, which can activate a vicious circle of decreasing labour demand and supply and generate a 'development trap' (Hallegate & Dumas, 2009; Loayza et al., 2012). In similar situations, policies

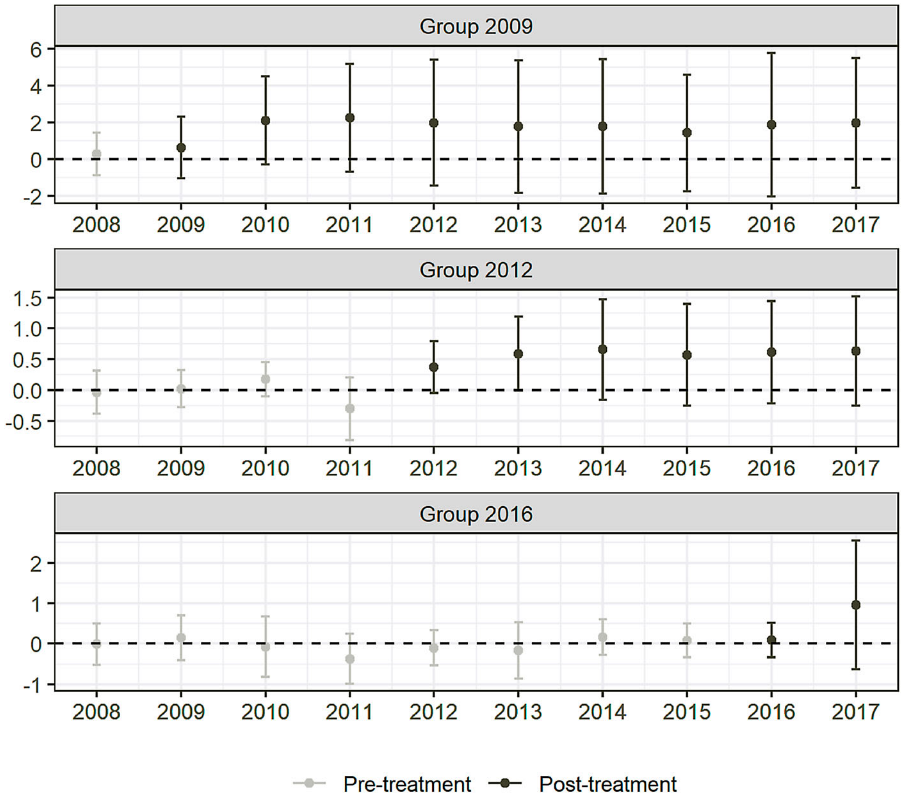

Figure 3. Effect of earthquakes on construction employment.
Note: See the Note to Figure 1.

aimed at improving the long-term prospects of the area under reconstruction should be seriously targeted at facilitating structural change and promoting good quality employment opportunities, so as to attract investment and human resources from other regions and reduce the incentive to migrate for the local population. This is much more important than offering short-term financial support to all firms hit by the earthquake. Priority should be rigorously given to business plans that are bound to precise and verifiable employment targets, especially in manufacturing. Otherwise, when the relief from reconstruction expenditures runs out, the region may suddenly realise that it has entered a long-term path of impoverishment.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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NOTES

1. To compute this indicator, we consider only the municipalities with significant damage and, therefore, with a Mercalli value above grade VI.
2. A thorough description of the socio-demographic and economic characteristics of the LLMAs in Italy is reported in Appendix B in the supplemental data online.
3. In some cases, such as floods or drought, natural disasters are not completely exogenous events. However, the exogeneity of the treatment can be easily assumed in the case of earthquakes, as also discussed by Porcelli and Trezzi (2019) and Mendoza et al. (2020).
4. All estimates are performed using the doubly robust approach developed by Sant'Anna and Zhao (2020) and available in the *R* package *DRDID*.
5. Five categories are considered based on the level of labour cost (€, thousands): (1) up to 24.2 (*LC*1); (2) between 24.2 and 31.2 (*LC*2); (3) between 31.2 and 34.6 (*LC*3); (4) between 34.6 and 38.1 (*LC*4); and (5) more than 38.1 (*LC*5).
6. Four categories are identified based on the quartile distribution of the ratio between imports plus exports (€, thousands) and the number of employees: (1) up to 2.3 (*Q*1), (2) between 2.4 and 10.3 (*Q*2), (3) between 10.4 and 31.6 (*Q*3), and between 31.7 and 40.1 (*Q*4).
7. Spatial lags are computed using a row-standardised symmetric binary weights matrix based on the cut-off distance of 41 km, which is the minimum distance ensuring that each location has at least one neighbour. In other

words, each element of the matrix takes the value of 1 if the great circle distance between LLMA i and j is less than the minimum cut-off distance of 41 km, 0 otherwise.
8. Callaway and Sant'Anna (2021) suggest choosing the 'never treated' option with respect to the 'not yet treated' one when there is a sizeable group of units that do not participate in the treatment in any period. We have also checked the robustness of the results compared with the alternative choice. The results do not change at all.
9. We used a restricted official definition of the LLMAs involved in these events. In the case of the 2009 earthquake, this definition excludes coastal areas, which were included in another enlarged official definition of the area hit by the L'Aquila quake. Our decision was based on the observation that municipalities and LLMAs in coastal Abruzzo were actually much less directly involved in the event and worked as reception areas for people displaced in the immediate aftermath of the quake.
10. The 2016 treatment group does not include the three LLMAs located in Abruzzo (L'Aquila, Penne and Teramo) which were hit by the 2016 earthquake, as they had been previously hit by the 2009 earthquake and have been included in the 2009 group.
11. As discussed above, our results are based on the conditional parallel trends assumption. In other words, we assume that, in the absence of treatment, only LLMAs with the same characteristics would follow the same trend in the outcome variable. This conditioning scheme is extremely important to us because the economic structure of LLMAs hit by the earthquake is different from those that are not, and because the paths of employment rates (absent the earthquake) are affected by the economic structure of each LLMA.

ORCID

Roberto Basile http://orcid.org/0000-0002-4531-2820
Luisa Giallonardo http://orcid.org/0000-0003-0759-1045
Pasquale Lelio Iapadre http://orcid.org/0000-0002-0690-1067
Maria Gabriela Ladu http://orcid.org/0000-0003-1339-9578
Riccardo Persio http://orcid.org/0000-0003-0966-7779

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