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DEMOGRAPHIC EFFECTS OF EARTHQUAKES IN CENTER-SOUTH ITALY

ROBERTO BASILE, FRANCESCA CENTOFANTI, GIOVANNA CIAFFI, FRANCESCA LICARI

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Roberto Basile
Full Professor of Economics
Department of Legal and Economic Studies
Sapienza University of Rome
roberto.basile@uniroma1.it

Francesca Centofanti
University of Rome Tor Vergata
francesca.centofanti@students.uniroma2.eu

Giovanna Ciaffi
University of Bari Aldo Moro
ciaffigiovanna@gmail.com

Francesca Licari
Italian National Institute of Statistics
francesca.licari@istat.it

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Demographic effects of earthquakes in Center-South Italy

Roberto Basile* Francesca Centofanti† Giovanna Ciaffi‡ Francesca Licari§

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Abstract

This paper evaluates the demographic effects of two major earthquakes - L'Aquila 2009 and Central Italy 2016 - in Central-Southern Italy, a wide area already experiencing depopulation due to factors unrelated to natural disasters. Using municipality-level data (2002-2023) and a difference-in-differences design with multiple groups and periods, we estimate causal impacts on depopulation, age structure, natural dynamics, and migration. Results suggest an acceleration of the decline in the overall population of the area due to these natural disasters, especially among elder Italians, largely driven by out-migration, while natural demographic dynamics remained stable. Effects differ across disasters: the 2016 earthquake caused declines in all age groups, whereas in 2009 population losses among elderly Italians were offset by gains in working-age foreigners.

Keywords: Natural disasters, Demography, Counterfactual analysis, Italy
JEL Codes: J11, Q54, R10

*University of Rome La Sapienza. Email: roberto.basile@uniroma1.it
†University of Rome Tor Vergata. Email: francesca.centofanti@students.uniroma2.eu
‡University of Bari Aldo Moro. Email: ciaffigiovanna@gmail.com
§ISTAT and University of Rome La Sapienza. Email: licari@istat.it

1 Introduction

Natural disasters invariably impact human life, abruptly altering its social and economic landscape and necessitating prompt responses to emergent crises. Various factors, including the nature and severity of the disaster and socio-economic and cultural considerations, can influence the demographic shifts in affected populations. Affected regions typically experience population decline due to natural and migratory factors, although the literature shows some heterogeneity in observed cases (Gráda, 2019; Mahajan and Yang, 2020). The demography-disaster nexus is becoming increasingly important as efforts to develop structural disaster prevention and mitigation plans intensify in parallel with the increasing frequency of extreme events (Coleman, 2006; Eshghi and Larson, 2008; Okuyama and Sahin, 2009). The demographic composition of the affected regions at the time of the disaster plays a crucial role in determining who is affected and the extent of the impact on residents and others. Disasters can accelerate pre-existing demographic changes or create new population profiles through immediate impacts and human reactions to such events (Karácsonyi et al., 2021). The most apparent demographic impacts are deaths and injuries, out-migration, and temporary relocation of residents and others from affected areas, which rapidly and noticeably alter the pre-existing demographic profile of a city or region. The most vulnerable cohorts (such as the elderly) are often disproportionately affected. Disasters may also encourage populations not immediately affected by the event to change their demographic behaviors, such as fertility or migration. Additionally, it is essential to account for the differing impacts on urban and rural areas. Reconstruction efforts often attract workers to rural areas, where lower living costs and affordable housing can influence settlement patterns (Arefian, 2018; Fabling et al., 2023).

This study focuses on earthquakes, wholly natural and unpredictable phenomena. In particular, the reference events are the Italian earthquakes that hit L'Aquila and surrounding municipalities in 2009 and Central Italy in 2016. Overall, these two events involved 182 municipalities, 708,888 inhabitants, and covering 9,749 km^2. This wide area of the Center-South Italy was already experiencing depopulation due to factors unrelated to natural disasters. Therefore, it is particularly challenging to assess the additional contribution of earthquakes on population dynamics. Specifically, using municipality-level annual data from 2002 to 2023 and employing a difference-in-difference approach with multiple periods and groups developed by Callaway and Sant'Anna (2021), we analyze the causal effects of these events on local demographic dynamics, with particular focus on depopulation, changes in age structure, natural demographic dynamics, and migration for both Italian and foreign citizens. Identification relies on defining treatment groups by shock year (2009 or 2016) and using "never-treated" or "not-yet-treated" units as controls. The outcome variables include resident population, share of elder people, net migration balance, natural demographic balance, and disaggregated migration flows by citizenship (Italian vs. foreign), distance (internal vs. international), and age group. Results suggest an acceleration of the decline in the overall population of the area due to these natural disasters, especially among elder Italians, largely driven by out-migration, while natural dynamics remained stable. Effects differ across disasters: the 2016 earthquake caused declines in all age groups, whereas in 2009 population losses among elderly Italians were offset by gains in working-age foreigners.

The paper provides a twofold contribution. First, it contributes methodologically to the international literature on the socio-economic and demographic impacts of natural disasters. We adopt a multi-treatment, multi-period difference-in-differences (DiD) approach (Callaway and Sant'Anna, 2021) which overcomes the well-known biases of traditional two-way fixed effects (TWFE) estimators in staggered designs (Baker et al., 2022). In our specific case, where the events considered are only two, it is particularly important to highlight both the average and the heterogeneous effects at the event level. Indeed, the average effect of the two earthquakes (2009 in L'Aquila and 2016 in Central Italy) could not have been correctly estimated using a traditional TWFE model, as already-treated units (i.e., municipalities already affected by the earthquake in 2009) act as controls for the municipalities "treated" in 2016. Thus, this approach enables the estimation of both heterogeneous and average effects across multiple events, providing more credible and generalizable evidence than single-event analyses. Although applied to Italy, the framework is fully replicable in other contexts and for different types of natural disasters — such as floods or hurricanes — offering a robust and transferable tool for causal evaluation. While the demographic effects studied here are inevitably country- and place-specific, the methodological contribution is general. Together with (Basile et al., 2024a) and (Basile et al., 2024b), this paper is among the first to implement a consistent and unbiased multi-event design when treatment timing varies across groups, providing a replicable framework for studying the cumulative and heterogeneous effects of repeated shocks.

Second, this study advances the literature on the demographic effects of earthquakes in Italy by bridging and extending Basile et al. (2024a) and Dottori (2024).[1] While Basile et al. (2024a) examined migration responses to multiple seismic shocks and Dottori (2024) focused on depopulation and aging after the 2016 event, our study integrates these approaches to analyze both population change and its underlying mechanisms. Compared to Basile et al. (2024a) this study offers a broader interpretative scope: it integrates migration flow analysis with the study of natural demographic balance and age structure, and highlights substitution effects between elder Italians and younger foreign workers. Furthermore, it explicitly adopts the Dottori (2024) control group construction, improving the empirical design over previous work. In this sense, the paper represents a successful attempt to synthesise two parallel research lines—the demographic focus of Dottori (2024) and the migration-centered approach of Basile et al. (2024a) —reworking them into a single coherent analytical framework. Overall, by jointly examining population losses, natural demographic balance, and migration flows, the paper provides a broader understanding of how seismic shocks reshape local population structures and generate persistent demographic transformations.

All in all, since the two events occurred in close temporal and spatial proximity, it becomes

[1]Italy is highly earthquake-prone, and several major events could be analyzed. Some, such as the 1980 Irpinia earthquake, are comparable in magnitude to the two considered here; others, such as the 2012 Emilia earthquake, occurred in a similar period. We focused on these two events based on: (a) spatial contiguity, ensuring a homogeneous low-density area with pre-existing depopulation unrelated to seismic shocks (thus excluding Emilia); and (b) temporal contiguity, allowing comparable initial conditions for propensity score estimation (thus excluding Irpinia). The Irpinia case was also excluded from the counterfactual analysis due to limitations in the measurement of the outcome variables. Specifically, the quality and consistency of statistical data on migration flows at the municipal level for the period surrounding 1980 are not comparable with those available for the time frames examined in this study. Consequently, including this event would have introduced substantial measurement heterogeneity and compromised the reliability of the comparative analysis.

essential to assess their combined impact through an analysis that is robust to the bias induced by staggered treatment adoption. While Dottori (2024)'s article provides a comprehensive examination of the 2016 earthquake, it does not account for the potential influence of the L'Aquila earthquake on the population dynamics of the broader area affected by both natural disasters. In our analysis we try to fill this gap.

The paper is organized as follows. Section 2 provides a literature review. Section 3 describes the two earthquakes and their aftermath. Section 4 presents the population data used for the analysis, while Section 5 describes the adopted methodology. Section 6 presents the main findings of the DID analysis. Finally, Section 7 concludes.

2 Literature Review

Compared to other sudden natural events, earthquakes generally have a broader impact on population dynamics (Hornbeck and Keniston, 2017; Siodla, 2021). For example, Schultz and Elliott (2013), in their study of demographic changes in US counties affected by natural disasters other than earthquakes (e.g., hurricanes, tornadoes, and floods), observed a positive correlation with population growth. Here we focus on reviewing the literature on the causal effects of earthquakes on resident populations. duPont IV et al. (2015) and Xu and Wang (2019) analyzed the impact of the 1995 Hanshin-Awaji earthquake in Japan, focusing on Kobe City and a broader area, respectively. Kim and Lee (2023) studied the 2017 Pohang earthquake in South Korea. The results showed a lasting impact with partial recovery (duPont IV et al., 2015), no adverse effect except in peripheral locations (Xu and Wang, 2019), and a negative effect within two years (Kim and Lee, 2023). These studies suggest that rural, less populated areas endure longer, more intense consequences following earthquakes.

Overall, studies on earthquakes' effects on resident populations have typically examined highly urbanized cities or regions in developing countries (Ishikawa, 2019; Sogabe and Maki, 2022). There is limited evidence regarding peripheral towns and rural municipalities in Western countries, particularly in Europe. In Italy, Fantechi et al. (2020) found that the 1997 Umbria earthquake mitigated demographic decline, attributed to positive reconstruction efforts. Territories' resilience to shocks may vary based on pre-event conditions (Martin and Sunley, 2014; Borsekova and Nijkamp, 2019). The geographical and demographic characteristics of the affected area in L'Aquila province and Central Italy make this case particularly interesting to analyze.

Only recently have demographic issues been studied in quasi-experimental settings. Research into the causal effects on population dynamics has primarily focused on international emigration (Fabling et al., 2023; Mahajan and Yang, 2020), which represents just one aspect of population changes. This study examines the impact on total resident population and key components of population dynamics (natural balance and migration) (Schultz and Elliott, 2013).

The literature identifies several conflicting mechanisms through which natural disasters affect migration (Spitzer et al., 2020). While the most straightforward mechanism involves increased push factors, such as the destruction of capital and infrastructure leading to labor displacement, natural disasters often do not necessarily induce outmigration. This has given rise to concepts such as 'trapped populations' (Nawrotzki and DeWaard, 2018) and an 'immobility paradox' (Beine et al., 2021), where impoverished populations may desire to migrate but are constrained by liquidity issues exacerbated by the disaster. Another potential mechanism that may counteract the push effect is the increase in local labor demand due to reconstruction efforts following a disaster, which could result in immigration rather than outmigration (Halliday, 2006; Spitzer et al., 2020). More generally, the evidence regarding the relationship between natural disasters and migration yields mixed results. While specific studies have indicated a rise in emigration flows following natural disasters, others have concluded that these events have no discernible effect on regular demographic trends. Additionally, the impacs vary by disaster type and region characteristics (Mbaye and Zimmermann, 2015).

Empirical research on natural disasters' impacts varies across macro/micro perspectives, migration types, and methodologies. Much of the literature relies on descriptive analyses of survey and census data, with a predominant emphasis on individual-level studies and comparatively fewer conducted at the household level (Berlemann and Steinhardt, 2017).

Finally, since our study focuses on the two major earthquakes in Italy, it is particularly relevant to examine previous research investigating the impact of earthquakes on migration in Italy. Recent studies on Italy reveal unique migration dynamics involving repeat and temporary migrants (Spitzer and Zimran, 2018; Bohra-Mishra et al., 2014). Additionally, disparities in migration determinants between Italian natives and foreign citizens are evident: while natives tend to gravitate towards densely populated regions, foreign citizens exhibit more diverse migration patterns. Nevertheless, both groups seem equally disinclined to engage in long-distance migrations (Lamonica and Zagaglia, 2013). All these insights are valuable for comprehending migration dynamics in response to natural disasters in Italy.

Spitzer et al. (2020) analyzed the Messina-Reggio Calabria earthquake of 1908, finding no significant impact on international migration. Ambrosetti and Petrillo (2016) studied L'Aquila (2009), finding that the earthquake significantly affected migration patterns and increased mobility within Abruzzo's provinces. Miccoli et al. (2023) noted that pre-existing vulnerabilities shaped population trends post-earthquake. Basile et al. (2024a) analyze the effects of the L'Aquila (2009), Emilia Romagna (2012), and Central Italy (2016) earthquakes. They utilize municipality-level data from 2002 to 2019 and employ a novel difference-in-difference approach with multiple periods and groups to explore how these events influenced internal and international migration patterns among Italian and foreign citizens. Their findings do not indicate a direct connection between these seismic events and Italian citizens' internal or international migration. Instead, they only observe evidence of the impact of the L'Aquila earthquake on the short-distance migration of foreign citizens. These observed movements align with the economic disruptions and opportunities created by natural disasters. Basile et al. (2024b) demonstrate how earthquakes can reshape local employment dynamics, particularly through reconstruction efforts, which generate labor demand and attract workers to affected areas. Dottori (2024) analyzes the effects on the resident population in the 2016 Central Italy earthquake by leveraging data at the municipality level and a diff-in-diff event-study model. His findings reveal that the event exacerbated ongoing demographic decline in affected areas. Municipalities that suffered the most damage experienced a more pronounced population decrease. Additionally, an increase in the proportion of elderly residents was observed. Furthermore, the author highlights that a deterioration in net internal migration patterns primarily drove the overall impact.

This paper builds on these works by addressing broader and less explored demographic outcomes. Specifically, it investigates depopulation, changes in age structure, and detailed migration flows across multiple citizenship categories and age cohorts, highlighting previously unstudied aspects of replacement effects and differential impacts across urban and rural settings. Moreover, by adopting a difference-in-differences framework tailored for multi-treatment and multi-period contexts, the analysis captures the temporal evolution of earthquake impacts with greater accuracy than prior studies reliant on traditional methods.

Given our focus on the population dynamics repercussions of the earthquakes in L'Aquila (2009) and Central Italy (2016), the subsequent section will describe these seismic events, focusing on their magnitude and the affected populations' characteristics.

3 Events description

The two major earthquakes that struck Central-Southern Italy in 2009 (L'Aquila) and 2016 (Central Italy) affected a vast area of the national territory. Taken together, the municipalities included in the two official seismic zones cover between about 9,700 and 13,000 km^2, depending on the definition adopted for the 2009 event.[2] Altogether, this area accounts for roughly one quarter of the combined surface of the four affected regions (Abruzzo, Lazio, Marche, and Umbria), and around 4% of the national territory. The total number of municipalities involved ranges from 172 to 277, depending again on the definition of the L'Aquila crater. Among these, 22 municipalities were hit by both earthquakes and are therefore counted only once in the overall total. In relative terms, roughly 25% of municipalities in the four regions were affected (corresponding to about 3% of all Italian municipalities). The resident population exposed to the earthquakes is estimated between about 0.7 and 1.3 million inhabitants—that is, nearly one in ten residents of the four regions (or about 2% of the national population).

This wide area is characterized by common features: relatively low population density, a higher-than-average share of elderly residents, and a pre-existing trend of demographic decline, which made it particularly vulnerable to the additional shocks caused by natural disasters. Despite these shared characteristics, the two earthquakes also differed in their timing, magnitude, and socio-demographic consequences. In the following subsections, we provide a concise overview of each event, focusing on their immediate impacts and the reconstruction processes.

3.1 The earthquake in L'Aquila: 2009

On April 6, 2009, a seismic event with a magnitude of 6.3 on the Richter scale struck L'Aquila, resulting in 309 fatalities and over 1,500 injuries, marking one of the most devastating events in recent years for Central Italy. The destructive impact was rated between 8 and 9 on the Mercalli scale, with about 2.5 million square meters of damaged area attributed exclusively to private buildings, accounting for 48% of the total housing stock.

There were more than 65,000 displaced people, nearly 90% of whom reside in L'Aquila. The displaced residents have been housed in durable housing units under the CASE Plan (Sus-

[2] The range reflects the two official perimeters of the L'Aquila earthquake zone—restricted and enlarged—defined by national legislation, as discussed in the following subsection.

tainable and Environmentally Friendly Anti-seismic Complexes) or in lightweight temporary structures known as Temporary Housing Modules (MAPs) (see Ambrosetti and Petrillo, 2016, for more details). Notably, these structures, located mainly in peripheral regions, have inevitably contributed to social fragmentation (Contreras et al., 2017), particularly in rural areas already affected by depopulation and aging.

In the Local Labor Market Area (LLMA) of L'Aquila, the resident population, which had shown growth between 2006 and 2009, experienced a sudden decline in the aftermath of the earthquake. Although there was a recovery phase, population dynamics weakened again starting in 2015, a trend that mirrors that of the region in general, albeit with a slightly more pronounced cumulative decline observed in the L'Aquila area (Banca d'Italia, 2019).

Decree of the Delegated Commissioner No. 3, dated April 16, 2009, and the subsequent Decree No. 11, dated July 17, 2009, identified 57 municipalities of the Abruzzo region (including the municipality of L'Aquila and other 41 municipalities in the province of L'Aquila, 8 municipalities in the province of Teramo, and 7 in the province of Pescara) that recorded an intensity equal to or greater than the sixth degree on the Richter scale (see the *restricted earthquake zone* highlighted in dark gray in Figure 1). This area covers 2.387 km^2, corresponding to 22% of the total area of the Abruzzo region. Subsequent legislative measures, including Law Decree No. 39 dated April 28, 2009, extended this designation to an additional 105 municipalities that reported earthquake-related damage (see the *enlarged earthquake zone* in Figure 1). This broader area covers 6,541 km^2, corresponding to 60.6% of the Abruzzo region.

– Insert Figures 1 about here –

Post-earthquake reconstruction management required an investment of nearly 17.5 billion euros, mainly for real estate and the revitalization of production activities[3].

Despite the heterogeneity, especially among municipalities of very small population size surrounding the urban area, reconstruction is nearing completion in the peripheral areas of L'Aquila, while the restoration of many buildings in the city center, constrained by historical and artistic considerations, is progressing more slowly.

3.2 The earthquake in Central Italy: 2016

The 2016 earthquake included multiple events known as the "Amatrice-Norcia-Visso seismic sequence", as defined by the National Institute of Geophysics and Volcanology (INGV). The initial strong tremor struck on August 24, 2016, registering a magnitude of 6.0 on the Richter scale, with epicenter in the Valle del Tronto, between the municipalities of Accumoli (RI) and Arquata del Tronto (AP). This earthquake killed 299 people and injured 388. Significant earthquakes occurred on October 26 and 30, with epicenters in Castelsantangelo sul Nera (magnitude 5.9) and Norcia (magnitude 6.5), respectively. These later quakes did not cause any fatalities, partly because of the low population density of the the region, characterized by agricultural and tourist

[3] Detailed information on allocated and disbursed funds, as well as the status of reconstruction projects, both completed and ongoing, are publicly available on the "Open Data Reconstruction" website. This initiative by the Gran Sasso Science Institute aims to compile statistics related to the reconstruction efforts in L'Aquila and other municipalities within the earthquake-affected area.

activities. Civil Protection data shows that nearly 17,000 people had already been displaced after the August quake.

The earthquake zone, as defined by Law no. 229 of Dec. 15, 2016, covers about 8,000 km^2, corresponding to 17.4% of the total area of the four affected Central Italian regions: Abruzzo, Umbria, Marche, and Lazio (Figure 1). Half of this area is in the Marche region and comprises over 40% of the regional territory. This region is less densely populated and has a higher share of elderly residents, making long-term relocation of residential settlements unnecessary, except for the duration of recovery efforts. In the Marche earthquake zone, 26% of the 190,000 homes (according to the 2011 census) were either vacant or occupied by non-residents, slightly above the national average (Banca d'Italia, 2017).

The characteristics of the 137 municipalities involved in the earthquake zone are similar to those impacted by the L'Aquila earthquake; considering the restricted definition of the L'Aquila earthquake, 12 municipalities were affected by both events (see the area highlighted in light gray in Figure 1).

The 2017 budget law allocated 7.1 billion euros to support reconstruction, with 85% earmarked for private buildings. In addition, Decree Law No. 189/2016 introduced measures to support businesses and the income of affected populations. Additional measures at the beginning of 2017 (Decree Law No. 8 of Feb. 9, 2017 and Decree Law No. 50 of April 2017) aimed to accelerate economic recovery for businesses in the tourism, agritourism, trade and crafts sectors, as well as for public enterprises that had suffered a reduction in turnover of at least 30% in the six months following the earthquake.

Reconstruction efforts have been particularly complex given the extent of the affected area and the varying conditions of pre-existing structures and their damage. Despite recent progress, eight years later, reconstruction remains incomplete and uneven across the region, making it difficult to collect data to assess the overall progress of the reconstruction process.

4 Data

The spatial unit of the analysis is the municipality and the sample period is from 2002 to 2023. Data on the resident population at the municipality level are as of January 1st of each year and are available by gender and age. From 2002 to 2018, they were taken from the post-censal population revision (Istat, 2021a), a database that provides information on annual births, deaths, and (reconstructed) migration flows. The reconstruction is based on the availability of census information (2001, 2011, and 2018 Population Censuses) and from demographic flows (births, deaths, migrations, acquisitions of citizenship) recorded between censuses. This source also provides reconstructed municipal demographic budgets for each year from 2002 to 2018, measuring the demographic movement (such as births, deaths, immigration, and emigration, both internal and international). One of the main advantages of the post-censal population revision is the consistency of administrative boundaries for the entire reporting period, based on the Istat classification in force in 2019. Data on the municipal resident population for the most recent years (2019 to 2023) are publicly available from the I.Stat portal. These data consider the results of the Permanent Population Census for the period in which they are available. For the entire sample period (2002-2023), we replaced the reconstructed data on internal and international migration flows for all earthquake-affected municipalities (the treated units) and other municipalities in the country with those provided by the Istat Population Register Database. Information on the geomorphological characteristics of municipalities (coastline, elevation zone, altitude of the capital center, land area in km2, degree of urbanization, and coastal areas) is also provided by Istat (2021b).

5 Methodology

This study employs the methodological framework introduced in Callaway and Sant'Anna (2021), which has been successfully applied in previous analyses (i.e., Basile et al., 2024a). To ensure clarity for the reader and contextualize the improvements made in this paper, we provide a summary of this approach, while emphasizing the novel aspects of its application to the current research question.

The methodology is based on the Difference-in-Differences (DID) framework, which is widely used for estimating causal effects. Traditional DID models rely on a *two-way fixed-effects* (TWFE) estimator, which assumes parallel trends between treated and control groups over time, and allows to estimate the Average Treatment effect on the Treated (ATT). However, in cases of *staggered adoption* like the one considered in our analysis (two groups of municipalities are treated, i.e. are affected by an earthquake, in two different periods), this approach can lead to biased estimates of the ATT. More precisely, with multiple groups, the estimated parameter of the TWFE model capturing the ATT represents 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 periods, as in our case, some of the 2×2 estimates enter the average with negative weights. This occurs because already-treated units (i.e., municipalities already affected by an earthquake) act as controls at different times, and changes in a portion of their treatment effect over time are subtracted from the DID estimates. Consequently, this can lead to biased estimates of the ATT when using the TWFE approach.

In this paper, we adopt the improved DID framework developed by Callaway and Sant'Anna (2021), which resolves these biases by calculating *group-time average treatment effects*, a measure capturing the impact of each of the two earthquakes for each year after the shock. This approach allows for heterogeneous effects across groups and time periods, offering a more nuanced analysis of demographic changes following the 2009 and 2016 earthquakes.

Following Callaway and Sant'Anna (2021), we define G as the period when a municipality is first exposed to treatment, corresponding to the occurrence of an earthquake (in this study, 2009 and 2016). This variable also determines the group to which each municipality belongs. The average treatment effect on the treated (ATT) for municipalities in group g at time t can be expressed as:

$$ATT(g,t) = \mathbb{E}[Y_t(g) - Y_t(0) \mid G_g = 1], \tag{1}$$

where G_g is a binary variable equal to 1 for municipalities that experienced their first earthquake in period g, $Y_t(g)$ represents the potential outcome at time t if the earthquake occurred in g, and $Y_t(0)$ represents the untreated potential outcome at time t for municipalities unaffected by any earthquake during the observation period. Callaway and Sant'Anna (2021) provide a framework for identifying and estimating $ATT(g,t)$ under the assumption that parallel trends hold after accounting for time-invariant observed pre-treatment covariates (X). Specifically, the group-time ATT can be identified as:

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

where $p_g(X)$ is the generalized propensity score (GPS), C is a binary variable equal to 1 for municipalities that were never treated, Y_t is the observed outcome at time t, Y_{g-1} is the outcome in the pre-treatment period $g-1$, and $m_{g,t}(X) = \mathbb{E}[Y_t - Y_{g-1} \mid X, C = 1]$ represents the expected long-term difference in outcomes for the never-treated municipalities, given covariates X. The weights in the formula adjust for differences in pre-treatment characteristics between treated and control municipalities, emphasizing control observations most comparable to treated ones.

The estimation of $ATT(g,t)$ proceeds in two steps. First, nuisance functions, including the GPS ($p_g(X)$) and the outcome regression function ($m_{g,t}(X)$), are estimated for each group and time period. These fitted values are then substituted into the sample counterpart of the ATT equation to calculate group-time treatment effects. For inference, Callaway and Sant'Anna (2021) suggest using a multiplier bootstrap procedure to construct simultaneous confidence intervals.

The $ATT(g,t)$ estimates provide insights into how the impact of earthquakes varies across groups and time periods. Additionally, these estimates can be aggregated to evaluate broader treatment effects. A straightforward aggregation involves weighting $ATT(g,t)$ by group size:

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

where $k = \sum_{g\in\mathbb{G}}\sum_{t=2}^{T} 1\{g \leq t\} P(G = g \mid G \leq T)$. Unlike traditional two-way fixed effects models, this approach avoids issues related to negative weights.

Estimated $ATT(g,t)$ values can also be aggregated to highlight treatment effect heterogeneity concerning the length of exposure to the treatment, thereby avoiding the pitfalls associated with the dynamic TWFE specification (i.e. the same bias affecting the static TWFE in the case of staggered adoption):

$$\theta_{es}(e) = \sum_{g\in\mathbb{G}} \mathbf{1}\{g + e \leq t\} P(G = g \mid G + e \leq T) ATT(g, g + e) \tag{4}$$

This represents the average effect of participating in the treatment e time periods after its adoption across all groups that have ever participated in the treatment for exactly e time periods. We can also compute an overall treatment effect parameter by averaging $\theta_{es}(e)$ across all event times (i.e. all positive lengths of exposure):

$$\theta_e^O = \frac{1}{T-1}\sum_{e=0}^{T-2} \theta_{es}(e) \tag{5}$$

Another useful aggregate measure is the group-specific average treatment effect:

$$\theta_{sel}(g) = \frac{1}{T-g+1}\sum_{t=g}^{T} ATT(g,t), \tag{6}$$

which represents the average impact of an earthquake for municipalities in group g across all post-treatment periods. A final aggregate measure averages $\theta_{sel}(g)$ across groups:

$$\theta_{sel}^{O} = \sum_{g \in \mathbb{G}} \theta_{sel}(g) P(G = g \mid G \leq T), \tag{7}$$

which has the advantage of not putting more weight on groups that participate in the treatment for longer.

As treated groups, we consider for the L'Aquila Earthquake (2009) 57 municipalities (restricted version) and 162 municipalities (enlarged version), and for the Central Italy earthquake 138 municipalities (identified by Laws 229/2016 and 45/2017). We select the control group following Dottori (2024). Specifically, we exclude municipalities classified as "coastal mountain", "inter-municipal poles", "ultra-peripheral areas", "flat land", "littoral", "island", "coastal" or otherwise with an elevation of fewer than 150 meters, since none of the municipalities affected by the two earthquakes fall into these classes municipalities with a density of more than 700 inhabitants per square kilometer (higher than the maximum detected for the treated municipalities). Additionally, always in line with Dottori (2024), we exclude municipalities not officially affected by the earthquake but belonging to the provinces of those affected. On the one hand, these municipalities may have suffered the direct effects of the earthquakes despite not being mentioned in the regulatory provisions that established the earthquake zone. On the other hand, again, these municipalities may be the destination of a substantial part of the population displaced from the earthquake zone for reasons of proximity. Although these two cases do not impact the direction of the estimates, both suggest excluding these municipalities from the control group because they might be partly treated.

6 Results and discussion

6.1 The impact on population

Table 1 reports the estimated average effects of the two earthquakes on the (log of) total population and on the (log of) population by age cohort. The first row presents the average treatment effects on the treated (ATT) estimated using the traditional two-way fixed effects (TWFE) specification without control variables. The coefficients are statistically significant at the 1% level and indicate a strong negative average impact on total population (around –5%) and across different age cohorts (up to –10% for the elderly population).

However, these coefficients are substantially larger in magnitude than the simple weighted average of all $ATT(g,t)$ obtained using the estimator proposed by Callaway and Sant'Anna (2021)[4], without propensity-score matching (see the second row in the table) — that is, under the unconditional parallel-trends assumption, for comparison purposes. This finding confirms the downward bias of the conventional TWFE estimator in the presence of staggered treatment adoption. Consequently, in the following analysis we do not rely on the TWFE estimates but

[4]The multi-period difference-in-differences estimations were implemented using the *did* package in *R*, developed by Callaway and Sant'Anna (2021)

focus instead on the parameters obtained from the alternative method that is robust to staggered-adoption bias. Moreover, preliminary analyses indicate that even the parameters estimated through the Callaway and Sant'Anna (2021) approach without propensity-score matching are affected by bias, as the unconditional parallel-trends assumption is not satisfied. Therefore, all the results discussed below refer to estimates obtained by combining propensity-score matching with the DiD estimator, which allows the (conditional) parallel-trends assumption to hold.

– Insert Table 1 about here –

The unbiased simple weighted averages of all $ATT(g,t)$ estimated under the conditional parallel-trends assumption suggest an average negative effect of –1.5% on the total population, –1.2% on the working-age population, and –2.6% on the old-age population, while no significant impact emerges for the youngest cohort.

The results also indicate that the earthquakes had a dynamic impact on population, as the coefficients for the overall dynamic (event-study) effects are negative and statistically significant. In particular, Figure 2 shows that the impact of the earthquakes intensifies over time, with treatment effects becoming increasingly negative as exposure lengthens. These findings underscore the importance of accounting for the temporal dimension when evaluating the demographic consequences of natural disasters.[5]

– Insert Figure 2 about here –

The cumulative dynamic effects, computed over seven post-treatment periods relative to the baseline ("long-difference") comparison,[6] indicate a population loss of approximately 11% in total, 9% among the working-age population, and 15% among the elderly due to the earthquakes.

Although our primary focus is on the overall demographic impact of the two earthquakes, it is also instructive to examine the heterogeneity between the two events. To this end, we report the weighted average of group-specific effects in Table 1, while Figure 3 displays the corresponding group-specific dynamics.

– Insert Figure 3 about here –

Table 1 clearly shows that the 2016 earthquake caused, on average, a 2.4% decline in the treated population over the observed period, relative to the counterfactual scenario without the shock, whereas there is no evidence of a significant overall impact for the 2009 event. In addition, the group-time $ATT(g,t)$ profile in Figure 3 indicates that the negative effect for the 2016 group is persistent and increases over time, reaching about –4% after eight years, consistent with the findings of Dottori (2024). Conversely, $ATT(g,t)$ parameters are never significant for the 2009 group, though a slight positive effect appears three years after the event, followed by a negative trend about ten years later.

[5] It is worth noting that all pre-treatment ATT parameters in Figure 2 are insignificant (their confidence intervals include zero) except for one concerning the old-age population, thereby supporting the conditional parallel-trends assumption.

[6] The time horizon considered reflects the fact that, for the 2016 event, only seven post-treatment years are available.

The negative impact of the 2016 earthquake is evident across all three age cohorts, though it is less pronounced for the elderly, whereas the 2009 earthquake produced a significant negative impact only among the elderly (Table 1). Again, the negative effects for the 2016 group increase over time across all age classes (Figure 3). For the 2009 group, the negative impact on the elderly rises for roughly ten years after the event and then stabilizes. Moreover, the nonlinear pattern observed in the total-population effects of the 2009 earthquake (a slight positive impact after three years and a negative trend a decade later) appears to be driven by the working-age cohort (15–64 years).

Given that municipalities in the "2009" group experienced a longer exposure to treatment than those in the "2016" group, the average of the group-specific ATT (θ^O_{sel}) is slightly more negative than the weighted average of all group-time treatment effects (θ^O_W) (–1.8% versus –1.5%).

We extend the analysis by considering the effects on population by citizenship (Table 2 and Figure 4). The average impact of the two earthquakes is negative and significant only for the Italian population in the conditional estimates (–2.2%), confirming the depopulation effect of the two natural disasters. By contrast, the simple weighted average for foreigners is positive but not significant, suggesting that the shocks and the subsequent reconstruction process may have indirectly attracted foreign workers, although the effect is not statistically significant.[7]

– Insert Table 2 about here –

– Insert Figure 4 about here –

In this analysis by citizenship, heterogeneity between the two event groups is even more pronounced. For the Italian population, the group-average ATT for the 2016 group is negative and highly significant (–1.7%), indicating a process of native population out-migration triggered by the 2016 event, compounding the depopulation trends already characterizing Italy's inner areas. In contrast, for the 2009 group, the impact is not significant: the average ATT over the entire period (–2.7%) is larger in magnitude than that for the 2016 group, but its confidence interval includes zero; the same applies to the yearly $ATT(g,t)$ estimates (Figure 4). This result reflects the greater heterogeneity of earthquake impacts among municipalities within the 2009-affected area. We return to this issue in a later section, distinguishing municipalities by their urban or rural character.

The impact on the foreign population is also heterogeneous across the two event groups: it is negative for the 2016 group (–7.3%) and positive for the 2009 group (+16%), particularly after the start of the reconstruction process in 2012 (Figure 4). The estimated effect reaches approximately +20 percentage points in 2012 and persists for 4–5 years. This finding is consistent with Basile et al. (2024a), which suggests that new economic opportunities and reconstruction needs stimulated migratory inflows of foreign workers into the area affected by the L'Aquila earthquake.

In summary, the overall depopulation observed in the areas affected by the 2009 and 2016 earthquakes is mainly attributable to the latter event, which generated a negative impact across all age groups. However, both earthquakes produced a negative effect on the elderly population.

[7] Note the substantial bias in the unconditional estimates, particularly for the foreign population.

The absence of an overall negative effect on total population for the municipalities hit by the 2009 earthquake can be explained by an offsetting mechanism between the decline in the Italian population and the increase in the foreign population. In particular, as shown in the online Appendix A, a replacement of the elderly Italian population with foreign working-age residents emerged at the beginning of the reconstruction period (Figures A1–A4 and Tables A1–A2 in *Appendix A*). Nonetheless, the positive effect on the foreign population has faded in recent years, while the decline of the elderly Italian population has continued over time.

6.2 The impact on migration

Table 3 reports the estimated average effects of the two earthquakes on migration outcomes. The previous results indicate that both events contributed to a depopulation process, particularly among Italian citizens, which was only partially offset by an increase in the number of foreign residents. This suggests that the most likely channel through which the population dynamics are affected is the deregistration of Italian citizens from municipal registries and/or the registration of foreign citizens. We therefore proceed by examining the effects on net migration separately for Italians and foreigners.

Table 3 shows that the effect of the two earthquakes is negative and statistically significant for the average of group-specific effects only in the case of Italian citizens.[8] The group-specific estimates reveal that the effect for Italians is negative and statistically significant for the 2016 event. Conversely, there are no statistically significant effects on the net migration of foreigners, either in the aggregate or for the individual events considered (see Figure 5).

– Insert Table 3 about here –

– Insert Figure 5 about here –

To further explore these dynamics, we replicate the analysis using migration flows, focusing specifically on the inflows of working-age foreign citizens. Figure 6 shows that, following the 2009 event, there was indeed an increase in the number of working-age foreign migrants, concentrated in the years immediately after the start of the reconstruction period. These results are consistent with the evidence on the foreign resident stock and with the findings in Basile et al. (2024a), which emphasize the rise in foreign migration driven by reconstruction activities since 2011.[9] In contrast, for the 2016 event, a slight negative effect seems to emerge, particularly in the most recent years of the sample.[10]

– Insert Figure 6 about here –

[8] It is worth noting that the simple weighted average appears biased due to the relatively higher weight assigned to the 2009 event; as a result, the corresponding estimate is not statistically significant.

[9] In Basile et al. (2024a), the last year of analysis was 2019. To allow a more direct comparison with our results, we replicate the analysis of working-age foreign inflows using the same time span (ending in 2019 instead of 2023). The results, available upon request, are fully consistent with the evidence presented here for the 2009 event.

[10] The group-specific effect for the 2016 event is indeed negative (-0.103), although not statistically significant.

Overall, the migration dynamics observed after the 2009 earthquake appear closely linked to local labor market conditions. Basile et al. (2024b) show that reconstruction efforts generated localized economic opportunities, particularly in construction and related sectors. Our findings are consistent with this evidence, highlighting a significant inflow of foreign workers into the affected areas during the early phases of reconstruction. This migration contributed to demographic recovery, as younger, working-age foreign migrants replaced elderly Italians who had relocated elsewhere. This demographic replacement effect underscores the crucial role of labor demand in shaping post-disaster population dynamics.

Taken together, the results suggest that migration acted as an adjustment mechanism in response to the shocks. In particular, immediately after the 2016 earthquake, the affected municipalities experienced an earthquake-induced outflow of native (Italian) residents, reinforcing the long-term depopulation trend that characterizes inland areas of Italy, especially in the South. In contrast, in the municipalities affected by the 2009 earthquake, we observed a substitution of elderly Italians with foreign workers. Moreover, the temporal pattern of the estimated $ATT(g,t)$ highlights the central role of the reconstruction process in reshaping local population structures — primarily by attracting working-age foreign individuals.

6.3 The impact on natural demographic balance

We also consider the natural balance between births and deaths (and separately the number of births and deaths) as outcome variables. Overall, Table A3 in *Appendix A* suggests that natural population dynamics (as opposed to migration dynamics) were positively — albeit indirectly — affected by the earthquakes, due to both fewer deaths (reflecting the lower presence of the elderly) and more births (driven by a higher presence of young foreigners). Therefore, it can be ruled out that the natural demographic dynamics triggered by the earthquakes contributed to the increased depopulation of these inner areas.

In particular, for the 2009 group, a positive effect on births emerges not in the aftermath of the natural disaster but a few years later (Figures A5 in *Appendix A*), probably due to the higher presence of young foreigners (who are known to have a higher fertility rate than Italians); for the 2016 group, a negative effect on deaths appears due to the lower presence of elderly Italians (Figure A6 in *Appendix A*).

6.4 Urban and Rural

The previous analyses did not explicitly distinguish between urban and rural contexts, implicitly treating the affected areas as internally homogeneous. However, the structural characteristics of municipalities may have shaped the demographic response to the earthquakes. In this subsection, we explore these heterogeneities by separating municipalities according to their degree of urbanization (see *Appendix B* for the corresponding figures and tables). All estimates refer to the enlarged definition of the treatment area.

Consistent with the aggregate results presented in the main analysis, the average treatment effects indicate a generalized depopulation following both earthquakes, although the magnitude and persistence of the effects differ sharply between rural and urban areas (Table B1). Overall, population losses are markedly more pronounced in rural municipalities. This pattern holds across age groups: while urban areas exhibit mild or statistically insignificant demographic responses, rural areas experience persistent population declines among both the working-age and elderly cohorts. These findings suggest that the demographic contraction documented in the aggregate analysis is primarily driven by rural municipalities.

Further distinguishing between the two earthquake groups clarifies these dynamics. For the 2009 event, the estimated effect on total population (Figure B1) is not statistically significant in urban areas, but a significant decline (–4.1%) among the elderly is observed in rural areas. By contrast, the 2016 earthquake produces unambiguously negative effects across all population groups (Figures B2–B4), with particularly severe losses in rural municipalities (–2.5% overall, –2.7% for the working-age cohort, and –1.5% for the elderly). These patterns are consistent with the stronger and more persistent negative effects estimated for the 2016 group in the main analysis, reinforcing the view that this event substantially intensified the pre-existing depopulation processes affecting inland and peripheral areas of Italy.

Disaggregating the results by citizenship provides additional insights (Table B2). The earthquakes had a significant negative impact on the Italian population, particularly in rural areas (–2.0% on average). The foreign population exhibits an asymmetric response: a negative average effect in urban areas and a positive (though not statistically significant on average) effect in rural areas. When distinguishing the two events, the negative impact on the Italian population in rural areas is stronger for the 2009 earthquake (–2.4%), whereas the effect on urban areas results statistically significant only for the 2016 event. For the foreign population, the 2016 earthquake produces substantial losses in both urban (–13.4%) and rural (–7.5%) areas. In contrast, the 2009 earthquake is associated with a positive effect on rural areas (+6.7%), possibly linked to the inflow of foreign workers during the reconstruction phase. These heterogeneous patterns are reflected in the temporal dynamics shown in Figure B6: while the foreign population in rural areas increased steadily for several years after the 2009 event, both rural and urban areas experienced sustained declines following the 2016 shock.

The influx of foreign workers into rural areas after natural disasters can be explained by lower housing costs and reconstruction-related job opportunities. Evidence from other contexts supports this mechanism: after the 2003 Bam earthquake (Iran) and the 2011 Christchurch earthquake (New Zealand), migrant workers played a major role in reconstruction and often settled in peripheral or peri-urban areas where accommodation was more affordable (Arefian, 2018; Fabling et al., 2023). A similar pattern likely followed the 2009 L'Aquila earthquake. Foreign workers may have chosen rural municipalities because temporary housing was cheaper and closer to reconstruction sites, reducing commuting costs. This helps explain the positive effect on rural foreign working-age residents, with the peak occurring in 2012, when major reconstruction efforts began. By contrast, the negative impact on the Italian population stems largely from losses among the elderly in rural areas. As noted in Section **??**, emergency management after 2009 placed temporary housing mostly in peripheral areas of the urban municipalities, often near residents' original homes. In rural areas, however, depopulation was harder to avoid and appears to have disproportionately affected the elderly.

Finally, the migration estimates in Table B3 indicate that net migration among Italians is negative and statistically significant only in urban areas affected by the 2016 event, while it remains insignificant elsewhere. By contrast, net migration among foreigners displays opposite signs in urban and rural areas-positive in the former and negative in the latter-although these estimates are not statistically significant for either earthquake group.

To further deepen the analysis, we assess the implications for the age structure of the affected population using the Potential Support Ratio (PSR), defined as the ratio of working-age (15–64) to elderly (65+) residents (Table B4). On average, the earthquakes exerted opposite pressures on demographic aging across space. Simple weighted averages indicate a mild overall deterioration in the PSR (though not statistically significant), concentrated in urban areas and partly offset by a modest improvement in rural municipalities.

Disaggregating by event group provides further insight. Following the 2009 earthquake, the PSR increased substantially in rural areas (+5.1) but showed no improvement in urban ones, indicating a temporary rejuvenation of the age structure outside major centers. This dynamic likely reflects the arrival of younger foreign working-age individuals who settled in peripheral municipalities during the early reconstruction phase. In contrast, the 2016 earthquake caused a marked decline in the PSR across all areas (–9.7 in urban and –5.7 in rural municipalities), signaling an accelerated aging process driven by the loss of working-age cohorts. Thus, while rural areas experienced a temporary recovery after 2009, both urban and rural contexts underwent sustained demographic deterioration after 2016 (see Figure B9).

Taken together, these results indicate that the positive post-disaster adjustments observed in 2009 were short-lived and spatially concentrated, whereas the 2016 event generated widespread and persistent demographic aging. By illustrating how population losses and labor-related migration jointly shape the age composition of affected communities, this analysis contributes to a deeper understanding of the demographic consequences of natural disasters beyond aggregate population effects.

7 Conclusions

This paper examined the demographic dynamics triggered by natural disasters, focusing specifically on the L'Aquila 2009 and Central Italy 2016 earthquakes. We estimated the causal effects of these events on depopulation, changes in the population age structure, and migration patterns for both Italian and foreign residents, while also distinguishing between urban and rural contexts.

Overall, the findings indicate that the two events jointly contributed to a depopulation process in the affected areas. The 2016 earthquake produced a persistent and increasingly severe population decline throughout the observed period, consistent with Dottori (2024), whereas there is no evidence of a significant adverse long-term effect associated with the 2009 earthquake. The negative consequences of the 2016 event are apparent across all age cohorts (0–14, 15–64, and 65+), with the most pronounced effects observed among the youngest group. In contrast, the 2009 earthquake significantly affected only the elderly population.

The analysis by citizenship further reveals marked heterogeneity. Both earthquakes had a negative and persistent impact on the Italian population. For foreign residents, however, the effects diverge sharply: the 2016 earthquake had a negative impact, whereas the 2009 event generated a positive response, particularly after reconstruction activities intensified in 2012. This pattern aligns with Basile et al. (2024a), who argue that reconstruction-related economic opportunities stimulated new inflows of foreign workers into the L'Aquila area. Indeed, the 15–64 age group—especially foreign working-age individuals—was the main driver of population dynamics across both events. In 2009, working-age foreigners partially offset the losses among elderly Italians, leading to a temporary replacement of the older native population. In 2016, by contrast, the decline in the total population resulted from simultaneous losses among Italian and foreign working-age residents as well as elderly Italians.

These results suggest that demographic change following the earthquakes—particularly the 2009 event—was not driven by natural population dynamics but rather by migration, which acted as an adjustment mechanism. Following the 2016 earthquake, affected municipalities experienced an earthquake-induced outflow of native Italians, exacerbating the long-standing depopulation of inland areas. By contrast, in the municipalities struck by the 2009 earthquake, the loss of elderly Italians was partially compensated by an inflow of foreign workers.

The earthquake effects also exhibited substantial heterogeneity across urban and rural contexts. Both events were associated with population losses, but their intensity and demographic composition varied markedly. In urban areas, the 2009 earthquake produced no significant decline in total population and affected only the elderly in the rural areas, whereas the 2016 event generated population losses in the working-age population in urban areas and across all age groups in rural areas. When distinguishing by citizenship, additional heterogeneity appears: the 2009 event produced a positive effect on the foreign population in rural municipalities and a negative effect on Italians, with no significant response in urban areas. In 2016, both Italians and foreigners experienced population losses in rural and urban areas alike. These results align with existing evidence showing that migrant workers are attracted to reconstruction-related employment and tend to settle in more affordable peripheral areas (Arefian, 2018; Fabling et al., 2023).

In conclusion, this study shows that earthquakes can induce complex and heterogeneous demographic adjustments, with substantial differences across citizenship groups, age cohorts, and spatial contexts. By documenting these patterns, the analysis contributes to a deeper understanding of the demographic consequences of natural disasters beyond aggregate population change.

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TABLE 1
Earthquakes Treatment Effects

	Log of Total pop	Log of Pop_{0-14}	Log of Pop_{15-64}	Log of Pop_{65+}
Unconditional				
TWFE	**-0.047**	**-0.054**	**-0.030**	**-0.104**
	(0.007)	**(0.015)**	**(0.007)**	**(0.010)**
Simple Weighted Average	**-0.030**	-0.008	**-0.024**	**-0.064**
	(0.006)	(0.015)	**(0.006)**	**(0.009)**
Conditional				
Simple Weighted Average	**-0.015**	0.001	**-0.012**	**-0.026**
	(0.005)	(0.015)	**(0.006)**	**(0.007)**
Dynamic Effects	**-0.014**	-0.017	**-0.011**	**-0.018**
	(0.003)	(0.011)	**(0.004)**	**(0.004)**
Cumulative Dynamic Effects	-0.113	-0.134	-0.091	-0.146
Avg. of group-specific effects	**-0.018**	-0.008	**-0.017**	**-0.022**
	(0.004)	(0.012)	**(0.004)**	**(0.006)**
Group specific effect: 2009	-0.004	0.035	0.006	**-0.043**
	(0.011)	(0.030)	(0.013)	**(0.015)**
Group specific effect: 2016	**-0.024**	**-0.029**	**-0.028**	**-0.012**
	(0.003)	**(0.011)**	**(0.004)**	**(0.005)**

Notes: The table reports aggregated treatment effect parameters under the unconditional and conditional parallel trends assumptions and with clustering at the municipality level. The row 'TWFE' reports the coefficient on a post-treatment dummy variable from a two-way fixed effects regression. The row 'Simple Weighted Average' reports the weighted average (by group size) of all available group-time average treatment effects. The row 'Group-Specific Effects' summarizes average treatment effects by the timing of the earthquake. The estimates use the doubly robust estimator. Standard errors in parenthesis. The bold character indicates significance at 5% level. Following Dottori (2024), we exclude from the control group: a) municipalities classified as "coastal mountain", "inter-municipal poles", "ultra-peripheral areas", "flat land", "littoral", "island", "coastal" or otherwise with an elevation of less than 150 meters; b) municipalities with a density of more than 700 inhabitants per-square kilometer (higher than the maximum detected for the treated municipalities); c) municipalities not officially affected by the earthquake but belonging to the provinces of those affected. The conditional model includes pre-trend covariates capturing (log) population density in 2002, population growth (2002-2006), and age-specific population (log of children aged 0–14, working-age population 15–64, and elderly 65+ in 2002).

TABLE 2
Earthquakes Treatment Effects

	Log of Total Italians	Log of Total Foreigners
Unconditional		
TWFE	**-0.050**	**-0.096**
	(0.007)	**(0.028)**
Simple Weighted Average	**-0.033**	-0.015
	(0.006)	(0.021)
Conditional		
Simple Weighted Average	**-0.022**	0.034
	(0.007)	(0.021)
Avg. of group-specific effects	**-0.020**	0.000
	(0.005)	(0.017)
Group specific effect: 2009	-0.027	**0.160**
	(0.019)	**(0.034)**
Group specific effect: 2016	**-0.017**	**-0.073**
	(0.003)	**(0.019)**

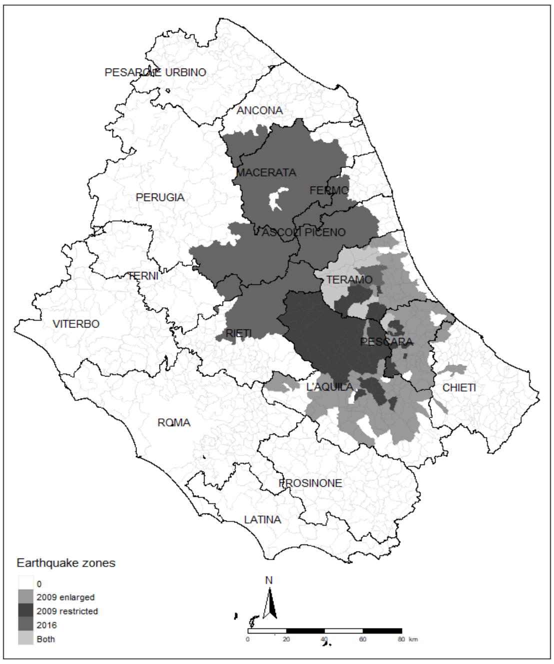
Notes: The table reports aggregated treatment effect parameters under the unconditional and conditional parallel trends assumptions and with clustering at the municipality level. The row 'TWFE' reports the coefficient on a post-treatment dummy variable from a two-way fixed effects regression. The row 'Simple Weighted Average' reports the weighted average (by group size) of all available group-time average treatment effects. The row 'Group-Specific Effects' summarizes average treatment effects by the timing of the earthquake. The estimates use the doubly robust estimator. Standard errors in parenthesis. The bold character indicates significance at 5% level. Following Dottori (2024) we exclude from the control group: a) municipalities classified as "coastal mountain", "inter-municipal poles", "ultra-peripheral areas", "flat land", "littoral", "island", "coastal" or otherwise with an elevation of less than 150 meters; b) municipalities with a density of more than 700 inhabitants per-square kilometer (higher than the maximum detected for the treated municipalities); c) municipalities not officially affected by the earthquake but belonging to the provinces of those affected. The conditional model includes pre-trend covariates capturing overall and Italian population growth (2002-2006), and overall, italian, and foreign (log) population and population density in 2002.

TABLE 3
Earthquakes Treatment Effects

	Net Migration of Italians	Net Migration of Foreigners
Unconditional		
TWFE	-4.293	**-4.941**
	(2.451)	**(1.824)**
Simple Weighted Average	-2.332	0.473
	(2.437)	(2.586)
Conditional		
Simple Weighted Average	-3.891	-0.408
	(2.218)	(2.445)
Avg. of group-specific effects	**-4.173**	-0.748
	(1.978)	(1.775)
Group specific effect: 2009	-2.863	0.835
	(4.868)	(5.418)
Group specific effect: 2016	**-4.770**	-1.470
	(1.912)	(1.718)

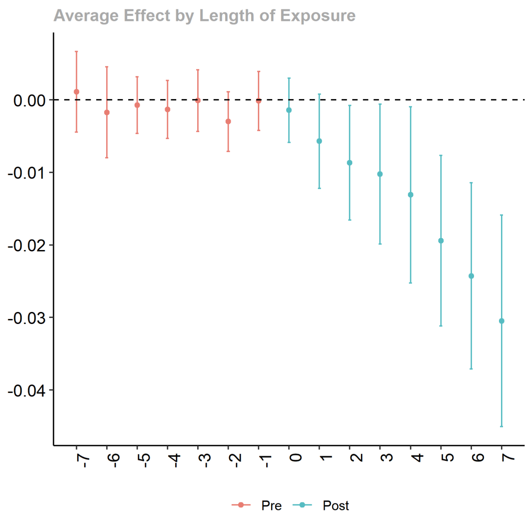
Notes: The table reports aggregated treatment effect parameters under the unconditional and conditional parallel trends assumptions and with clustering at the municipality level. The row 'TWFE' reports the coefficient on a post-treatment dummy variable from a two-way fixed effects regression. The row 'Simple Weighted Average' reports the weighted average (by group size) of all available group-time average treatment effects. The row 'Group-Specific Effects' summarizes average treatment effects by the timing of the earthquake. The estimates use the doubly robust estimator. Standard errors in parenthesis. The bold character indicates significance at 5% level. Following Dottori (2024) we exclude from the control group: a) municipalities classified as "coastal mountain", "inter-municipal poles", "ultra-peripheral areas", "flat land", "littoral", "island", "coastal" or otherwise with an elevation of less than 150 meters; b) municipalities with a density of more than 700 inhabitants per-square kilometer (higher than the maximum detected for the treated municipalities); c) municipalities not officially affected by the earthquake but belonging to the provinces of those affected. The conditional model includes pre-trend covariates capturing the (log) Italian resident population in 2002 and the overall population growth (2002-2008).

FIGURE 1
Earthquakes: 2009 and 2016

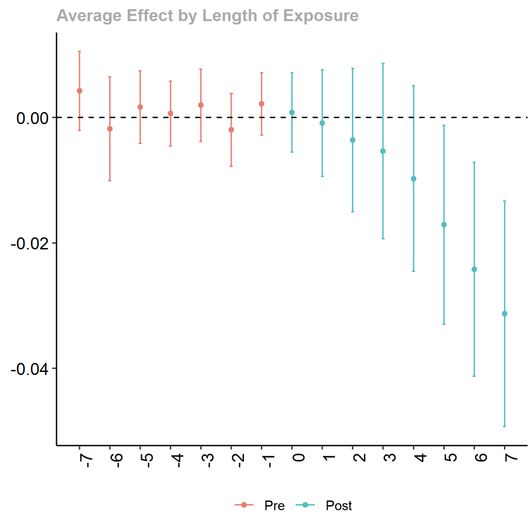


Source: our elaboration on INGV data

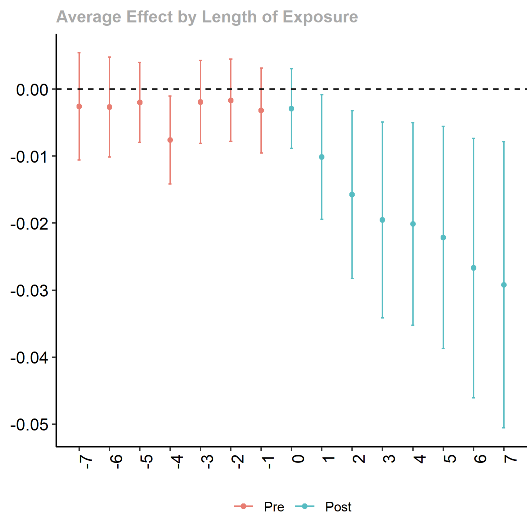
FIGURE 2
The dynamic effect of earthquakes



(a) Log of total population



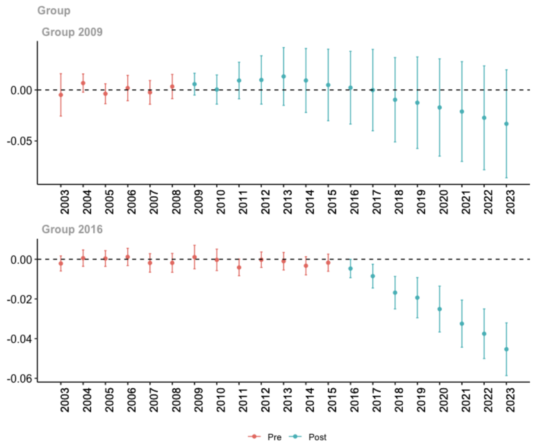
(b) Log of working-age population (Pop_{15-64})



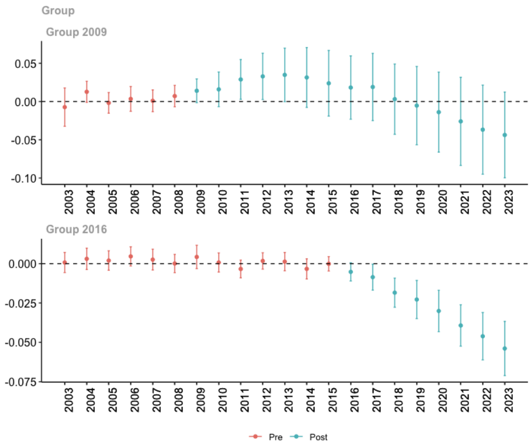
(c) Log of old-age population (Pop_{65+})

Notes: Following Dottori (2024) we exclude from the control group: a) municipalities classified as "coastal mountain", "inter-municipal poles", "ultra-peripheral areas", "flat land", "littoral", "island", "coastal" or otherwise with an elevation of less than 150 meters; b) municipalities with a density of more than 700 inhabitants per-square kilometer (higher than the maximum detected for the treated municipalities); c) municipalities not officially affected by the earthquake but belonging to the provinces of those affected.

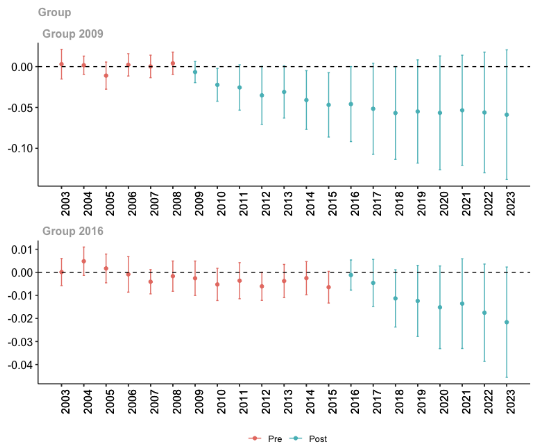
FIGURE 3
The effect of earthquakes by group and time



(a) Log of total population



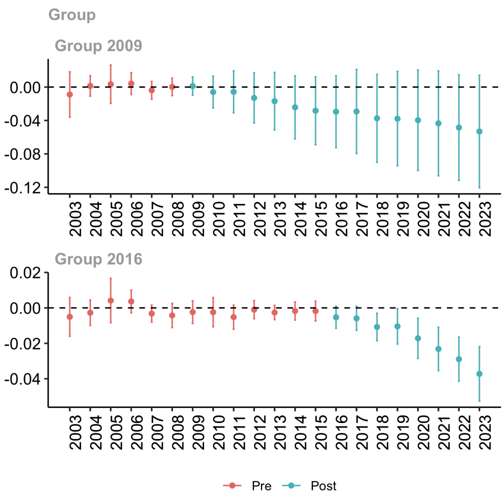
(b) Log of working-age population (Pop_{15-64})



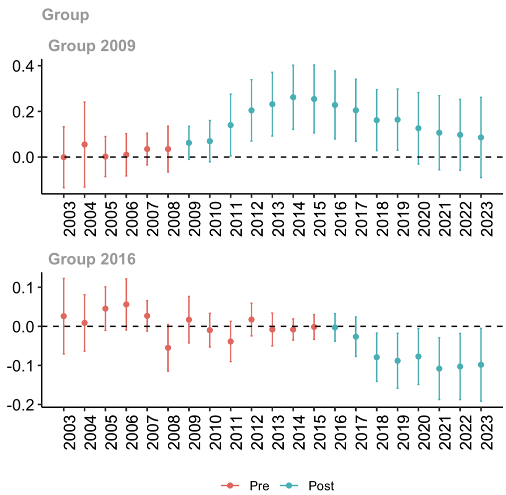
(c) Log of old-age population (Pop_{65+})

Notes: see Figure 2.

FIGURE 4
The effect of earthquakes on Total Italians and on Total Foreigners



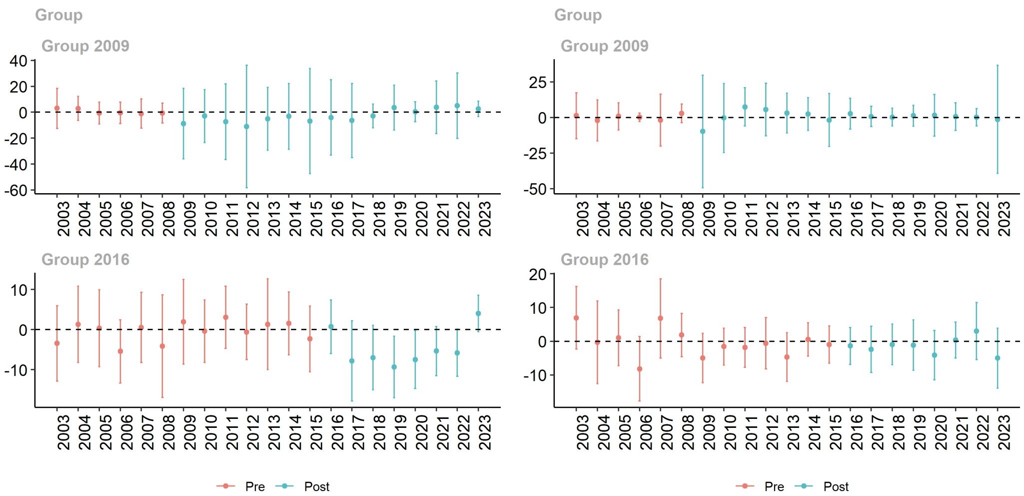
(a) Log of total Italians



(b) Log of total Foreigners

Notes: see Figure 2.

FIGURE 5
The effect of earthquakes on Net Migration of Italians and Foreigners

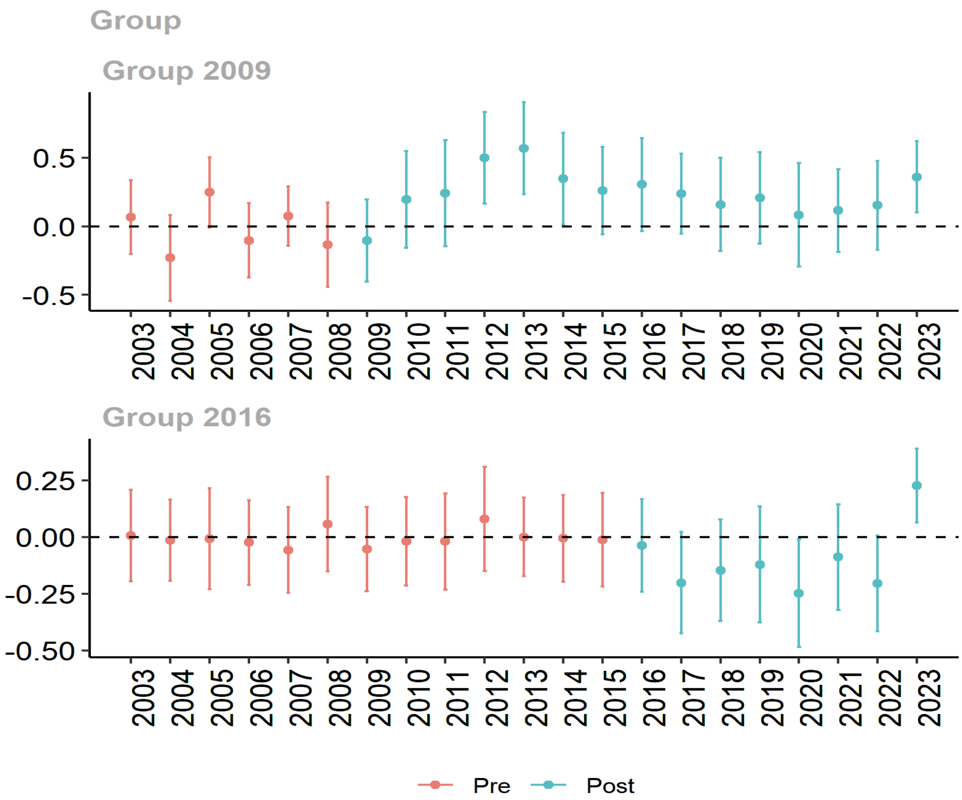


(a) Net Migration of Italian (b) Net Migration of Foreigners

Notes: see Figure 2.

FIGURE 6

The effect of earthquakes on internal inflows of Foreigners (Pop_{15-64})



Notes: see Figure 2.

1 Appendix A: The impact on Population, Migration, and Natural Demographic Balance by age-class and citizenship

TABLE A1
Earthquakes Treatment Effects

	Log of $Italians_{15-64}$	Log of $Italians_{65+}$
Simple Weighted Average	**-0.025**	**-0.028**
	(0.011)	**(0.007)**
Avg. of group-specific effects	**-0.026**	**-0.024**
	(0.010)	**(0.006)**
Group specific effect: 2009	-0.022	**-0.044**
	(0.019)	**(0.015)**
Group specific effect: 2016	**-0.028**	**-0.014**
	(0.008)	**(0.005)**

Notes: The table reports aggregated treatment effect parameters under the conditional parallel trends assumptions and with clustering at the municipality level. The row 'Simple Weighted Average' reports the weighted average (by group size) of all available group-time average treatment effects. The row 'Group-Specific Effects' summarizes average treatment effects by the timing of the earthquake. The estimates use the doubly robust estimator. Standard errors in parenthesis. The bold character indicates significance at 5% level. Following Dottori (2024) we exclude from the control group: a) municipalities classified as "coastal mountain", "inter-municipal poles", "ultra-peripheral areas", "flat land", "littoral", "island", "coastal" or otherwise with an elevation of less than 150 meters; b) municipalities with a density of more than 700 inhabitants per-square kilometer (higher than the maximum detected for the treated municipalities); c) municipalities not officially affected by the earthquake but belonging to the provinces of those affected. The conditional model includes pre-trend covariates capturing overall, elderly (65+), and Italian population growth (2002-2006), the (log) Italian and foreign working-age (15-64) population in 2002, and the population density in 2002.

TABLE A2

Earthquakes Treatment Effects

	Log of $Foreigners_{15-64}$	Log of $Foreigners_{65+}$
Simple Weighted Average	0.000	0.038
	(0.034)	(0.036)
Avg. of group-specific effects	-0.030	0.032
	(0.023)	(0.031)
Group specific effect: 2009	0.112	0.058
	(0.107)	(0.066)
Group specific effect: 2016	**-0.095**	0.020
	(0.048)	(0.033)

Notes: The table reports aggregated treatment effect parameters under the conditional parallel trends assumptions and with clustering at the municipality level. The row 'Simple Weighted Average' reports the weighted average (by group size) of all available group-time average treatment effects. The row 'Group-Specific Effects' summarizes average treatment effects by the timing of the earthquake. The estimates use the doubly robust estimator. Standard errors in parenthesis. The bold character indicates significance at 5% level. Following Dottori (2024) we exclude from the control group: a) municipalities classified as "coastal mountain", "inter-municipal poles", "ultra-peripheral areas", "flat land", "littoral", "island", "coastal" or otherwise with an elevation of less than 150 meters; b) municipalities with a density of more than 700 inhabitants per-square kilometer (higher than the maximum detected for the treated municipalities); c) municipalities not officially affected by the earthquake but belonging to the provinces of those affected. The conditional model includes pre-trend covariates capturing overall and Italian working-age (15-64) population growth (2002-2004), and the (log) Italian working-age and elderly (65+) population in 2002.

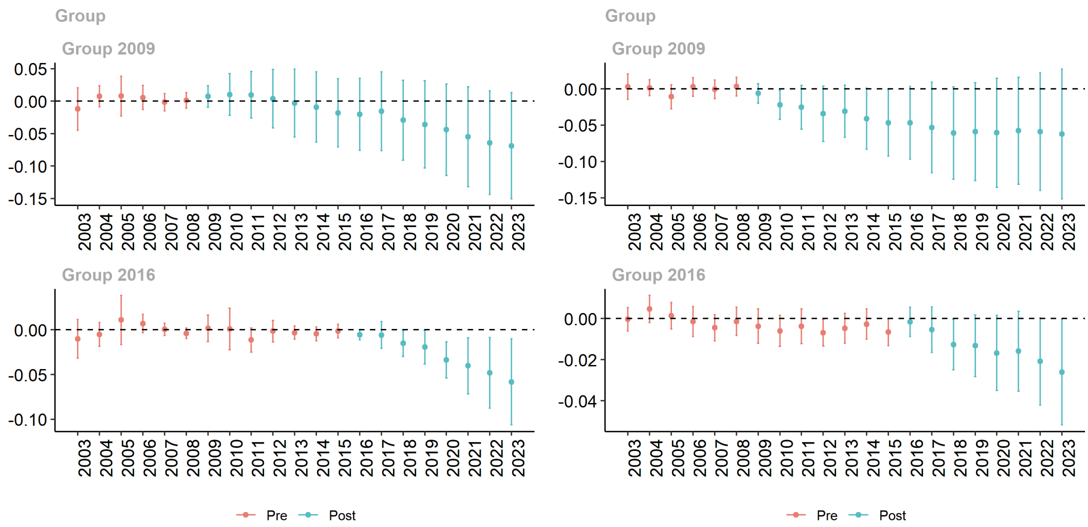
TABLE A3

Earthquakes Treatment Effects

	Natural Balance	Births	Deaths
Simple Weighted Average	**1.810**	0.033	**-0.057**
	(0.711)	(0.030)	**(0.027)**
Avg. of group-specific effects	**1.698**	0.009	**-0.058**
	(0.788)	(0.028)	**(0.020)**
Group specific effect: 2009	**2.283**	**0.121**	-0.053
	(0.860)	**(0.053)**	(0.049)
Group specific effect: 2016	1.404	-0.042	**-0.061**
	(1.050)	(0.032)	**0.023**

Notes: The table reports aggregated treatment effect parameters under the conditional parallel trends assumptions and with clustering at the municipality level. The row 'Simple Weighted Average' reports the weighted average (by group size) of all available group-time average treatment effects. The row 'Group-Specific Effects' summarizes average treatment effects by the timing of the earthquake. The estimates use the doubly robust estimator. Standard errors in parenthesis. The bold character indicates significance at 5% level. Following Dottori (2024) we exclude from the control group: a) municipalities classified as "coastal mountain", "inter-municipal poles", "ultra-peripheral areas", "flat land", "littoral", "island", "coastal" or otherwise with an elevation of less than 150 meters; b) municipalities with a density of more than 700 inhabitants per-square kilometer (higher than the maximum detected for the treated municipalities); c) municipalities not officially affected by the earthquake but belonging to the provinces of those affected. The conditional model includes pre-trend covariates capturing the (log) population in 2002.

FIGURE A1
The effect of earthquakes on $Italians_{15-64}$ and $Italians_{65+}$

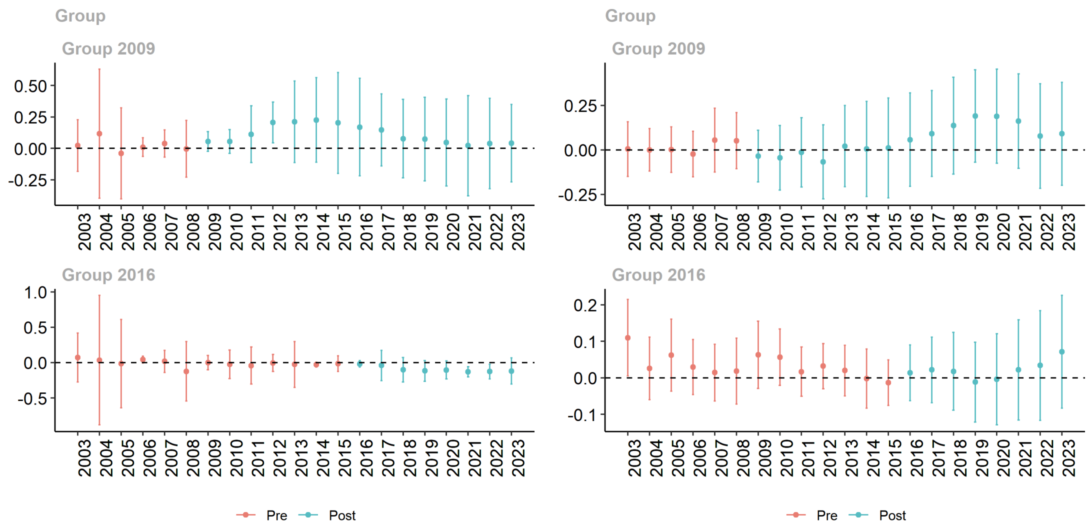


(a) Log of working-age population ($Italians_{15-64}$)

(b) Log of old-age population ($Italians_{65+}$)

Notes: Following Dottori (2024) we exclude from the control group: a) municipalities classified as "coastal mountain", "inter-municipal poles", "ultra-peripheral areas", "flat land", "littoral", "island", "coastal" or otherwise with an elevation of less than 150 meters; b) municipalities with a density of more than 700 inhabitants per-square kilometer (higher than the maximum detected for the treated municipalities); c) municipalities not officially affected by the earthquake but belonging to the provinces of those affected.

FIGURE A2
The effect of earthquakes on $Foreigners_{15-64}$ and $Foreigners_{65+}$

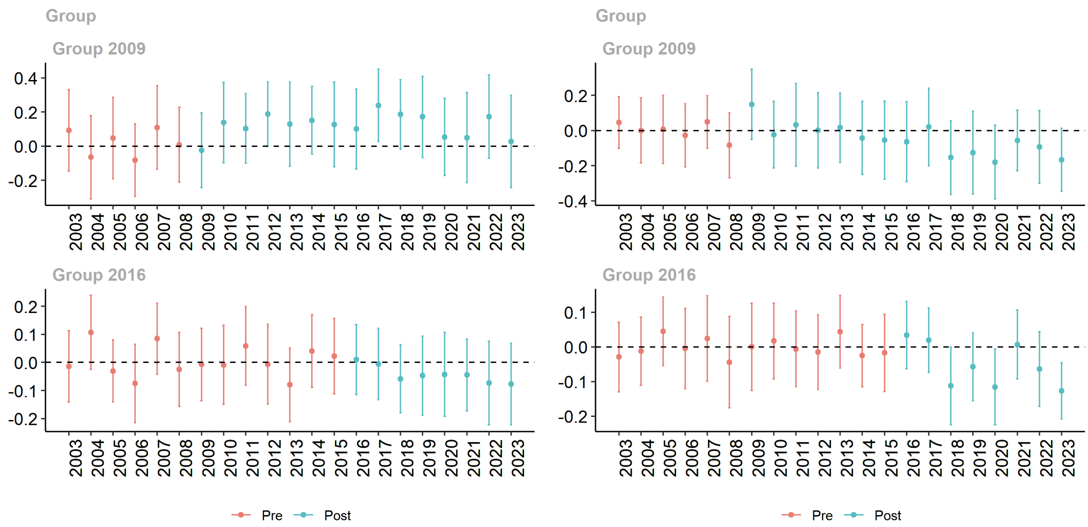


(a) Log of working-age population ($Foreigners_{15-64}$)

(b) Log of old-age population ($Foreigners_{65+}$)

Notes: see Figure A1.

FIGURE A3
The effect of earthquakes on Births and Deaths



(a) Births

(b) Deaths among Pop_{65+}

Notes: see Figure A1.

2 Appendix B: The impact on Urban and Rural areas

TABLE B1
Earthquakes Treatment Effects - Urban and Rural

	Log of Total pop	Log of Pop_{0-14}	Log of Pop_{15-64}	Log of Pop_{65+}
Urban				
Simple Weighted Average	-0.002	0.011	-0.002	-0.005
	(0.008)	(0.015)	(0.012)	(0.006)
Avg. of group-specific effects	-0.004	0.008	-0.006	-0.003
	(0.006)	(0.013)	(0.009)	(0.005)
Group specific effect: 2009	0.002	0.015	0.004	-0.009
	(0.010)	(0.020)	(0.016)	(0.007)
Group specific effect: 2016	**-0.014**	-0.001	**-0.022**	0.006
	(0.004)	(0.009)	**(0.004)**	(0.003)
Rural				
Simple Weighted Average	**-0.016**	-0.018	-0.006	**-0.034**
	(0.004)	(0.013)	(0.005)	**(0.006)**
Avg. of group-specific effects	**-0.017**	-0.021	**-0.010**	**-0.030**
	(0.004)	(0.011)	**(0.005)**	**(0.005)**
Group specific effect: 2009	-0.012	-0.011	0.003	**-0.041**
	(0.005)	(0.017)	(0.007)	**(0.009)**
Group specific effect: 2016	**-0.025**	**-0.035**	**-0.027**	**-0.015**
	(0.003)	**(0.014)**	**(0.004)**	**(0.006)**

Notes: The table reports aggregated treatment effect parameters under the conditional parallel trends assumptions and with clustering at the municipality level. The row 'Simple Weighted Average' reports the weighted average (by group size) of all available group-time average treatment effects. The row 'Group-Specific Effects' summarizes average treatment effects by the timing of the earthquake. The estimates use the doubly robust estimator. Standard errors in parenthesis. The bold character indicates significance at 5% level. Following Dottori (2024) we exclude from the control group: a) municipalities classified as "coastal mountain", "inter-municipal poles", "ultra-peripheral areas", "flat land", "littoral", "island", "coastal" or otherwise with an elevation of less than 150 meters; b) municipalities with a density of more than 700 inhabitants per-square kilometer (higher than the maximum detected for the treated municipalities); c) municipalities not officially affected by the earthquake but belonging to the provinces of those affected. The conditional model includes pre-trend covariates capturing overall population growth (2002-2006), (log) population density in 2002, 0–14 (log) population and population growth (2002-2006), (log) working-age (15-64) and elderly (65+) population in 2002.

TABLE B2
Earthquakes Treatment Effects - Urban and Rural

	Log of Total Italians	Log of Total Foreigners
Urban		
Simple Weighted Average	-0.007	-0.046
	(0.007)	(0.032)
Avg. of group-specific effects	-0.008	**-0.062**
	(0.006)	**(0.027)**
Group specific effect: 2009	-0.006	-0.016
	(0.010)	(0.038)
Group specific effect: 2016	**-0.010**	**-0.134**
	(0.002)	**(0.034)**
Rural		
Simple Weighted Average	**-0.020**	0.027
	(0.005)	(0.021)
Avg. of group-specific effects	**-0.019**	0.007
	(0.004)	(0.018)
Group specific effect: 2009	**-0.024**	**0.067**
	(0.009)	**(0.028)**
Group specific effect: 2016	**-0.014**	**-0.075**
	(0.003)	**(0.023)**

Notes: The table reports aggregated treatment effect parameters under the conditional parallel trends assumptions and with clustering at the municipality level. The row 'Simple Weighted Average' reports the weighted average (by group size) of all available group-time average treatment effects. The row 'Group-Specific Effects' summarizes average treatment effects by the timing of the earthquake. The estimates use the doubly robust estimator. Standard errors in parenthesis. The bold character indicates significance at 5% level. Following Dottori (2024) we exclude from the control group: a) municipalities classified as "coastal mountain", "inter-municipal poles", "ultra-peripheral areas", "flat land", "littoral", "island", "coastal" or otherwise with an elevation of less than 150 meters; b) municipalities with a density of more than 700 inhabitants per-square kilometer (higher than the maximum detected for the treated municipalities); c) municipalities not officially affected by the earthquake but belonging to the provinces of those affected. The conditional model includes pre-trend covariates capturing total, Italian, and foreign (log) population in 2002, overall and Italian population growth (2002-2006), and foreign (log) population density in 2002.

TABLE B3

Earthquakes Treatment Effects - Urban and Rural

	Net Migration of Italians	Net Migration of Foreigners
Urban		
Simple Weighted Average	-27.883	15.186
	(24.934)	(27.971)
Avg. of group-specific effects	-29.316	15.253
	(23.143)	(26.911)
Group specific effect: 2009	-25.204	15.062
	(33.913)	(30.178)
Group specific effect: 2016	**-35.776**	15.554
	(16.568)	(19.687)
Rural		
Simple Weighted Average	-1.479	-1.501
	(1.413)	(0.790)
Avg. of group-specific effects	-1.278	**-1.526**
	(1.130)	**(0.748)**
Group specific effect: 2009	-1.874	-1.452
	(2.017)	(0.943)
Group specific effect: 2016	-0.451	-1.629
	(1.271)	(1.108)

Notes: The table reports aggregated treatment effect parameters under the conditional parallel trends assumptions and with clustering at the municipality level. The row 'Simple Weighted Average' reports the weighted average (by group size) of all available group-time average treatment effects. The row 'Group-Specific Effects' summarizes average treatment effects by the timing of the earthquake. The estimates use the doubly robust estimator. Standard errors in parenthesis. The bold character indicates significance at 5% level. Following Dottori (2024) we exclude from the control group: a) municipalities classified as "coastal mountain", "inter-municipal poles", "ultra-peripheral areas", "flat land", "littoral", "island", "coastal" or otherwise with an elevation of less than 150 meters; b) municipalities with a density of more than 700 inhabitants per-square kilometer (higher than the maximum detected for the treated municipalities); c) municipalities not officially affected by the earthquake but belonging to the provinces of those affected. The conditional model includes pre-trend covariates capturing overall (log) population in 2002, overall population growth (2002-2008), and the altimetric zone.

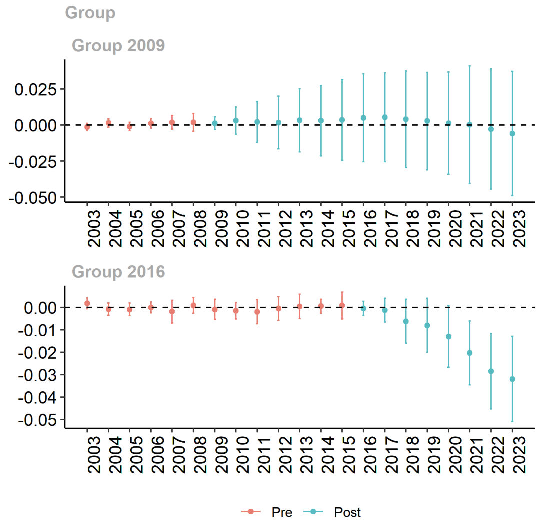
TABLE B4

Earthquakes Treatment Effects - Potential Support Ratio (PSR)

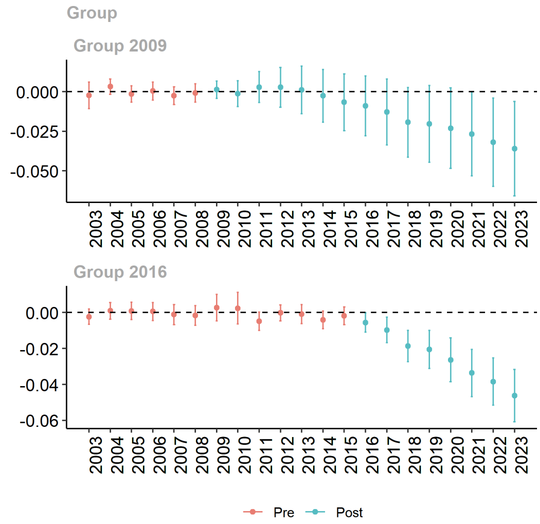
	PSR	PSR urban	PSR rural
Simple Weighted Average	-0.425	-0.393	2.027
	(1.581)	(2.440)	(1.376)
Avg. of group-specific effects	-1.914	-2.084	0.507
	(1.281)	(2.041)	(1.157)
Group specific effect: 2009	5.010	2.769	**5.016**
	(2.879)	(3.123)	**(1.654)**
Group specific effect: 2016	**-5.071**	**-9.711**	**-5.744**
	(1.101)	**(1.458)**	**(1.256)**

Notes: The table reports aggregated treatment effect parameters under the conditional parallel trends assumptions and with clustering at the municipality level. The row 'Simple Weighted Average' reports the weighted average (by group size) of all available group-time average treatment effects. The row 'Group-Specific Effects' summarizes average treatment effects by the timing of the earthquake. The estimates use the doubly robust estimator. Standard errors in parenthesis. The bold character indicates significance at 5% level. Following Dottori (2024) we exclude from the control group: a) municipalities classified as "coastal mountain", "inter-municipal poles", "ultra-peripheral areas", "flat land", "littoral", "island", "coastal" or otherwise with an elevation of less than 150 meters; b) municipalities with a density of more than 700 inhabitants per-square kilometer (higher than the maximum detected for the treated municipalities); c) municipalities not officially affected by the earthquake but belonging to the provinces of those affected. The conditional model includes pre-trend covariates capturing growth of the working-age (15-64) and elderly (65+) population (2002-2006), the working-age and elderly (log) population in 2002, PSR in 2002, and (log) population density in 2002.

FIGURE B1
The effect of earthquakes on Total Population



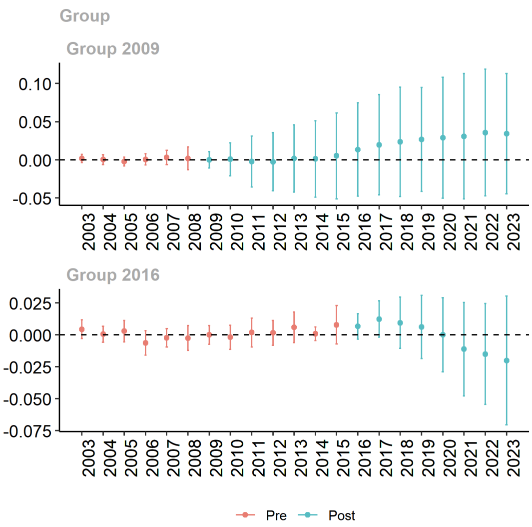
(a) Urban



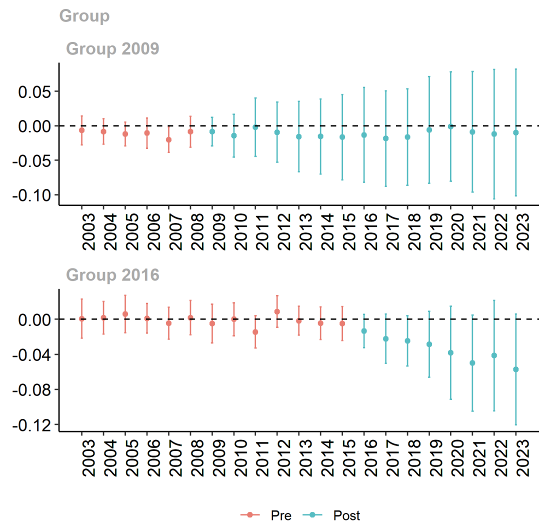
(b) Rural

Notes: Following Dottori (2024) we exclude from the control group: a) municipalities classified as "coastal mountain", "inter-municipal poles", "ultra-peripheral areas", "flat land", "littoral", "island", "coastal" or otherwise with an elevation of less than 150 meters; b) municipalities with a density of more than 700 inhabitants per-square kilometer (higher than the maximum detected for the treated municipalities); c) municipalities not officially affected by the earthquake but belonging to the provinces of those affected.

FIGURE B2
The effect of earthquakes on Pop_{0-14}



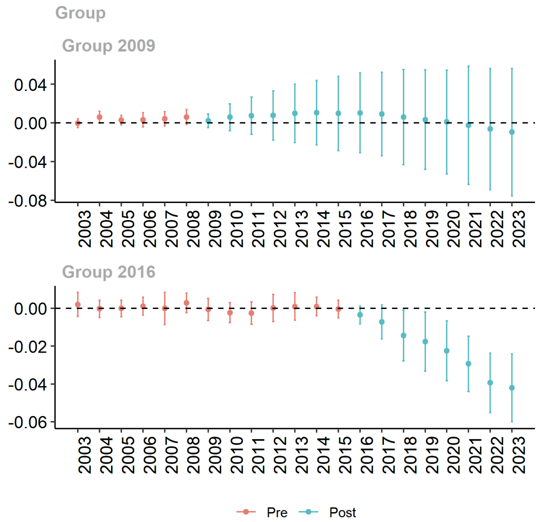
(a) Urban



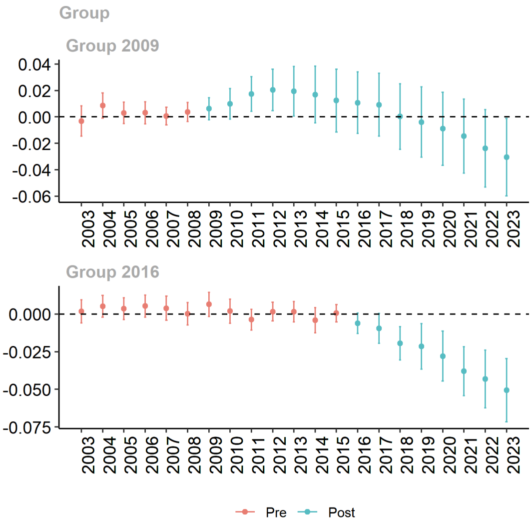
(b) Rural

Notes: see Figure B1.

FIGURE B3
The effect of earthquakes on Pop_{15-64}



(a) Urban

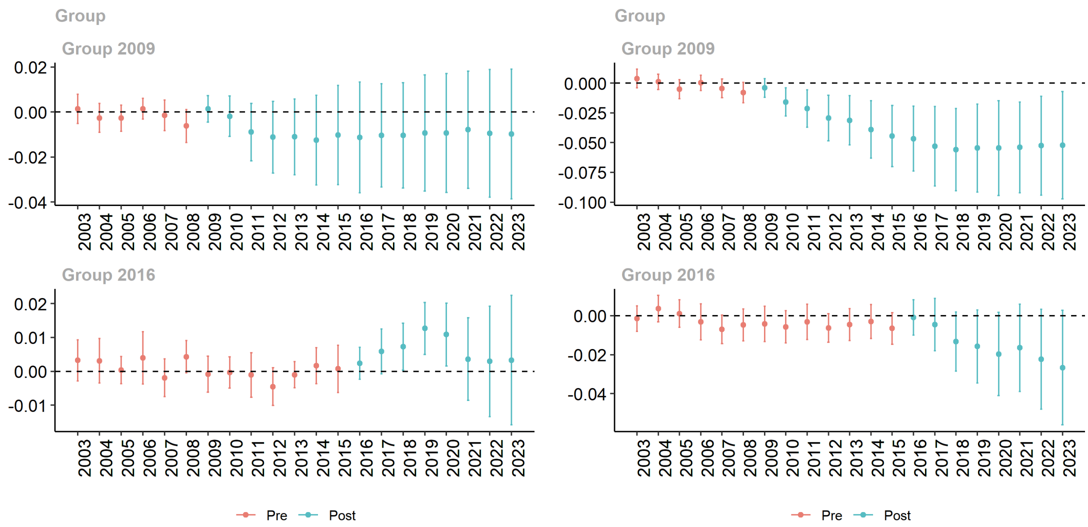


(b) Rural

Notes: see Figure B1.

FIGURE B4

The effect of earthquakes on Pop_{65+}

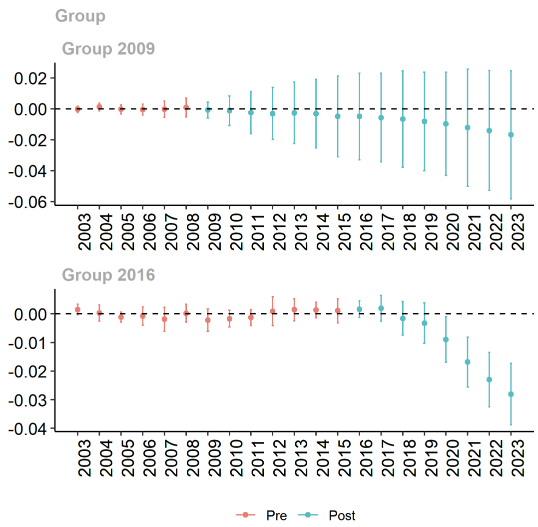


(a) Urban (b) Rural

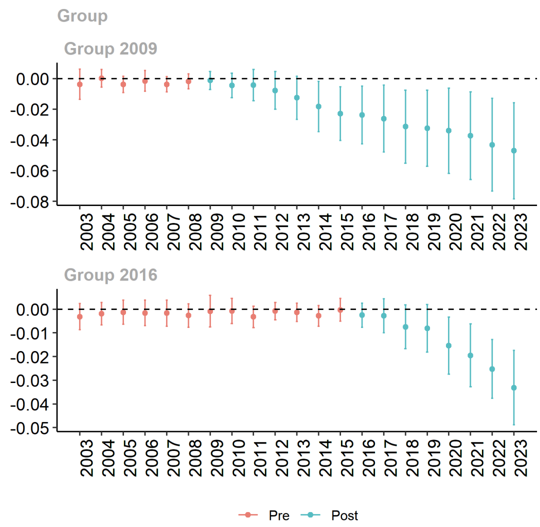
Notes: see Figure B1.

FIGURE B5

The effect of earthquakes on Total Italians



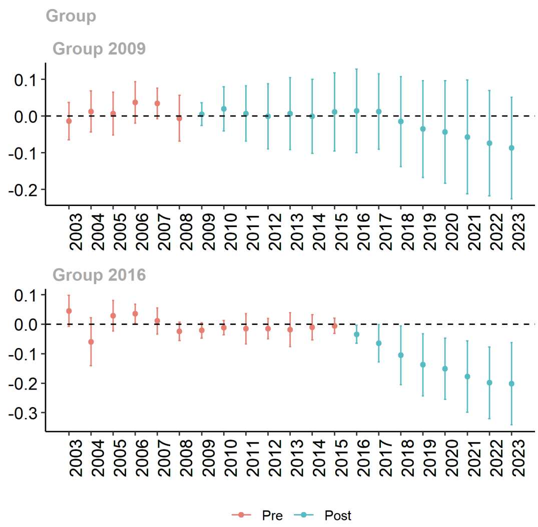
(a) Urban



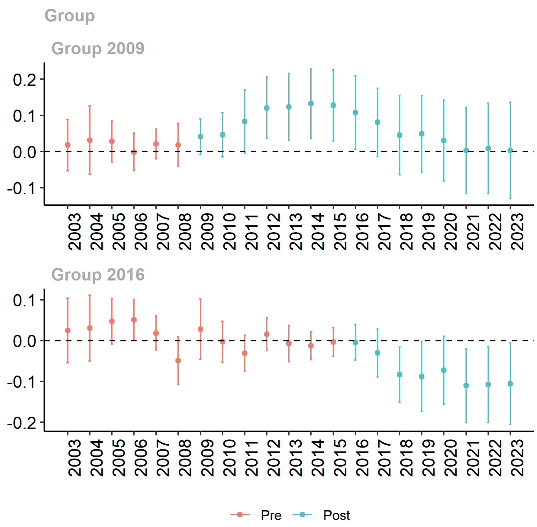
(b) Rural

Notes: see Figure B1.

FIGURE B6
The effect of earthquakes on Total Foreigners



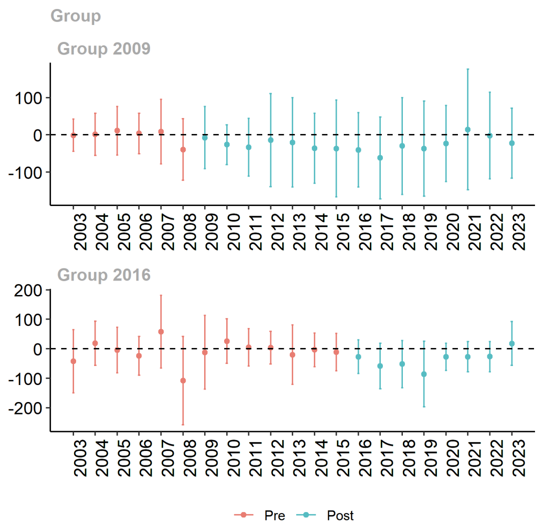
(a) Urban



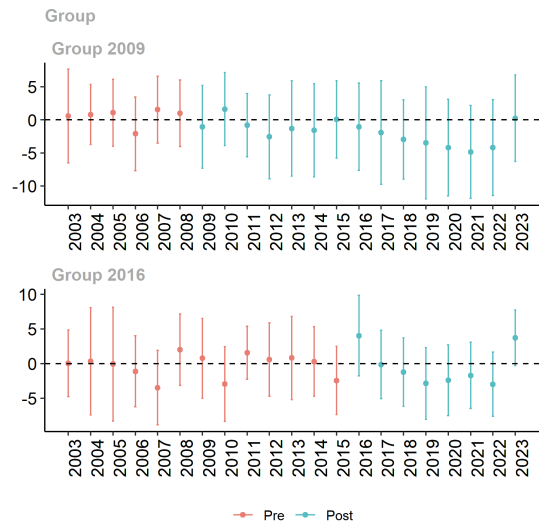
(b) Rural

Notes: see Figure B1.

FIGURE B7
The effect of earthquakes on Net Migration of Italians



(a) Urban

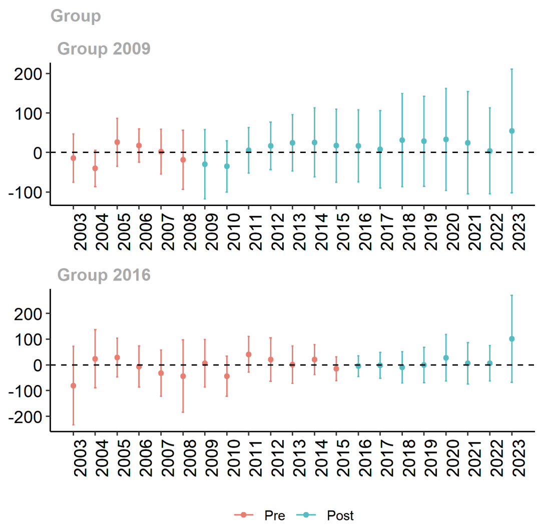


(b) Rural

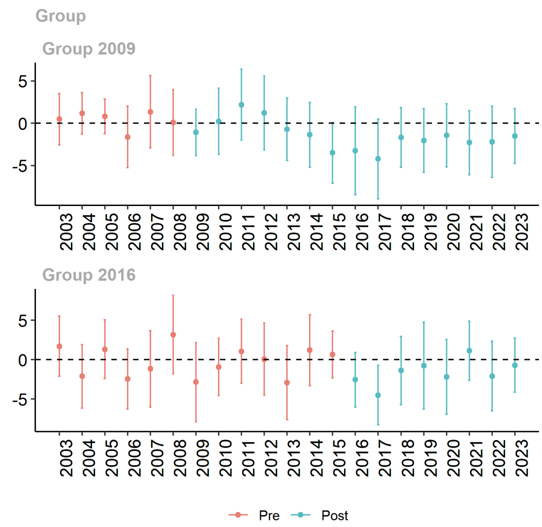
Notes: see Figure B1.

FIGURE B8

The effect of earthquakes on Net Migration of Foreigners



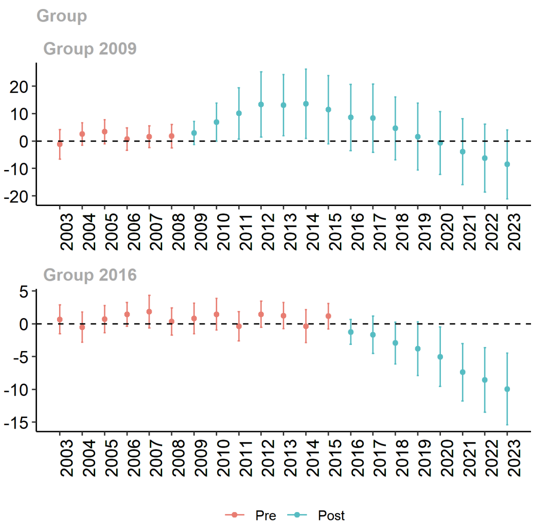
(a) Urban



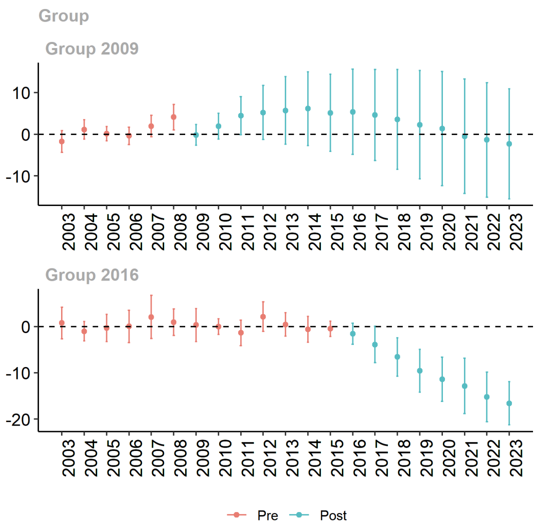
(b) Rural

Notes: see Figure B1.

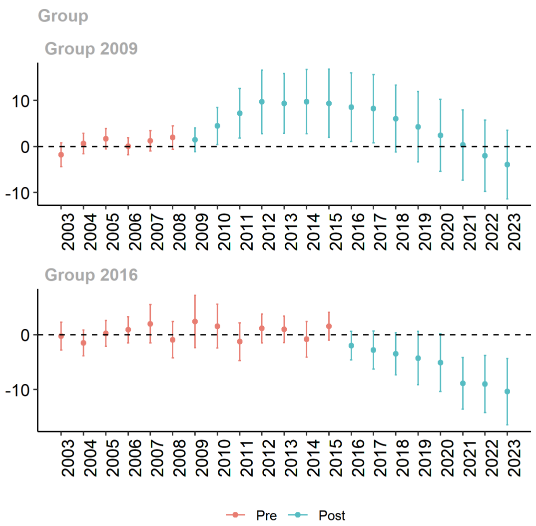
FIGURE B9
The effect of earthquakes on Potential Support Ratio



(a) National



(b) Urban



(c) Rural

Notes: see Figure B1.

References

DOTTORI, D. (2024): "The effect of the earthquake in Central Italy on the depopulation of the affected territories," *Regional Science and Urban Economics*, 105, 103985.