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When Capital Falls to Pieces: Public Investment and the Role of Private Capital Stock

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Abstract

This paper considers the role played by capital stock endowments at local level in the private sector's responsiveness to public investment. Using innovative municipality-level data, empirical evidence is obtained within the context of Northern Italy through a spatial regression discontinuity approach, exploiting the 2012 earthquake as an exogenous shock to private capital stock. The results suggest that, following the shock, areas with lower levels of private capital are more responsive to state-funded investment incentives targeted at production, than direct public investments in transport infrastructure. Investment incentives for production show higher returns in areas with lower private capital stock, on the back of a larger increase in access to secured credit associated with the policy. Instead, direct public investments in infrastructure appear to have a higher return to private employment and investment in areas with higher private capital stock, where private activity can be stimulated through public investment complementary with private capital stock. Overall, these results provide insights applicable to both post-disaster emergency response programmes and public development policies. In order to stimulate private capital and broader economic development, interventions should first aim to develop a sufficiently strong private capital basis and, later, leverage on its complementarity with public infrastructures, in order to further foster economic development.

JEL Classification: F10, F14, L80.
Keywords: Trade Agreements.

1 Introduction

The uptake of public investment projects to stimulate economic growth is long-dated and, through the adoption of place-based policies, public investment has become an established tool to support local economic development and reduce/address inter-regional inequalities. Economic growth is stimulated through the increase in private productivity associated with public capital investment (Aschauer, 1989). At local level, this fosters additional job creation and higher income, improving the competitiveness of the area receiving the investment.

Public investment accounts for a significant share of GDP in developed countries. In EU member states in 2020 it was around 3% of GDP and more than half of that was financed through the EU Cohesion Policy, accounting for €355bn between 2014-2020 (European Commission, 2022). The toolbox of governments, supranational and international organisations today comprises a vast range of public investment interventions, ranging from more traditional infrastructure investments, to co-financing or interest rate subsidies for private investments in productive assets or in research & development (R&D).

The debate is still open, however, on the context-specific factors affecting the effectiveness of public investment projects in stimulating economic activity and the optimal type of investment intervention, given those context-specific features. Institutional characteristics, politics and intensity of treatment have all been shown to significantly matter (Banister and Berechman, 2001). These are all factors affecting the supply side of public investment provision. Less rich is literature analysing demand side factors at play, but empirical evidence, with empty EU-financed Portuguese highways coming to mind, shows that those are, nonetheless, very likely to matter too.

This paper looks at the role played by capital stock endowments at local level in the private sector's responsiveness to public investment. Private capital stock affects the private sector's demand for public capital services determining, in equilibrium with the supply of those, the utilisation rate of public capital services (Zhu, 1995). This, therefore, crucially affects the gains in private productivity derived from public capital investment and, as a consequence, the resulting stimulus to local economic growth. Despite the centrality of private capital stock in determining the effectiveness of public investment on local economic growth at a theoretical level, empirical literature is scarce in analysing the contribution of this specific factor. This is understandable given the strong endogeneity associated with such a research question. Private capital stock levels are strongly correlated to broader economic development, access to credit, institutional quality and the public sector's investment strategy experience.

This paper aims to fill this specific gap in the literature, by exploiting a negative shock to local private capital, in order to derive insights into the level of its importance in determining the stimulus to local economic growth from different types of public investment interventions. Empirical evidence is obtained within the context of Northern Italy, through a quasi-experimental approach, exploiting the 2012 earthquake as an exogenous shock to private capital stock. Fundamental to the analysis carried out in this paper is the creation of a novel database, compiling and harmonising rich micro-level data from different sources.

The paper is structured as follows: Section II contextualises the paper within the relevant theoretical and empirical literature; Section III outlines the theoretical model; Section IV provides details on the 2012 earthquake in Northern Italy, the event used as a quasi-experimental setup; Section V discusses the main data sources used; whilst Section VI and VII detail respectively the empirical identification design and econometric model. The aggregate results are presented in Section VIII; whilst Section IX illustrates sectoral heterogeneity, with conclusions presented in Section X.

2 Literature Review

Led by the seminal works of Aschauer (1989) and Gramlich (1994), macro literature has investigated at length public investment as a source of stimulus to economic growth. Economic growth is stimulated through the increase in private productivity associated with public capital investment (Aschauer, 1989). Formally, this derives from an expansion of the standard private firm's Cobb-Douglas production function, to include the stock of public capital (G) as a production input beside private capital and labour, $Y = f(L, K, G)$. This implies the existence of increasing aggregate returns in the economy upon the standard assumption of constant returns to scale in private labour and capital factors. Considering total factor productivity being a function of both public and private capital stock1, a net positive impact of public investment is expected to materialise until the point when the marginal product of public capital outweighs that of private capital (Aschauer, 1998). In Aschauer's framework, at aggregate level, the optimal level of public capital stock is, therefore, a direct function of the level of private capital stock. Zhu (1995) innovates Aschauer (1989)'s framework,2 attributing outcomes on private output, not to public capital stock directly but to the use of public capital services. In Zhu (1995), the return to public investment also depends upon the private demand for it and, therefore, a-less-than-full utilisation rate can equally erode the productivity gains from the investment.

As place-based policies have started gaining a foothold, economic geography literature has considered the impact of public investment at local level and the spatial spillovers and dynamics, which are triggered as a result. At firm-level, public investment is expected to generate an increase in private productivity (Aschauer, 1989; Gramlich, 1994; Zhu, 1995), which fosters an increase in demand for labour and higher income at a local level, improving the competitive position of the area receiving the investment. Subject to mobility in labour and capital markets, this has consequences on the pre-existing spatial equilibrium.

[1] In a standard Cobb-Douglas production function $Y = \mathrm{A}\, f(L, K, G)$, where A represents total factor productivity, Aschauer (1997) posits that $\mathrm{A} = \mathrm{A}\left(\frac{KG}{K}\right)$ with A”>0.

[2] For Zhu (1995) $Y = f(L, K, S)$, where $S = f(U, G)$ and U is the utilisation rate of public capital.

The extent of spatial spillovers and impact on spatial equilibria at national level differs, depending on the type of public investment.

Kline and Moretti (2014) show, through a spatial equilibrium model, how with perfectly mobile workers and an inelastic housing supply, the entire benefit of location-based investment (or labour) subsidies would be capitalised in land rents. As place-based policies often have the explicit aim of decreasing territorial inequalities, this brings into question their validity to achieve that objective. Kline and Moretti (2014) argue that, with less than perfect mobility of workers, such policies would positively affect the utility of infra-marginal workers but, in the absence of perfect residential segregation by income, a direct transfer of income or one that is demographic-targeted, would provide a more efficient solution to reducing inequalities.

Literature considers the impact of infrastructure investment on regional growth through two different approaches. One is associated with Solow (1956), which sees infrastructure increasing the productivity of human and physical capital, leading to lower production and logistic costs and higher regional demand. When infrastructure serves as a direct input in the production process, then regional output should also increase as a direct consequence of the public investment.

The other approach follows from the work of Richardson and Townroe (1986), in which natural resources provide the endowment supporting the initial regional growth stimulus. Regions more highly endowed to start with, provide initially higher returns on investment, which attract additional investment and agglomeration economies further reinforce these advantages. In this framework, investments in infrastructure promote regional development by providing an improvement in public facilities/services that complement private investment, reduce congestion and relax capacity constraints. These increase the attractiveness of the region for additional firms and increase the private capital growth rate.

Furthermore, private capital can be used as collateral to access secured credit in the banking sector (reference). This suggests a self-reinforcing feedback loop from private capital development, as any increase is associated with a growing leverage potential (reference)

Cross-country empirical evidence corroborates the importance of complementarity between public and private capital in the ability of public investment to foster regional growth (Fratesi and Perucca, 2019, 2020; Romp and De Haan, 2007; Bayraktar, 2019, Martino, 2021). Higher levels of private capital at regional level are generally associated with increasing returns from EU Cohesion policy investments (Fratesi and Perrucca, 2019, 2020) and public R&D investments (Martino, 2021; Sadraoui and Chockri, 2010). Policy investments in immaterial assets (e.g., labour market policies) appear to be more effective in regions that are more highly endowed with territorial assets. On the other hand, the effectiveness of investments in tangible assets negatively correlates with the region's level of urbanisation and agglomeration economies (Fratesi and Perrucca, 2014). Delving more deeply through evidence collected from western EU countries, Fratesi and Perrucca (2019) show that areas poorly endowed with territorial capital exhibit lower returns on all types of investment, except those directly related to the establishment of private businesses (e.g., policies targeting SMEs). This is consistent with findings from Bachtrogler et al. (2018), in which the impact of public grants on firm growth is actually larger in regions with lower income or scant endowment of territorial assets, as firms in those regions are unlikely to be able to rely on external assets.

The different types of public investment not only interact through different channels with private capital but also on a different spatial level. Whilst public subsidies or grants are much more localised in their impact, public investment in infrastructure is characterised by a network effect (Álvarez-Ayuso et al., 2016), especially in the case of investment in transportation (Deng, 2013). Any piece of transport network is related and, thus, an individual investment by improving connectivity of a link, for instance, can affect the entire network (Moreno and Lopez-Bazo, 2007). The economic impact is also not confined as a result but diffused through the transport network. This also has consequences for an empirical identification of the impact of an investment in transport infrastructure, which is generally captured at the transportation network-wide level, rather than in local proximity to the investment's location.

This paper studies a negative shock on private capital stock, making two main contributions to existing literature. First, it contributes to the literature, just discussed, by deriving empirical evidence on the role of private capital's complementarity with the impact of public investment on private productivity and local economic growth. Second, it provides insight into the ramifications of destruction from natural disasters and the local response to public policy interventions post-disaster.

Natural disasters affect the economy through direct and indirect channels. The direct economic impacts are the ones associated with the destruction of assets directly associated with the natural disaster event. These direct economic losses, in turn, affect production and consumption within the economy, in the short and long term (Kousky, 2014). Botzen et al. (2019) provide an in-depth review of the literature contributions, analysing direct and indirect losses from natural disasters from a theoretical and empirical standpoint.

Destruction of machinery and real estate affects the ability of firms to produce in the short term which, together with the temporary relocation of people and/or their inability to work, has negative consequences on consumption. Theoretical economic models differ in their predictions associated with a similar negative shock on capital and labour. Computable General Equilibrium models and Neoclassical Growth models predict a gradual return to the pre-disaster steady state, except in the instance in which natural disasters permanently affect savings, depreciation or growth in productivity (Berlemann, Steinhardt and Tutt, 2015). Instead, endogenous growth models predict that the accelerated depreciation of capital, due to the disaster, would be associated with additional investment, resulting in higher growth in productivity because technology would be updated. This is the so-called "build-back-better" hypothesis (Klomp and Valckx, 2014). Similar to this is the estimated impact from models of learning, in which the destruction of capital and labour may stimulate learning and growth in productivity during reconstruction. The disruption to specific sectors and local economy generates distortions in inputs supplied to other sectors and regions. The substitutability across goods and regional markets partly mitigates the negative impacts directly associated with the shock (Koks and Thissen, 2016; Carrera et al., 2015).

Empirical literature studying the economic effect of natural disasters is not rich but has grown recently, especially in light of the increased interest in climate change and the anticipated associated increase in extreme weather events. Empirical evidence shows an increase in direct losses over time from natural disasters, which has been attributed historically to economic and population growth and, more recently, to climate change (Estrada, Botzen and Tol, 2015). Negative indirect effects from natural disasters are detected at an empirical level and appear to be a significant drag on economic growth, particularly in low-income countries, which show a lower resilience to shocks. Evidence on the longer-term indirect impact is scarce but, so far, points to a persistently negative impact on growth associated with natural disaster, in particular for hydro-meteorological disasters. This suggests that studies focusing on the short-term effects are likely to be underestimating the total loss associated with the calamity.

Methodologically, this paper applies a spatial regression discontinuity design (RDD) (Calonico et al., 2019; Keele and Titiunik, 2015), technique originating from the seminal work of Holmes (1998) and later applied to a variety of fields, amongst which is recent Economic Geography literature (Albanese et al. 2020; Crescenzi and Giua, 2020). The technique exploits the existence of a threshold, around which no self-sorting can occur, which leads to exogenous allocation to treatment and control groups of the units of observation.

3 Theoretical Model

This paper studies the role of private capital's complementarity with the impact of public investment on private productivity and local economic growth. It does so by being grounded theoretically in a model of a private firm's production function, augmented to incorporate the impact of public capital services available to the firm.

The firm produces output, Y, based on an à la Zhu (1995) production function

$$Y = f(L, K, S)$$

Where L corresponds to labour inputs, K to capital inputs and S to the level of public capital services.

The traditional Zhu (1995) specification ($S = U \times G$) is innovated by adjusting the effective public capital stock for congestion

$$S = U \times G^{(1-\zeta)}$$

with U being the utilisation rate of public capital, G being the stock of public capital available (G^S) and ζ being the congestion factor. The utilisation rate, U, is defined within an interval going from 0 (no utilization) to +∞ posing no limit to the over-utilisation of capital. The firm production function can, therefore, be rewritten as $Y = f(L, K, UG^{(1-\zeta)})$. Public capital is used at full capacity when $U = 1$. Congestion occurs upon over-utilisation of capital, so $\zeta = 0$ if $U \leq 1$ and $\zeta > 0$ if $U > 1$.

Capital stock, both public and private, evolves through a standard law of motion. The law of motion for the public capital stock, G, can be defined as follows:

$$G_t = (1 - \delta_t)G_{t-1} + I_t + \varphi_t$$

Where I_t is the investment flow and $\varphi_t \delta_t$ is the depreciation factor, which can be augmented by splitting it into two components, one related to time depreciation $\theta(t)$ and one related to usage $\gamma(U_t)$.

$$\delta(t, U_t) = \theta(t) + \gamma(U_t)$$

The first component is akin to technology becoming obsolete over several years, whilst the second one monotonically increases with usage. Following Taubman and Wilkinson (1970), Greenwood, Hercowitz and Huffman (1988), Finn (1995, 2000) and Vasilev (2018), the endogenous usage-related depreciation can be defined with the following functional form, consistent with faster depreciation upon higher usage (Keynes, 1936).

$$\gamma(U_t) = \gamma_0 + \frac{U_t^{\gamma_1}}{\gamma_1}$$

Where $\gamma_0 > 0$ and $\gamma_1 > 1$, with the former constituting the usage-related depreciation on "launch day" and the latter determining the usage resistance, the higher γ_1 the lower the resilience to usage.

The utilisation rate of public capital services is endogenously determined by the equilibrium between private sector demand for public capital services G^D and the public sector supply of public capital G^S.

$$U_t \equiv \frac{G_t^D}{G_t} = \frac{f(Y)}{G_t^S}$$

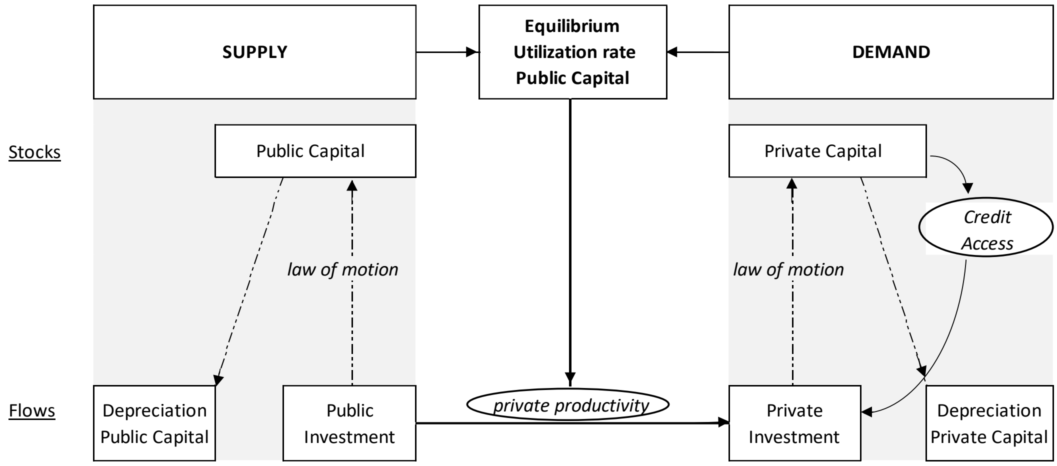
The demand for public capital services from the private sector depends on private output Y and on its price, but for the purposes of this model inelasticity to price is assumed.[3]

At steady state, assuming the public sector has perfect information over the private sector's demand and no budget constraints, the utilisation rate should be equal to 1. Budget constraints can result in under provision of public capital, driving the utilisation rate above 1, with consequent congestion.

Figure 1 summarises the theoretical model just presented.

[3] Although the demand for public capital in principle depends on its price (like any other goods or service), in most cases firms pay a shadow price for public capital, notwithstanding their direct use of it, hence, why it is possible to assume price inelasticity.

Figure 1: Theoretical Framework



Five main takeaways relevant for the research question of interest are, therefore, derivable from this modelling framework and tested empirically:

a) An investment in public capital does not necessarily translate into an increase in private output or productivity. The extent to which it does, largely depends on the pre-investment utilisation rate and on the rate of complementarity with private capital stock.
b) An exogenous negative shock to private capital stock should decrease the utilisation rate of complementary public capital at local level. The same shock should also decrease the value of assets which can be used as collateral for investment financing. Upon no prior congestion (initial steady-state equilibrium), these are expected to decrease the "local fiscal multiplier effect" associated with public investment.
c) The sensitivity of the "local fiscal multiplier effect" on private capital stock depends on the type of private investment the public investment aims to stimulate. The higher the complementarity of private investment with prior private capital stock levels, the higher the sensitivity.
d) In case of prior congestion, a negative private capital shock could reduce congestion, leading to efficiency gains, partly offsetting lower private demand.
e) An exogenous negative shock on private capital stock should also directly curtail private investment through the reduction in the value of assets pledged as collateral for investment financing.

4 Background

In 2012, a series of earthquakes struck Northern Italy, at the crossroad between the regions of Emilia-Romagna, Lombardia and Veneto. A long series of seismic shocks culminated in two main earthquakes occurring on 20th and 29th May 2012 with the epicentre respectively in Bondeno (province of Ferrara) and Medolla (province of Modena). The first one registered an epicentral magnitude of 6.1 and hypocentral depth of 9.5 km, the latter recording a epicentral magnitude of 5.9 and depth of 8.1 km.[4] The human and economic losses generated by these events have been recently officially quantified in 2017.[5] It is estimated that 28 people died and another 300 were injured. The damage and destruction of physical capital rivalled the one observed only few years earlier at L'Aquila, in 2008. More than 31 thousand private housing units were damaged and 45,000 people had to flee their homes. 39 townhalls were deemed inaccessible, 570 schools, 16 libraries, 12 theatres and 782 churches damaged. Overall, public emergency funding covered damages amounting to about €5 billion, of which €4.5 billion was assigned privately to cover damages and €653.2 million was invested by the state directly in public works. As part of the process to allocate state emergency funding and, in some cases, temporary housing solutions, the Civil Protection Department identified 104 eligible municipalities on the basis of the existence of damages directly related to the seismic shocks.[6] For those municipalities the state offered contributions of up to 80% of the cost of repairs and the reconstruction of private housing real estate[7] and up to 80% of the cost of repairs and reconstruction of commercial real estate, the purchase/reparation of machinery damaged by the seismic shock and any other expenses related to the resumption of productive activity.[8] Furthermore, access to below-market interest rate financing, as well as state guarantees of up to 80% of the total financing for up to 3 years after the seismic shock, were extended to firms located in the municipalities affected by the seismic activity.[9]

5 Data

This section provides an overview of the datasets used in the empirical analysis. The dataset used in this paper is novel and is the result of extensive work conducted in collecting and merging six different highly granular data sources.

Municipality-level annual data on private employment and private business generation from 2004 to 2017 is derived from the Italian Business Register of Local Units (ASIA LU). The business register provides information on the number of local units of active enterprises and the number of persons employed in the local units of active enterprises.

[4] Source: Parametric Catalogue of Italian Earthquakes (CPTI15 v2.0).
[5] Official data and related documents available at https://docsismaemilia.it/
[6] The list of damaged municipalities eligible for emergency support measures is contained in Annex 1 of 1 June 2012 Decree.
[7] Ordinance n.29 Section 3(1), Regione Emilia-Romagna (28 August 2012)
[8] Ordinance n.57 Section 2-4, Regione Emilia-Romagna (12 October 2012)
[9] Legislative Decree 74, Section 10-11 (6 June 2012)

A measure of annual private sector investment at a municipality level, for which no official data is publicly available, is obtained by integrating records from two datasets sourced from the Italian Statistical Office, the Structural Business Statistics (SBS) and the regional decomposition of National Accounts with the Business Register of Local Units (ASIA LU).

Project-level data on public sector investments is obtained from the OpenCup database, the official open data platform of the Italian government for public investments. The platform records all programmed investments carried out with public funds (national, European, regional or local authorities, with or without private co-funding). OpenCup contains, for every project, details on the year of approval, the year of completion, the total cost, the total public financing, the nature of the public investment (public works, investment incentives or natural disasters emergency funding), the area of intervention (e.g., real estate, transport, R&D, environment, productive sector, etc) and the status (open closed or revoked/cancelled). Annual project-level information is used to construct municipality-level indicators of public investment through a bottom-up approach.

Data on seismic intensity at a municipality level for the 2012 earthquake is obtained from the application of Pasolini et al. (2008) attenuation law model to epicentral macroseismic and instrumental data, obtained from the Parametric Catalogue of Italian Earthquakes (CPTI15 v2.0) and municipality-level geographical coordinates obtained from the Italian Statistical Office.

Additional detail on the data and the construction of variables is provided in **Section A of the Appendix**.

6 Empirical Identification Strategy

This paper looks at the role played by capital stock endowments at local level in the private sector's responsiveness to public investment. In particular, it aims to derive insights into the importance of its level in determining the stimulus to local economic growth from different types of public investment interventions.

As already discussed in **Section I**, the endogenous nature of the relationship between private capital stock and broader economic development, access to credit, institutional quality and a range of other factors affecting fiscal multipliers, makes it hard to answer such a question empirically. Most literature contributions have adopted a (S)VAR, time-series or panel-data approach (Martinez-Lopez, 2006; Aschauer, 1989), which pose clear limitations to the causal interpretation of their estimates. The lack of data and measurement difficulties for capital stocks, both at a public and private level, adds an additional layer of difficulty in the empirical identification of such a research question.

A quasi-experimental approach is adopted in this paper, to address the endogeneity associated with private capital stock levels. Destruction from the 2012 earthquake in Northern Italy is used as an exogenous negative shock to physical private capital at local level. Earthquakes with a major destructive power can be considered as random events in time and space.[10] They provide appropriate empirical case studies, therefore, for a negative shock to capital. The case for randomness is particularly strong for the 2012 Northern Italy earthquake, as it occurred in an area characterized by low seismic risk according to the National Institute of Geophysics and Volcanology (INGV).[11]

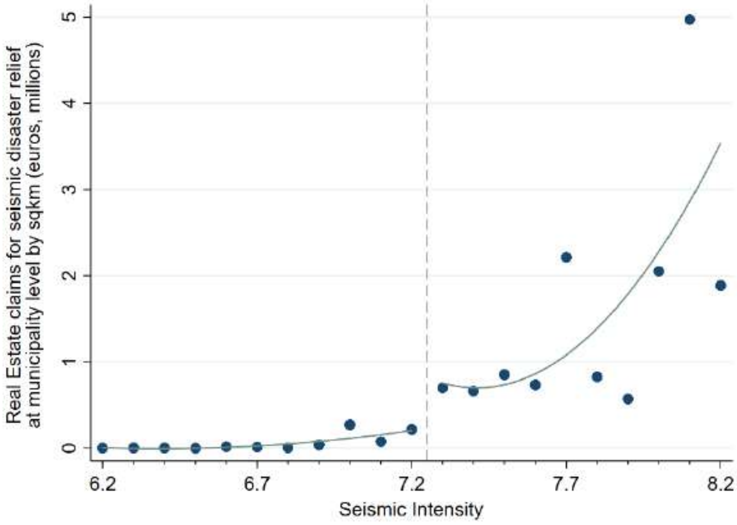
Destruction of physical assets occurring from earthquakes, however, can also be associated with the relocation of businesses and human capital, loss of human capital and, in the most extreme cases, complete erasure of the social and economic system at local level. In order to control for these aspects and to exclusively study the exogenous shock to capital associated with it, a regression discontinuity design is employed. A threshold for severe damage to buildings from a seismic shock is identified by civil engineering and risk hazard assessment literature (Barbat et al., 2012), on one side of which damages from the horizontal ground displacement are structural and on the other side of which they are purely cosmetic. This threshold is estimated to correspond to a seismic intensity of 7.25 in Italy (Bindi et al., 2011; Pasolini et al., 2008). Additional detail on the identification of the threshold for severe damage is provided in **Section B of Appendix**.

The validity of this threshold is tested through the data on damages used in this paper. As discussed in **Section IV**, only days after the two main events of the 2012 earthquake, the Italian government passed an emergency decree allocating state funding to cover the cost of repair and reconstruction of residential real estate located in municipalities damaged by the seismic shocks. Only properties located in municipalities having experienced a seismic intensity above 6.1 were eligible for damage compensation[7] as this was deemed to be the lowest intensity at which damages could be directly attributable to the seismic shock. Due to the exogeneity of the seismic intensity experienced, no self-sorting is possible around the threshold. Data on the private claims submitted for compensation of private housing seismic damage is obtained from the OpenCup database. **Figure 2** shows the average value of those claims by municipality, plotted against the estimated seismic intensity of the eligible municipalities from which they originate. The total value of housing real estate damage claims by square kilometre by municipality jumps when the intensity perceived during the seismic shock is above 7.25, with the difference in the trend below and above the threshold being statistically significant at less than the 5% level. The presence of such a threshold is also

[10] From a broad geographical point of view, earthquakes show spatial autocorrelation: seismic areas - coinciding with boundaries between tectonic plates and the area of deformation surrounding them - are pretty well-defined across the world. Of course, areas can over time experience changes to their level of seismicity but, broadly speaking, one can see a pattern in terms of spatial location of earthquakes. That is not to say, however, that the specific location of a future earthquake can be confidently predicted, nor the time at which that would occur. Despite the efforts in this direction, earthquakes can still be considered as random shocks in space and time and all the more so in the case of major earthquakes carrying a major destructive power. Furthermore, if one could not agree on the spatial randomness of the epicentre, which often falls within already well-known seismic regions, one would hardly be able to argue in favour of non-randomness, when considering not just the epicentre location, but also the depth of the hypocentre and the magnitude of a given earthquake. As I will discuss in detail later, it is the first two factors, together with the density of the medium of transmission, which jointly determine the rate of decay of the seismic shock intensity from the hypocentre to the epicentre and the surroundings.
[11] Stucchi M., Meletti C., Montaldo V., Akinci A., Faccioli E., Gasperini P., Malagnini L., Valensise G. (2004). Pericolosità sismica di riferimento per il territorio nazionale MPS04 [Data set]. Istituto Nazionale di Geofisica e Vulcanologia (INGV).

detected in data coming from post-2009 L'Aquila earthquake claims, which we do not show here.

Figure 2: Discontinuity in Real Estate damage based on seismic intensity



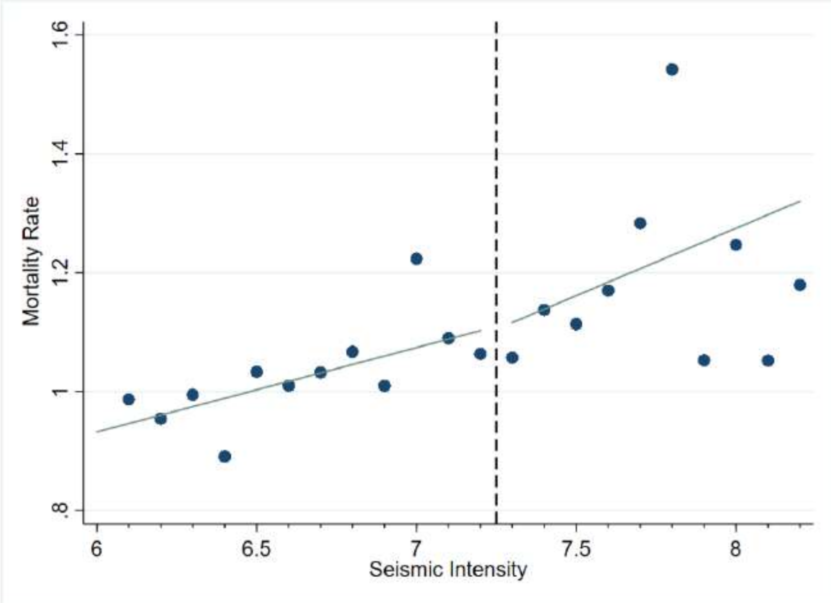
Notes: Data is sourced from Opencup.

By using data exclusively from municipalities that were equally eligible for state damage compensation, it is possible to claim that the differences observed across the threshold, in the size of the claims submitted, was not driven by differences in upper limits to the claim submitted, nor in the likelihood of submitting one, but genuinely reflects the differences in the average value of damages to residential properties. Furthermore, there is no reason to believe that private claimants in municipalities below the threshold have artificially lowered the value of their claim, nor that cost claims are inflated right above the threshold, given the need for a professional independent certification of the cost claim prior to submission.[12] Finally, given the randomness of the threshold location, it is possible to claim that the jump at the threshold is not driven by significant differences in the quality of buildings across the threshold, or by other factors affecting the resistance to seismic shocks. **Section B of the Appendix** contains robustness checks in this respect.

The observed discontinuity in physical capital destruction at a seismic intensity of 7.25 is not associated with a significant increase in the loss of human capital, as shown by **Figure 3** reporting the average mortality rate at municipality level experienced in 2012. It is possible to observe how the average mortality rate increases nearer to the epicentre but, up until a seismic intensity of 7.75, the trend is not significantly different from the one observed below the threshold, suggesting that no discontinuity in human capital occurs at the threshold.

[12] Legislative Decree 74, Section 3 (1 a-b) (6 June 2012)

Figure 3: Smoothness of Human Capital around the threshold



This provides reassurance on the effectiveness of the Regression Discontinuity Design, adopted to control for confounding dynamics previously mentioned, which can be associated with destruction of physical assets from earthquakes. This threshold, therefore, appears to represent a robust discontinuity in the destruction of physical assets without being associated with the discontinuity of other factors affecting production.

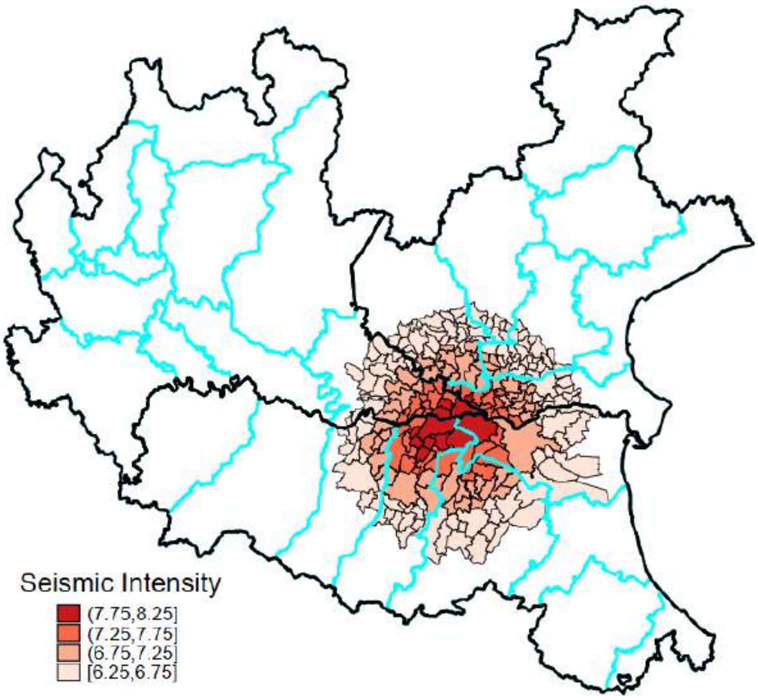
Physical capital encompasses both public and private capital. However, their nature differs and so does the validity of the threshold. The network character of public capital (Deng, 2013; Moreno and Lopez-Bazo, 2007; Álvarez-Ayuso et al., 2016), which was already discussed in Section II, means the impact of destruction to one part of the network does not remain confined but rather diffuses through the entire network. This means that in the case of public capital, such a physical destruction threshold does not correspond with a threshold for the use of public capital services. In practice, a destruction of a bridge on the right side of the threshold equally affects municipalities on the left-side of the threshold sharing the same network of public services. We, therefore, assume that the threshold in physical capital destruction adopted here refers exclusively to a discontinuity of private capital destruction.

7 Econometric Modelling Strategy

This paper adopts a Spatial Regression Discontinuity Design to identify the role played by private capital in the effectiveness of different public investment policies over local economic development. The discontinuity of interest is represented by a threshold for severe destruction of physical private capital set at 7.25 in seismic intensity, as discussed in the previous section.

Figure 4 provides a map of the estimated seismic intensity for the municipalities more directly affected by the 2012 earthquake in Northern Italy, representing the case study of choice. As discussed at length in **Section VI**, within a sufficiently small distance from either side of the threshold, the loss of human capital and other dynamics generally correlated with seismic destruction, are assumed to be constant. Public capital networks, in this context, are assumed to be organised at provincial level (NUTS 3 level), with their extension marked by the light blue within-region borders in **Figure 4**. In Italy, particularly in the case of public transport infrastructure, management is mostly occurring at provincial level, with the consequence that season tickets, timetables and connectivity are also provided at that level. This means that, on the basis of the network character of public capital, within a sufficiently small estimation bandwidth and within the same province, it is possible to assume that no significant differences in public capital stock variations should occur, on average, for municipalities on either side of the seismic threshold.

Figure 4: Map of estimated seismic intensity at municipality level



Notes: Thick black lines define NUTS2 regional borders, light blue lines define NUTS3 provincial borders and thin black lines define NUTS4 municipalities borders. Seismic intensity is estimated based on Pasolini et al. (2008) and colour-coded for eligible state financing municipalities.

In line with RDD literature, within each province (NUTS 3 region), municipalities (NUTS 4 regions) with seismic intensity above the threshold are matched to those falling below the threshold. Seismic intensity is the forcing variable in the model. As seismic intensity is a function of the relationship between the geo-coordinates of the epicentre and the municipality centroids, methodologically this paper contributes to the spatial RDD literature by presenting a non-standard application of a spatial discontinuity framework going beyond the more classic Euclidean distance setup.

In order to obtain medium term estimates, the regression model adopts a 5 year pre- and post-estimation window. The year of the seismic shock, 2012, is excluded to avoid exceptional circumstances, such as the possible temporary displacement of residents occurring over H2 2012 and temporary damage to critical infrastructure, such as electricity power lines, affecting the regression estimates.

Municipality-specific impacts are estimated by means of the non-parametric model, specified in equation (1) in each of the provinces affected by seismic intensity above 7.25.

$$(1)\quad Y_{i,t} = \alpha_0 + \alpha_1 T_i + \alpha_2 P_t + \alpha_3 P_t T_i + \alpha_4 I_{i,t} + \alpha_5 (T_i I_{i,t}) + \alpha_6 (P_t I_{i,t}) + \alpha_7 (P_t T_i I_{i,t}) + \alpha_8 (S_i I_{i,t}) + \alpha_9 (T_i S_i I_{i,t}) + \alpha_{10} (T_i P_t S_i I_{i,t}) + \alpha_{11} (P_t S_i I_{i,t}) + \alpha_{12} S_i + \varepsilon_{i,t}$$

where i indicates the municipality, and t the year of observation.

On the left-hand side, $Y_{i,t}$ is the natural logarithm of the outcome variable of interest. The following outcome variables are considered: private sector's net business generation, net changes in employment and gross fixed capital investment. On the right-hand side, T_i is a dummy variable indicating the municipality's treatment status, equal to 1 for municipalities experiencing estimated seismic intensity higher or equal to 7.25 (the threshold for severe damage to private capital stock), 0 if below 7.25; P_t is a dummy variable equal to 1 for the post-treatment period 2012 < year ≤ 2017, 0 for the pre-treatment period 2007 ≤ year < 2012 - the treatment year is excluded from the sample. S_i is a variable representing the difference between the estimated seismic intensity experienced in municipality i and the threshold intensity of 7.25. This is the forcing variable of the RDD and is akin to a Euclidean distance. Finally, $I_{i,t}$ is the natural logarithm of the value of public investments completed in municipality i in year t. Two distinct types of public investments are individually considered: direct public investments in transport infrastructures and investment incentives to the private sector, in the form of interest rate reductions.

The tables presented in **Section VIII** show the results of a non-parametric estimation over seismic intensity bandwidth $[7.25 - 0.5 \leq Intensity \leq 7.25 + 0.5]$. The estimates exclude very large municipalities to ensure further comparability across the units of observation and, by restricting the sample to the near proximity of the destruction threshold (through the non-parametric bandwidth), epicentre municipalities are also excluded. This is to avoid results being driven by confounding effects occurring in epicentre municipalities where, as previously discussed, displacement and loss of production and human capital may last longer, whilst extra non-governmental aid may be received**. Sections C and D of the Appendix,** nonetheless, also contain the results for bandwidth $[7.25 - 1.0 \leq Intensity \leq 7.25 + 1.0]$ as a sensitivity test. Standard errors are clustered at municipality-level, to control for autocorrelation of the error over the same municipality over time.

The use of an exogenous threshold for seismic generated destruction ensures exogeneity in the change in physical private capital stock in the municipalities that are the object of observation. **Section VI** discusses at length the robustness checks carried out to support this. Challenges to the causal interpretation of the coefficients in equation (1) could, however, come from potential sources of unobservable omitted variable bias, arising from the other factors that capital depletion is interacted with. The seismic destruction and the subsequent reconstruction surely have had an impact, for instance, on public and private investment decisions in general. Several steps are taken in this paper to ensure estimates are unbiased - from endogenous responses to the seismic destruction: (i) the year in which the shock occurs is excluded; (ii) the chosen indicators of private business outcomes, net business generation and net changes in private employment and the proxy for gross fixed capital investment are unaffected by reconstruction work; (iii) the public investments considered exclude public investments related to natural disaster response, (iv) the impact of public investments is considered at their realisation date. With an average time to completion of 4 years, this means that over the time span 2013-2017, we are mostly looking at public investments approved before the seismic shock, thus ruling out endogeneity in that respect (**Table D.1 in Section D of the Appendix** provides additional evidence on this).

The specification presented in equation (1) is, therefore, robust to fundamental challenges to exogeneity, but it does not allow for more than a directional interpretation of the role of capital stock in the stimulus channel of incentives and infrastructure investment over private investment and employment creation. In an effort to obtain a quantitative interpretation of the role of private capital, ideally one would want to have data on the financial value of pre-existing private capital stock in the municipalities considered and on the damages to physical private capital they suffered. But as this data is not available, data on the amount of residential real estate seismic destruction claims by municipality is used in this paper as a proxy for a measure of capital destruction, using the most damaged municipality as a numeraire. This variable, thus defined, is a percentage ranging from 0 to 100, labelled K_i, whose highest value is attributed to the municipality most heavily damaged, based on real estate damages claims and proportionally relative to that. In this specification, laid out in equation (2), the econometric model is equal to equation (1) except for variable S_i in the interactions, which is substituted by K_i.

$$(2)\ Y_{i,t} = \alpha_0 + \alpha_1 T_i + \alpha_2 P_t + \alpha_3 P_t T_i + \alpha_4 I_{i,t} + \alpha_5 (T_i I_{i,t}) + \alpha_6 (P_t I_{i,t}) + \alpha_7 (P_t T_i I_{i,t}) + \alpha_8 (K_i I_{i,t}) + \alpha_9 (T_i K_i I_{i,t}) + \alpha_{10} (T_i P_t K_i I_{i,t}) + \alpha_{11} (P_t K_i I_{i,t}) + \alpha_{12} S_i + \varepsilon_{i,t}$$

The main assumption behind the suitability of this proxy to represent changes in the level of capital stock is that pre-shock capital stock levels per square kilometre were homogenous across the municipalities observed which, given the proximity across the municipalities, it is deemed to be satisfied by the evidence presented in **Section VI** and minor sample adjustments.

8 Main Results

The case for randomness of the 2012 earthquake and the destruction threshold has been discussed at length in **Section VI and VII**. **Table 1** presents additional evidence on the similarity between municipalities[13] located on either side of the threshold within a 1.0 and 2.0 seismic intensity bandwidth, represented respectively, by the second and third concentric circle from the epicentre, and the whole red shaded circular area in **Figure 3**. Municipalities near the destruction threshold present no statistically significant difference in their size. They also show no statistically significant difference in the relative size of their most important sectors by business units and employment prior to the seismic shock, except for the relative distribution of business unit density across sectors within the larger bandwidth. Finally, no significant difference is detected in the per square kilometre value of public works realised prior to the shock.

Table 1: Table of Means

	6.75≤Int≤7.75			*6.25≤Int≤8..25*		
	Int<7.25	7.25≤Int	Difference	Int<7.25	7.25≤Int	Difference
Municipality Area (sqkm)	37.57 [28.542]	36.02 [25.773]	-1.55 (2.859)	39.69 [34.448]	41.71 [35.133]	2.02 (2.805)
Share of Manufacturing business units	19.61 [7.368]	19.53 [6.912]	-0.08 (0.733)	16.87 [6.576]	19.87 [6.655]	3.01 *** (0.532)
Share of Construction business units	17.27 [5.359]	17.54 [4.760]	0.28 (0.516)	18.16 [5.605]	16.90 [4.836]	-1.26 *** (0.401)
Share of Wholesale and Retail trade business units	24.35 [4.897]	23.89 [4.558]	-0.46 (0.485)	25.03 [4.917]	24.05 [4.274]	-0.98 *** (0.354)
Share of Manufacturing employment	42.72 [15.176]	42.39 [13.769]	-0.33 (1.480)	41.35 [15.813]	42.99 [13.559]	1.64 (1.126)
Share of Construction employment	12.11 [6.453]	12.49 [5.677]	0.38 (0.618)	12.07 [6.506]	12.66 [6.263]	0.59 (0.506)
Share of Wholesale and Retail trade employment	17.93 [6.998]	18.09 [7.589]	0.16 (0.765)	18.40 [7.452]	17.53 [7.130]	-0.87 (0.577)
Public works per sqkm (euro, millions)	18107 [55760]	13971 [43048]	-4136 (4964)	19921 [78436]	19900 [65709]	-21 (5492)
Public incentives per sqkm (euro, millions)	452 [2696]	105 [348]	-347 ** (168)	1617 [18070]	91 [306]	-1526 ** (658)
Number of municipalities	36	66		49	189	
Number of observations	264	144		756	196	

[13] Five municipalities are excluded from the sample on account of being outliers in size (Ferrara) and amount of public investment received (Bosaro, Gaiba and Isola Rizza).

This further supports the case for the exogeneity of the destruction threshold, since there is no significant difference in public intervention prior to the shock, which might have made one area more resilient to such a shock than another (e.g., through more frequent bridge maintenance, newer building structures, etc.). **Section B in the Appendix** provides further robustness checks for RDD assumptions, including the density test.

To start, we consider the impact of private capital stock levels on the elasticity of private investment and employment outcomes relating to direct public investment in transport infrastructures.

As already discussed in **Section VI**, it is assumed that given the network nature of public capital stock, within a sufficiently small estimation bandwidth and within the same province, the destruction of public infrastructure stock is homogeneous across municipalities located on either side of the seismic threshold. This means that the only difference following the seismic shock between treated and non-treated municipalities should be the level of destruction of physical private capital stock. As a consequence, based on an endogenous utilisation rate framework of public capital services (**Section II**), following an initial decrease in supply of public capital for all municipalities within the same infrastructure network (i.e., same province/NUTS 3 region), holding private demand constant, the utilisation rate of public capital services should increase. Treated municipalities however, also affected by private capital destruction, should experience a larger decrease in public capital demand than non-treated municipalities, resulting in a lower equilibrium utilisation rate. This is expected to lead to lower complementarity, with private capital coming from a public investment in transport infrastructure for treated municipalities and, hence, lower increases in private productivity, investment and employment associated with it.

These theoretical findings are tested empirically, with the results presented in **Table 2** based on the RDD model (1) outlined in **Section VII**. The regression model is estimated at provincial level, therefore only provinces presenting municipalities on either side of the threshold are considered, namely: Modena, Ferrara, Mantova, Rovigo and Bologna.

Public transport infrastructure investments carried out in treated municipalities (i.e., those having experienced severe destruction of physical private capital) present a lower effectiveness on private employment, business creation and investment following the shock. Every additional point of seismic intensity higher than the threshold is associated with a statistically significant 0.28% decrease in the stimulus to private investment, from an additional 1% in public transport investments for three out of five provinces. In the case of Modena, that is associated with a 0.09% and 0.10% reduction, respectively, in the stimulus to private employment and net business generation. A significant effect is estimated at the threshold for almost all private business indicators.

This is consistent with the expected theoretical results. The municipalities not affected by serious private capital destruction are able to fully absorb in their private production the benefit given by additional transport infrastructure and, possibly, gain from the reduction in congestion, which was generated by the initial reduction in supply in the network straight after the seismic shock. Instead, municipalities where severe private capital destruction occurred, are likely to have experienced a reduction in the utilisation rate straight after the shock, as the reduction in private demand from private physical capital destruction dominated the reduction in congestion, generated at network level from the negative shock to public capital stock.

Based on the complementarity between public transport investment and physical private capital stock, the results suggest that private investment did not pick up at the same rate as public investment in transport infrastructure and, therefore, private firms were not fully able to pick up the additional potential productive contribution of public transport investment, as much as firms located in areas not affected by serious private capital destruction.

Table 3 contains the results obtained from a regression model explicitly proxying for physical private capital levels. The estimates are directionally consistent with the ones contained in Table 2. A 1% lower private capital stock level is associated with a statistically significant decrease in the effectiveness of an additional 1% in public transport investments in every province over private employment (ranging from 0.3% to 0.9%), and over net business generation (ranging from 0.2% to 0.9%). No significant marginal impact on gross fixed capital formation was found, but the threshold effect remains largely negative and significant. Robustness checks of these results by bandwidth size are contained in Section C of the Appendix (**Tables C.1-C.2**).

One of the concerns associated with these estimates is that lower returns from public investment could also be associated with the impact of severe private capital destruction in the local market demand for goods and services. These concerns are addressed in consideration of the results by tradeable and non-tradeable sectors separately and by further excluding from the tradeable sector construction firms, which could have benefitted from the post-disaster reconstruction. The results presented in **Table 4** are akin to those presented in Table 2 in terms of model specification. Overall, as in Table 2, the loss in physical private capital has the strongest impact on the return of public investment from private investment. Firms operating in tradeable sectors appear to experience a larger reduction in the stimulus from public transport infrastructures investment, as a result of the shock to private capital, than those operating in the service sector. The impact is even higher if the construction sector is excluded. This suggests that the results presented in Table 2 and 3 are unlikely to suffer from a bias associated with a change in local demand for goods and services in the treated municipalities, as that would point to the opposite balance of results between tradeable and non-tradeable. Firms in the construction sector, however, appear to have suffered less than those in other tradeable sectors, partly as a result of the increased business associated with reconstruction and the possible local nature of that. The higher impact on tradeable firms versus non-tradeable firms could, however, be rationalised through the higher importance of transport infrastructures in tradeable goods production than in services and the resulting higher complementarity of private capital stock to transport infrastructure.

Table 2: Within-province RDD results for transport public infrastructures

	6.75 ≤ Seismic Intensity ≤ 7.75				
	Modena			Ferrara	
	(1)	(2)	(3)	(4)	(5)
VARIABLES	N.Workers	N.BU	GFCF	N.Workers	N.BU
Post	0.397	0.303	0.544	0.441	0.343
	(0.460)	(0.422)	(0.427)	(0.464)	(0.426)
Treated	-1.576*	-1.479*	-3.886**	-2.294***	-1.948***
	(0.858)	(0.737)	(1.544)	(0.383)	(0.381)
Post X Treated	0.640	0.863	4.109**	0.679	0.795
	(0.705)	(0.676)	(1.609)	(0.500)	(0.526)
Int.- 7.25	1.235***	1.052***	1.402***	1.235***	1.052***
	(0.337)	(0.304)	(0.315)	(0.339)	(0.306)
Transport Public works X Post	-0.0432	-0.0330	-0.0895**	-0.0466	-0.0361
	(0.0447)	(0.0391)	(0.0378)	(0.0452)	(0.0394)
Transport Public works X Treated	0.122*	0.125**	0.399***	0.145***	0.129***
	(0.0655)	(0.0573)	(0.118)	(0.0113)	(0.0189)
Transport Public works X Post X Treated	-0.0613	-0.0735	-0.434***	-0.0784*	-0.0788*
	(0.0712)	(0.0679)	(0.138)	(0.0445)	(0.0418)
Transport Public works X (Int.- 7.25)	-0.134***	-0.118***	-0.144***	-0.135***	-0.119***
	(0.0280)	(0.0248)	(0.0256)	(0.0282)	(0.0250)
Transport Public works X (Int.- 7.25) X Treated	0.0157	-0.0109	0.0722	0.126	0.0938
	(0.111)	(0.106)	(0.122)	(0.0989)	(0.0835)
Transport Public works X (Int.- 7.25) X Post	0.0150*	0.0132*	0.00799	0.0153*	0.0135*
	(0.00788)	(0.00654)	(0.00861)	(0.00805)	(0.00667)
Transport Public works X (Int.- 7.25) X Treated X Post	-0.0896*	-0.0972*	-0.165	-0.0803	-0.0790
	(0.0515)	(0.0539)	(0.132)	(0.0947)	(0.0907)
Constant	4.230***	2.875***	6.192***	4.200***	2.847***
	(0.271)	(0.240)	(0.257)	(0.278)	(0.246)
Observations	5,748	5,748	5,692	5,704	5,704
R-squared	0.142	0.153	0.111	0.145	0.155

	6.75 ≤ Seismic Intensity ≤ 7.75				
	Ferrara	Mantova			Rovigo
	(6)	(7)	(8)	(9)	(10)
VARIABLES	GFCF	N.Workers	N.BU	GFCF	N.Workers
Post	0.598	0.441	0.343	0.597	0.441
	(0.429)	(0.465)	(0.427)	(0.430)	(0.465)
Treated	-4.980***	-2.334***	-2.069***	-5.029***	-2.334***
	(1.007)	(0.391)	(0.369)	(1.102)	(0.391)
Post X Treated	4.849***	0.503	0.713	5.053***	0.503
	(1.156)	(0.481)	(0.521)	(1.208)	(0.481)
Int.- 7.25	1.413***	1.235***	1.052***	1.413***	1.235***
	(0.317)	(0.339)	(0.306)	(0.318)	(0.339)
Transport Public works X Post	-0.0964**	-0.0466	-0.0360	-0.0964**	-0.0466
	(0.0377)	(0.0452)	(0.0395)	(0.0378)	(0.0452)
Transport Public works X Treated	0.455***	0.149***	0.141***	0.460***	0.149***
	(0.0511)	(0.0106)	(0.0120)	(0.0601)	(0.0106)
Transport Public works X Post X Treated	-0.474***	-0.0635	-0.0736*	-0.498***	-0.0635
	(0.0865)	(0.0439)	(0.0419)	(0.0906)	(0.0439)
Transport Public works X (Int.- 7.25)	-0.145***	-0.135***	-0.119***	-0.145***	-0.135***
	(0.0257)	(0.0282)	(0.0250)	(0.0258)	(0.0282)
Transport Public works X (Int.- 7.25) X Treated	0.175	0.126	0.0933	0.175	0.126
	(0.161)	(0.0994)	(0.0848)	(0.162)	(0.0994)
Transport Public works X (Int.- 7.25) X Post	0.00742	0.0153*	0.0135*	0.00742	0.0153*
	(0.00874)	(0.00806)	(0.00668)	(0.00875)	(0.00806)
Transport Public works X (Int.- 7.25) X Treated X Post	-0.280**	-0.1000	-0.0952	-0.281**	-0.1000
	(0.131)	(0.0924)	(0.0908)	(0.129)	(0.0924)
Constant	6.188***	4.200***	2.847***	6.188***	4.200***
	(0.266)	(0.278)	(0.246)	(0.266)	(0.278)
Observations	5,647	5,693	5,693	5,637	5,693
R-squared	0.112	0.145	0.155	0.112	0.145

	6.75 ≤ Seismic Intensity ≤ 7.75				
	Rovigo		Bologna		
	(11)	(12)	(13)	(14)	(15)
VARIABLES	N.BU	GFCF	N.Workers	N.BU	GFCF
Post	0.343	0.597	0.417	0.326	0.582
	(0.427)	(0.430)	(0.458)	(0.420)	(0.423)
Treated	-2.069***	-5.029***	-2.207***	-1.899***	-4.771***
	(0.369)	(1.102)	(0.488)	(0.443)	(1.462)
Post X Treated	0.713	5.053***	0.843	0.784	4.133**
	(0.521)	(1.208)	(0.549)	(0.556)	(1.749)
Int.- 7.25	1.052***	1.413***	1.235***	1.049***	1.417***
	(0.306)	(0.318)	(0.335)	(0.302)	(0.314)
Transport Public works X Post	-0.0360	-0.0964**	-0.0443	-0.0341	-0.0945**
	(0.0395)	(0.0378)	(0.0447)	(0.0390)	(0.0374)
Transport Public works X Treated	0.141***	0.460***	0.164***	0.142***	0.492***
	(0.0120)	(0.0601)	(0.0376)	(0.0294)	(0.130)
Transport Public works X Post X Treated	-0.0736*	-0.498***	-0.108**	-0.0873*	-0.460***
	(0.0419)	(0.0906)	(0.0505)	(0.0490)	(0.159)
Transport Public works X (Int.- 7.25)	-0.119***	-0.145***	-0.134***	-0.119***	-0.145***
	(0.0250)	(0.0258)	(0.0280)	(0.0248)	(0.0256)
Transport Public works X (Int.- 7.25) X Treated	0.0933	0.175	0.0593	0.0486	0.0523
	(0.0848)	(0.162)	(0.0968)	(0.0785)	(0.141)
Transport Public works X (Int.- 7.25) X Post	0.0135*	0.00742	0.0153*	0.0136*	0.00755
	(0.00668)	(0.00875)	(0.00784)	(0.00652)	(0.00847)
Transport Public works X (Int.- 7.25) X Treated X Post	-0.0952	-0.281**	-0.0681	-0.0735	-0.174
	(0.0908)	(0.129)	(0.0683)	(0.0728)	(0.109)
Constant	2.847***	6.188***	4.216***	2.851***	6.208***
	(0.246)	(0.266)	(0.265)	(0.233)	(0.253)
Observations	5,693	5,637	5,749	5,749	5,693
R-squared	0.155	0.112	0.144	0.155	0.112

Robust standard errors clustered at municipality level in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Post is a dummy variable equal to 1 for 2012<year<2017 , 0 for 2007<year<2012 - the treatment year is excluded from the sample. Treated is a dummy variable equal to 1 for municipalities that experienced seismic intensity larger or equal to 7.25, 0 if below 7.25. (Int. - 7.25) represents the difference between seismic intensity and the threshold intensity of 7.25. All the dependent variables (private firms' number of business units, number of workers and gross fixed capital investment) are per square kilometres and expressed in natural logarithm. Also public investments in transport infrastructures (Transport Public works) are per square kilometre and expressed in natural logarithm.

Table 3: Within-province RDD results for trasport public infrastructures with proxy for capital stock levels

	6.75 ≤ Seismic Intensity ≤ 7.75														
	Modena			Ferrara			Mantova			Rovigo			Bologna		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
VARIABLES	N.Workers	N.BU	GFCF	N.Workers	N.BU	GFCF	N.Workers	N.BU	GFCF	N.Workers	N.BU	GFCF	N.Workers	N.BU	GFCF
Post	-2.977***	-2.682***	-3.101***	-2.973***	-2.679***	-3.097***	-2.973***	-2.678***	-3.097***	-2.973***	-2.678***	-3.097***	-2.971***	-2.673***	-3.093***
	(0.161)	(0.140)	(0.184)	(0.161)	(0.140)	(0.185)	(0.161)	(0.140)	(0.185)	(0.161)	(0.140)	(0.185)	(0.160)	(0.139)	(0.184)
Treated	-1.792***	-1.585***	-4.581***	-2.250***	-1.899***	-5.014***	-2.265***	-1.989***	-4.977***	-2.265***	-1.989***	-4.977***	-2.103***	-1.803***	-4.530***
	(0.628)	(0.557)	(1.063)	(0.660)	(0.550)	(1.015)	(0.686)	(0.580)	(1.061)	(0.686)	(0.580)	(1.061)	(0.566)	(0.485)	(1.100)
Post X Treated	4.392***	4.115***	8.797***	4.165***	3.883***	8.996***	3.963***	3.796***	9.157***	3.963***	3.796***	9.157***	4.244***	3.821***	8.048***
	(0.645)	(0.601)	(1.296)	(0.785)	(0.638)	(1.342)	(0.882)	(0.708)	(1.525)	(0.882)	(0.708)	(1.525)	(0.641)	(0.497)	(1.238)
Int.- 7.25	-0.0137	-0.0522	-0.00573	-0.0191	-0.0575*	-0.00924	-0.0192	-0.0576*	-0.00923	-0.0192	-0.0576*	-0.00923	-0.0142	-0.0551*	-0.00297
	(0.0365)	(0.0320)	(0.0370)	(0.0367)	(0.0320)	(0.0372)	(0.0367)	(0.0320)	(0.0372)	(0.0367)	(0.0320)	(0.0372)	(0.0356)	(0.0310)	(0.0362)
Transport Public works X Post	0.268***	0.242***	0.269***	0.268***	0.242***	0.268***	0.268***	0.242***	0.268***	0.268***	0.242***	0.268***	0.268***	0.242***	0.268***
	(0.0147)	(0.0127)	(0.0170)	(0.0147)	(0.0127)	(0.0171)	(0.0147)	(0.0127)	(0.0171)	(0.0147)	(0.0127)	(0.0171)	(0.0147)	(0.0127)	(0.0170)
Transport Public works X Treated	0.119*	0.111*	0.452***	0.153**	0.131**	0.489***	0.155**	0.140**	0.485***	0.155**	0.140**	0.485***	0.146**	0.127**	0.457***
	(0.0681)	(0.0615)	(0.118)	(0.0753)	(0.0641)	(0.116)	(0.0768)	(0.0659)	(0.120)	(0.0768)	(0.0659)	(0.120)	(0.0629)	(0.0551)	(0.121)
Transport Public works X Post X Treated	-0.427***	-0.397***	-0.917***	-0.422***	-0.390***	-0.947***	-0.398***	-0.379***	-0.963***	-0.398***	-0.379***	-0.963***	-0.429***	-0.383***	-0.870***
	(0.0675)	(0.0634)	(0.136)	(0.0782)	(0.0647)	(0.137)	(0.0851)	(0.0692)	(0.154)	(0.0851)	(0.0692)	(0.154)	(0.0698)	(0.0549)	(0.133)
Transport Public works X Kdestruction	-0.00467	-0.00740**	0.00616	-0.00717**	-0.0100***	0.00641	-0.00716**	-0.0100***	0.00641	-0.00716**	-0.0100***	0.00641	-0.000861	-0.00223**	0.00398***
	(0.00401)	(0.00366)	(0.00481)	(0.00301)	(0.00263)	(0.00461)	(0.00301)	(0.00263)	(0.00461)	(0.00301)	(0.00263)	(0.00461)	(0.000782)	(0.000880)	(0.000563)
Transport Public works X Kdestruction X	0.00651	0.00863**	-0.00141	0.00848***	0.0111***	-0.00189	0.00844***	0.0109***	-0.00182	0.00844***	0.0109***	-0.00182	0.00193	0.00285*	0.000534
Treated	(0.00414)	(0.00378)	(0.00501)	(0.00325)	(0.00294)	(0.00536)	(0.00324)	(0.00289)	(0.00542)	(0.00324)	(0.00289)	(0.00542)	(0.00161)	(0.00154)	(0.00275)
Transport Public works X Kdestruction X	0.00539**	0.00699***	-0.00776	0.00693***	0.00867***	-0.00940	0.00693***	0.00867***	-0.00940	0.00693***	0.00867***	-0.00940	0.00205***	0.00227***	-0.00289***
Post	(0.00252)	(0.00232)	(0.00667)	(0.00213)	(0.00177)	(0.00731)	(0.00213)	(0.00177)	(0.00731)	(0.00213)	(0.00177)	(0.00731)	(0.000712)	(0.000859)	(0.000780)
Transport Public works X Kdestruction X	-0.00630**	-0.00750***	0.00437	-0.00700**	-0.00811***	0.00604	-0.00864***	-0.00926***	0.00559	-0.00864***	-0.00926***	0.00559	-0.00300*	-0.00232*	-0.000625
Treated X Post	(0.00264)	(0.00245)	(0.00681)	(0.00274)	(0.00236)	(0.00803)	(0.00261)	(0.00218)	(0.00821)	(0.00261)	(0.00218)	(0.00821)	(0.00154)	(0.00138)	(0.00303)
Constant	4.352***	2.985***	6.165***	4.334***	2.967***	6.154***	4.334***	2.967***	6.154***	4.334***	2.967***	6.154***	4.347***	2.973***	6.173***
	(0.0956)	(0.0845)	(0.0951)	(0.0957)	(0.0844)	(0.0959)	(0.0957)	(0.0844)	(0.0959)	(0.0957)	(0.0844)	(0.0959)	(0.0921)	(0.0811)	(0.0926)
Observations	5,748	5,748	5,692	5,704	5,704	5,647	5,693	5,693	5,637	5,693	5,693	5,637	5,749	5,749	5,693
R-squared	0.083	0.091	0.062	0.084	0.093	0.062	0.084	0.093	0.062	0.084	0.093	0.062	0.084	0.093	0.062

Robust standard errors clustered at municipality level in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Post is a dummy variable equal to 1 for 2012<year<2017 , 0 for 2007<year<2012 - the treatment year is excluded from the sample. Treated is a dummy variable equal to 1 for municipalities that experienced seismic intensity larger or equal to 7.25, 0 if below 7.25. (Int. - 7.25) represents the difference between seismic intensity and the threshold intensity of 7.25. All the dependent variables (private firms' number of business units, number of workers and gross fixed capital investment) are per square kilometres and expressed in natural logarithm. Also public investments in transport infrastructures (Transport Public works) are per square kilometre and expressed in natural logarithm. Kdestruction represents the percentage of destruction in physical capital stock coming from the seismic shock.

Table 4: Aggregate RDD results for public transport infrastructures by sector's tradeability

	6.75 ≤ Seismic Intensity ≤ 7.75								
	N. Workers			N. Business Units			Gross Fixed Capital Formation		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	Tradeables	Tradeables excl. construction	Non-Tradeables	Tradeables	Tradeables excl. construction	Non-Tradeables	Tradeables	Tradeables excl. construction	Non-Tradeables
Post	0.437**	0.798***	0.338	0.258	0.536***	0.327*	0.916**	0.606	0.294
	(0.205)	(0.241)	(0.211)	(0.165)	(0.187)	(0.188)	(0.404)	(0.418)	(0.260)
Treated	-1.370**	-1.624**	-1.826***	-0.831	-0.776	-1.670***	-3.348	-2.983	-3.755***
	(0.659)	(0.637)	(0.605)	(0.514)	(0.638)	(0.515)	(2.138)	(2.401)	(1.296)
Post X Treated	0.164	-0.0349	0.822	0.0551	-0.396	0.784	2.552	3.792	3.134**
	(0.644)	(0.680)	(0.612)	(0.500)	(0.617)	(0.529)	(2.404)	(2.689)	(1.314)
Int.-7.25	1.312***	1.579***	1.198***	1.022***	1.227***	1.069***	1.559***	1.082***	1.378***
	(0.0996)	(0.123)	(0.100)	(0.0808)	(0.0941)	(0.0896)	(0.164)	(0.161)	(0.116)
Transport Public works X Post	-0.0476**	-0.0770***	-0.0370*	-0.0343**	-0.0552***	-0.0322*	-0.0939**	-0.0502	-0.0810***
	(0.0207)	(0.0245)	(0.0215)	(0.0168)	(0.0191)	(0.0191)	(0.0421)	(0.0446)	(0.0271)
Transport Public works X Treated	0.117	0.151*	0.148**	0.0672	0.0690	0.146**	0.469**	0.524**	0.412***
	(0.0795)	(0.0785)	(0.0708)	(0.0617)	(0.0770)	(0.0601)	(0.229)	(0.258)	(0.141)
Transport Public works X Post X Treated	-0.0401	-0.0336	-0.0731	-0.00103	0.0322	-0.0716	-0.464*	-0.623**	-0.341**
	(0.0743)	(0.0786)	(0.0672)	(0.0558)	(0.0691)	(0.0578)	(0.256)	(0.289)	(0.141)
Transport Public works X (Int.-7.25)	-0.137***	-0.158***	-0.131***	-0.113***	-0.129***	-0.120***	-0.144***	-0.117***	-0.146***
	(0.00852)	(0.0104)	(0.00883)	(0.00693)	(0.00797)	(0.00785)	(0.0142)	(0.0144)	(0.0103)
Transport Public works X (Int.-7.25) X Treated	-0.0874	-0.0932	0.0469	-0.0834	-0.0626	0.000500	-0.373***	-0.488***	0.0703
	(0.0997)	(0.110)	(0.132)	(0.0913)	(0.0999)	(0.120)	(0.106)	(0.167)	(0.146)
Transport Public works X (Int.-7.25) X Post	0.0174***	0.0180***	0.0136***	0.0139***	0.0143***	0.0130***	0.00577	0.00695	0.00884**
	(0.00351)	(0.00405)	(0.00340)	(0.00277)	(0.00307)	(0.00300)	(0.00740)	(0.00816)	(0.00445)
Transport Public works X (Int.-7.25) X Treated X Post	0.0292	0.0412	-0.134	-0.0158	-0.0147	-0.0954	0.372***	0.361*	-0.182
	(0.0656)	(0.0718)	(0.0993)	(0.0677)	(0.0726)	(0.0897)	(0.143)	(0.204)	(0.135)
Constant	3.605***	3.312***	3.430***	1.796***	1.054***	2.447***	4.983***	4.276***	5.309***
	(0.101)	(0.118)	(0.111)	(0.0800)	(0.0900)	(0.0963)	(0.187)	(0.216)	(0.118)
Observations	5,835	5,760	5,838	5,835	5,760	5,838	5,424	4,833	5,750
R-squared	0.131	0.123	0.138	0.154	0.146	0.148	0.050	0.040	0.108

Robust standard errors clustered at municipality level in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Post is a dummy variable equal to 1 for 2012<year<2017, 0 for 2007<year<2012 - the treatment year is excluded from the sample. Treated is a dummy variable equal to 1 for municipalities that experienced seismic intensity larger or equal to 7.25, 0 if below 7.25. (Int.-7.25) represents the difference between seismic intensity and the threshold intensity of 7.25. All the dependent variables (private firms' number of business units, number of workers and gross fixed capital investment) are per square kilometre and expressed in natural logarithm. Also public investments in transport infrastructures (Transport Public works) are per square kilometre and expressed in natural logarithm.

We now move to consider the impact of private capital stock levels on the elasticity of private investment and employment outcomes for state-funded investment subsidies. When studying the stimulus to private sector activity from investment subsidies, the discontinuity in physical private capital stock destruction no longer affects the fiscal multiplier effect through the complementarity/private demand for the public capital services channel explored in transport infrastructure investments, but through the collateral channel.

In fact, an exogenous reduction in physical private capital also corresponds with a negative shock in the size of available collateral, which can be pledged when accessing credit through the banking sector.

As long as private capital investment is debt financed, a state-funded investment subsidy can be thought of as a reduction in the total amount of debt service associated with the loan needed to finance the investment. Whether carried out through a reduction in the financing interest rate or through a direct contribution to the investment cost, the subsidy reduces the total liability of the private firm to the bank providing the loan and, as a consequence of holding the risk of the borrower constant, it reduces the amount of collateral, which needs to be pledged in order to obtain the loan, given the market interest rate. This means that a given subsidy leads to a larger pool of credit-eligible applicants. This suggests that, in general, the lower the pre-subsidy private capital stock level, the larger will be the positive impact on private employment, investment and business creation, through the larger increase in access to credit.

In this context, two mechanisms are at play: investment subsidies were already available prior to the seismic shock, but they are increased homogeneously for municipalities experiencing seismic intensity above 6.1, thus corresponding to an equal increase for both control and treated municipalities within a bandwidth from the seismic threshold smaller than 0.5 on each side. But treated municipalities experience a larger reduction in collateral size than control municipalities, thus suggesting an expected larger impact of investment subsidies over private sector employment, business generation and investment.

Empirical estimates to test these theoretical mechanisms are presented at aggregate level. In the case of investment subsidies, the level of public capita stock is less of a source of omitted variable bias and aggregate estimates, relative to province specific ones, allowing for an easier comparison with other existing studies.

Overall, empirical results are consistent across the models and with the expected theoretical outcomes. **Table 5** contains aggregate results by regression model, with detail on the results by province included in the Appendix (**Section D Table D.2-D.3**). Sensitivity tests by bandwidth are also contained in the Appendix (**Section D Table D.4**). The treated municipalities experiencing serious private capital destruction, show a stronger response to investment incentives in terms of net business creation, net employment creation and fixed capital investment. Every additional point of seismic intensity higher than the threshold is associated with a statistically significant 0.15-0.29% increase in the stimulus to private employment and net business creation from an additional 1% in investment incentives. Every 1 percentage point of lower capital stock is associated with a significant 0.5% increase in stimulus to employment and 1.0% increase to gross fixed capital investment. The outcome on net business creation is estimated to be positive but insignificant.

One possible concern could be that the larger impact of investment incentives for treated municipalities is driven by a concession of more generous incentives from the state. This does not appear to be the case, as no significant difference between treated and control municipalities across the threshold is detected in the share of state-financing, relative to the total cost of the investment (**Table D.1 in Section D of the Appendix**).

Table 5: RDD results for investment incentives

6.75 ≤ Seismic Intensity ≤ 7.75

	(1)	(2)	(3)
VARIABLES	N.Workers	N.BU	GFCF
Post	1.126***	0.932***	0.798***
	(0.189)	(0.162)	(0.212)
Treated	-1.590***	-1.184**	-2.703***
	(0.583)	(0.502)	(0.643)
Post X Treated	-0.886*	-0.841*	0.491
	(0.532)	(0.446)	(0.708)
Int.- 7.25	0.942***	0.813***	0.999***
	(0.0948)	(0.0836)	(0.110)
Incentives	0.0570	0.0457	0.00652
	(0.0350)	(0.0317)	(0.0392)
Incentives X Post	-0.157***	-0.132***	-0.123***
	(0.0301)	(0.0262)	(0.0334)
Incentives X Treated	0.294***	0.226***	0.611***
	(0.0990)	(0.0831)	(0.100)
Incentives X Post X Treated	0.0167	0.0497	-0.321***
	(0.0925)	(0.0782)	(0.110)
Incentives X (Int.- 7.25)	-0.175***	-0.157***	-0.181***
	(0.0141)	(0.0128)	(0.0166)
Incentives X Treated X (Int.- 7.25)	-0.216**	-0.220**	-0.355***
	(0.109)	(0.0956)	(0.117)
Incentives X Post X (Int.- 7.25)	0.0105*	0.00861*	0.0145**
	(0.00547)	(0.00490)	(0.00685)
Incentives X Post X Treated X (Int.- 7.25)	0.166**	0.147**	0.257***
	(0.0837)	(0.0737)	(0.0944)
Constant	3.491***	2.257***	5.700***
	(0.219)	(0.195)	(0.248)
Observations	5,912	5,912	5,895
R-squared	0.259	0.266	0.155

Robust standard errors clustered at municipality level in parentheses
**** p<0.01, ** p<0.05, * p<0.1*

	(4)	(5)	(6)
VARIABLES	N.Workers	N.BU	GFCF
Post	0.700***	0.548***	0.359
	(0.202)	(0.175)	(0.221)
Treated	0.807	0.972**	-0.258
	(0.548)	(0.476)	(0.567)
Post X Treated	-0.152	-0.206	1.254*
	(0.558)	(0.480)	(0.671)
Int.- 7.25	-0.219***	-0.225***	-0.184***
	(0.0313)	(0.0285)	(0.0327)
Incentives	0.403***	0.354***	0.363***
	(0.0279)	(0.0241)	(0.0299)
Incentives X Post	-0.125***	-0.102***	-0.0964***
	(0.0286)	(0.0249)	(0.0311)
Incentives X Treated	-0.117	-0.156*	0.137
	(0.0907)	(0.0821)	(0.100)
Incentives X Post X Treated	-0.0435	0.00450	-0.340***
	(0.0976)	(0.0861)	(0.109)
Incentives X Kdestruction	0.00422**	0.00200	0.00911***
	(0.00207)	(0.00174)	(0.00227)
Incentives X Treated X Kdestruction	-0.00434*	-0.00170	-0.00803***
	(0.00223)	(0.00191)	(0.00262)
Incentives X Post X Kdestruction	-0.00331	-0.00214	-0.00936***
	(0.00228)	(0.00171)	(0.00266)
Incentives X Post X Treated X Kdestruction	0.00477*	0.00293	0.00977***
	(0.00245)	(0.00184)	(0.00285)
Constant	1.226***	0.237	3.393***
	(0.194)	(0.167)	(0.209)
Observations	5,912	5,912	5,895
R-squared	0.216	0.222	0.125

Robust standard errors clustered at municipality level in parentheses
**** p<0.01, ** p<0.05, * p<0.1*

Post is a dummy variable equal to 1 for year>2012, 0 for year<2012 - the treatment year is excluded from the sample. Treated is a dummy variable equal to 1 for municipalities that experienced seismic intensity larger or equal to 7.25, 0 if below 7.25. (Int. - 7.25) represents the difference between seismic intensity and the threshold intensity of 7.25. All the dependent variables (private firms' number of business units, number of workers and gross fixed capital investment) are per square kilometres and expressed in natural logarithm. Also state-funded incentives for private firms (Public investment incentives) are per square kilometre and expressed in natural logarithm. Kdestruction represents the percentage of destruction in physical capital stock coming from the seismic shock.

These results are, therefore, consistent with the role of private capital stock as financing collateral and, consequently, with the value of state-funded investment incentives as "enablers" for credit access and business investment in areas where private capital is scarce.

Overall, these results provide suggestive evidence on the ability of direct public investment in transport infrastructures to stimulate private activity, only when there is already sufficient private capital stock and possibly spare capacity. Infrastructures at that point appear to support further development through the boost to private productivity coming from complementarity effects. Instead, when private capital is underdeveloped, subsidies seem to be more effective than direct investments, as they allow private capital to develop through credit access, which supports business creation and, ultimately, employment.

9 Heterogeneity by type of incentive

The results presented in the previous section showed how investment subsidies appear to be better suited to stimulating development than transport infrastructure, in areas with lower levels of physical private capital. Different types of investment incentives can, however, be identified by destination and this section aims to discuss the heterogeneity of the results, depending on the type of incentive. Five different types of state-funded investment subsidies have been offered in Italy by targeted activity: Research and Development (R&D), productive activities, real estate, environment and energy, and transport.

Table 6 reports the results for Research and Development-oriented incentives and Productive activity incentives for both regression models, the only ones paying towards a significant share of the municipalities object of observation. The estimates obtained for Production-oriented incentives are similar but slightly less significant than those observed at aggregate level. A 1 percentage point higher destruction in the stock of physical capital is associated with every 1% increase in production-oriented incentives to 0.5% higher employment generation, 0.3% higher new business generation and 1.0% higher private investment response. Instead, incentives for R&D do not show the same higher return from lower private capital. Rather, the lower the level of private capital, the lower the impact of state-funded incentives, which can turn also negative. The estimates are robust to the regression model adopted.

Table 6: RDD results for investment incentives by type

	6.75 ≤ Seismic Intensity ≤ 7.75			
	Productive Incentives		R&D Incentives	
	Seismic Intensity model	Capital stock proxy	Seismic Intensity model	Capital stock proxy
Threshold effect				
N.Workers	-0.0396	-0.0895	0.444**	0.345
	(0.112)	(0.122)	(0.177)	(0.300)
N.BU	-0.00769	-0.0493	0.412***	0.337
	(0.0946)	(0.103)	(0.113)	(0.269)
GFCF	-0.352***	-0.407***	0.412	0.981
	(0.125)	(0.116)	(0.438)	(0.724)
Marginal effect				
N.Workers	0.143*	0.00489**	-0.441**	-0.0193*
	(0.0856)	(0.00248)	(0.196)	(0.0103)
N.BU	0.112	0.00318*	-0.312**	-0.0198**
	(0.0725)	(0.00191)	(0.153)	(0.00806)
GFCF	0.253**	0.01000***	-0.0229	0.00957
	(0.106)	(0.00289)	(0.556)	(0.0179)

Robust standard errors clustered at municipality level in parentheses
**** p<0.01, ** p<0.05, * p<0.1*

Two different mechanisms could help explain this finding: (i) the lower incidence of debt financing for R&D private investment compared to productive investments (such as machinery, etc.), as a consequence of the higher uncertainty surrounding R&D investment returns, and (ii) the complementarity between physical private capital and R&D investments. The long payback period, high risk and the confidentiality of R&D investments means that internal financing is preferred in the pecking order theory to external equity and debt financing. Empirical evidence consistently shows R&D investments being mostly funded through internal financing or equity financing (Myers, 1984; Himmelberg and Petersen, 1994; Liu, 2011; Teece, 1986; Teece and Pisano, 1994). However, as R&D investment generally requires a large capital investment, often, internal and equity funding is supplemented by debt funding, as it is possible to observe from the funds paid out by the state in R&D investment incentives through interest rate reductions.

As the empirical investigation of the US petroleum industry in the 1970-1980s by Helfat (1997) suggests, the amount of R&D investments undertaken by a given firm strongly depends on the complementary technological know-how and physical assets. The production and delivery of new products or services developed through R&D often requires complementary assets, typically downstream. Therefore, physical private assets are less important as collateral in the context of R&D financing, given the limited reliance on external capital markets, but are essential in the productive transformation of R&D activities.

10 Conclusions

This paper looks at the role played by capital stock endowments at local level in the private sector's responsiveness to public investment. In particular, it derives insights into its level of importance in determining the stimulus to private sector investment, business generation and employment from two types of public investment interventions: public transport infrastructure and investment subsidies. Theoretical predictions are obtained using a framework incorporating the use of public capital services in the private firm's production function, derived from Zhu (1995). The theoretical model endogenous utilisation rate of public capital services is augmented in this paper to adjust for congestion.

Empirical evidence is obtained exploiting a severe earthquake as a negative shock to private capital stock. The 2012 earthquake in Northern Italy provides the case study, with empirical results derived within the context of developed regions of Northern Italy between 2007 and 2017. The econometric identification rests on a discontinuity in physical private capital destruction, with estimates obtained from a Spatial Regression Discontinuity Design Model calibrated at municipality level.

This paper makes two main contributions to existing literature. First, it contributes to the literature, previously discussed, by deriving empirical evidence on the role of private capital's complementarity in the impact of public investments on private productivity and local economic growth. Second, it provides insight on the ramifications of destruction from natural disasters and the local response to public policy interventions post-disaster.

The empirical results, based on innovative municipality-level data, suggest that following the shock, areas with a lower level of private capital stock are more responsive to state-funded investment incentives targeted at production than direct public investments in transport infrastructure. Direct public investments in infrastructure appear to have a higher effectiveness in areas characterised by higher levels of private capital stock, where private activity can be stimulated through the complementarity of public investment with pre-existing private capital stock. Firms operating in tradeable sectors appear to experience a larger reduction in the stimulus from public transport infrastructure investment on private investment in particular, as a result of the shock to private capital, than those operating in the service sector. The higher impact on tradeable firms versus non-tradeable firms is likely to be associated with the higher importance of transport infrastructure in tradeable goods production than in services and the resulting higher complementarity of private capital stock to transport infrastructure.

Investment incentives for production, which effectively increase access to credit, appear to be effective in increasing the level of physical private capital available at local level, fostering private productive capacity and, eventually, potential gains in complementarity from public infrastructure. These appear not only to be favoured over direct public investments in context with lower levels of private capital, but they also appear to show returns inversely related to the pre-existing levels of capital stock. This is not the case, however, for investment incentives targeted at R&D. Lower levels of capital stock are associated with smaller impacts of R&D investment incentives. This can be explained by the complementarity between R&D investment and pre-existing in-firm capital stock, and the lower incidence of debt financing for R&D investments.

The quasi-experimental nature of the identification design, hereby adopted, allows one to obtain strongly causal estimates, but with caveats in terms of external validity. The estimates are obtained within the context of Northern Italy, in areas which experienced significant capital destruction but with high quality institutions and a well-developed banking sector. A generalisation of these results for regions with scarce private capital, accompanied by low quality institutions and limited access to credit should, therefore, be treated with caution.

Overall, these results provide insights applicable to both post-disaster emergency response programmes and public development policies. In order to stimulate private capital and broader economic development, interventions should first aim to develop a sufficiently strong private capital basis and, later, leverage on its complementarity with public infrastructures, in order to further foster economic development. The scarcity of a private capital base observed in less developed regions, appears to act as a constraint to the positive effect that public infrastructures can generate over private productivity and, therefore, it is crucial that public investments in infrastructure are coupled with interventions aimed at supporting private capital development.

11 References

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12 Appendix

Section A – Data

A1. Private business statistics

The Business Register of Local Units (ASIA LU) constitutes the main source of data on private business statistics at municipality-level, used in this paper. ASIA LU, updated on a yearly basis through administrative sources, provides data at municipality level by sector of economic activity (NACE 2 digits) on the number of local units of active enterprises and the number of persons employed in local units of active enterprises. A local unit is defined as "an enterprise or part thereof (e.g., a workshop, factory, warehouse, office, mine or depot) situated in a geographically identified place. In or from that place, at least one person carries out (even if only part-time) economic activities for that enterprise"[14]. Therefore, the information contained in this dataset allows one to obtain a mapping of private economic activity at municipality level, which correctly accounts for branches and subsidiaries of single firms. Data from ASIA LU, covering private business activity from 2004 to 2017 at municipality level, by sector of economic activity, is sourced from the Italian Statistical Office.

The Business Register of Local Units is integrated with two other datasets sourced from the Italian Statistical Office, the Structural Business Statistics (SBS) and the regional decomposition of National Accounts, in an effort to obtain a measure of private sector investment at municipality-level, on/for which no official data is publicly available.

Structural Business Statistics provide official data on economic performance indicators of private enterprises by sector of economic activity (based on Ateco 2007 classification) at NUTS 2 level, from 2002 to 2017. Data on gross investments in tangible goods is available from 2002 to 2015. The data covers all economic sectors with private participation, except for agricultural and credit activities. Gross Fixed Capital Formation from Regional National Accounts data, available from 2005 to 2017, is used to integrate the SBS for the credit sector[15] and to extrapolate SBS data for 2016 and 2017, based on the average private share in gross fixed investments by sector over the last three years of SBS-NA overlapping data (2013-2015). These two sources provide our base for private investments data at regional level (NUTS 2). ASIA LU data is then used to decompose the regional private investment figures at municipality level. Although the information contained in the Business Register does not explicitly track tangible investments carried out at local unit level, it provides information on the distribution sectoral economic activity across the region at NACE 2 level and its evolution over time through data on the number of business units and workers, respectively providing insight into net business creation and changes in employment at municipality-level over time.

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[14] Council Regulation on statistical units (N. 696-1993).

[15] This rests on the assumption that this sector does not receive any public investment. Such assumption, reasonable given the low government participation in the sector, is validated by the data on public investment. The NA data is not used to integrate the dataset for the Agricultural sector, in consideration of the sizeable funds received through the Common Agricultural Policy and of the lack of ASIA LU data for that sector, enabling a decomposition at municipality level.

I believe this approach leads to a superior proxy of municipality-level private investment data than the one achievable through a redistribution of the regional figure, based on firm-level balance sheet data (e.g., obtainable from Orbis). In fact, this alternative approach not only would not be based on a full coverage of entrepreneurial activity (with missing data being skewed towards small businesses, which are heterogeneously geographically distributed), but it has the potential of generating error in the data, as balance sheet data is often geographically localised based on the headquarter location, without accounting for branches and accounting for subsidiaries only (rarely) if data on each single subsidiary balance sheet is available.

Private investment is decomposed from NUTS 2 to NUTS 5 level, based on the distribution of the positive changes to the number of local enterprise units and employment by sector of economic activity. Theoretically, this assumes that fixed investment is associated with an expansion in productive capacity, proxied by an increase in the number of local units and/or an increase in employment within a pre-existing local unit. Such a redistribution, therefore, does not account for capital investment carried out with the purpose of substituting labour with capital, but it assumes that the capital to labour ratio stays constant over the period of observation. Adopting the approach outlined below, the higher the granularity of economic activity sectoral decomposition for investment and local unit data, the higher will be the precision in territorial allocation. Statistical confidentiality thresholds posed at 50 observation units counterbalance this, however, particularly when operating at municipality level. The investment decomposition is, therefore, carried out at a single digit sectoral classification[16] as it provides the best balance between precision and data availability.

For any given sector j, private investment in municipality i at time t ($I_{ji,t}$) is a share ($X_{kj,t}$) of the total investment in that given sector in the region k ($I_{jk,t}$), to which municipality i belongs.

(1) $$I_{ji,t} = X_{kj,t}(I_{jk,t})$$

Such share, $X_{kj,t}$, can be thought of as a function of changes in the number of local units of active enterprises and in their employment in sector j in municipality i. For simplicity, we adopt a weighted average such that

(2) $$I_{ji,t} = W1_{kj,t}(ULw_{ji,t})I_{jk,t} + W2_{kj,t}(EMPw_{ji,t})I_{jk,t}$$

[16] For the 2011-2017 period, the sectoral decomposition follows single digit Ateco 2007, the Italian version of NACE 2: "B" Mining and quarrying, "C" Manufacturing, "D" Energy supply, "E" Water supply and sewerage, "F" Construction, "G" Wholesale and retail trade, "H" Transport, "I" Accommodation and food service activities, "J" Information and communication", "K" Financial and insurance activities, "L" Real Estate activities, "M" Professional, scientific and technical activities; administrative and support service activities, "N" Rental and leasing activities, "P" Healthcare activities, "Q" Social work activities, "R" Arts entertainment and recreation, "S" Other service activities. Data for 2007-2010 is aggregated for BCDE, GHI, PQ and RS; data for 2005-2006 is aggregated further for JKLMNPQRS, otherwise the same as 2007-2010. The decomposition is carried out at the most disaggregated possible single digit level for each year.

Where $W1_{kj,t}$ and $W2_{kj,t}$ are positive weights summing up to 1, identifying respectively the importance of changes in the number of local units and their employment for the purposes of the decomposition. $ULw_{ji,t}$ indicates the share of a municipality i in the changes in number of local units observed at regional level for sector j, such that

(3) $$ULw_{ji,t} = \frac{\Delta UL_{ji,t}}{\sum_{i=0,\forall i \in K}^{n} \Delta UL_{ji,t} | \Delta UL_{ji,t} > 0} \; if \; \Delta UL_{ji,t} > 0, 0 \; otherwise$$

Where $\Delta UL_{ji,t} = UL_{ji,t} - UL_{ji,t-1}$ Only positive changes are considered, as it is assumed that negative changes do not affect investment, that being a flow measure.

$EMPw_{ji,t}$ indicates instead the share of municipality i in the changes in employment in the local units of active enterprises observed at regional level for sector j. However, in order to avoid double-counting, such a share needs to be adjusted, to subtract from the changes in employment those related to the creation of new business local units. $EMPw_{ji,t}$ should, in fact. represent changes in employment occurring in pre-existing business local units and is specified as follows:

(4) $$EMPw_{ji,t} = \frac{\Delta EMP_{ji,t}^{norm}}{\sum_{i=0,\forall i \in K}^{n} \Delta EMP_{ji,t}^{norm} | \Delta EMP_{ji,t}^{norm} > 0} \; if \; \Delta EMP_{ji,t}^{norm} > 0, 0 \; otherwise$$

Where $\Delta EMP_{ji,t}^{norm}$ represents changes in employment in municipality i and sector j ($\Delta EMP_{ji,t} = EMP_{ji,t} - EMP_{ji,t-1}$) "normalised" by subtracting the changes in the number of local business units ($\Delta UL_{ji,t}$) multiplied by the average number of employees per local unit at time t-1 ($\overline{EMP\_UL}_{ji,t-1}$).

(5) $$\Delta EMP_{ji,t}^{norm} = \Delta EMP_{ji,t} - \left(\Delta UL_{ji,t} \times \overline{EMP\_UL}_{ji,t-1}\right)$$

(6) $$\overline{EMP\_UL}_{ji,t-1} = \frac{EMP_{ji,t-1}}{UL_{ji,t-1}}$$

Finally, weights $W1_{kj,t}$ and $W2_{kj,t}$ are dynamic to the relative importance of changes in the number of business local units and their employment in a given region k and sector j and time t. This is to ensure that those changes are given equal weight, conditional on representing equal changes in terms of labour. This is ensured by setting the ratio of $W2_{kj,t}$ and $W1_{kj,t}$ equal to the absolute value of the ratio between regional changes in employment and the average number of employees of a local unit.

(7) $$\frac{W2_{kj,t}}{W1_{kj,t}} = \left| \frac{\Delta EMP_{kj,t}}{\overline{EMP_{UL}}_{kj,t}} \right|$$

The decomposition approach, hereby presented, (and currently implemented to obtain municipality level investment data) does not adjust for differences in starting capital investments and marginal capital intensities amongst sectors. In simple terms it does not account, for instance, for the fact that mining and quarrying activities require a relatively much larger initial investment than service activities, but they require almost no additional capital investment per change in marginal units of labour, unlike for services in which an additional hiring would likely need to be matched by additional investment in ITC (e.g., computer, software) and facilities (e.g., office desks). This does not represent a significant concern for the purposes of this paper, however, as the municipalities part of the sample analysed is not significantly involved in activities of mining and quarrying or in activities with elevated capital investment entry barriers.

A2. Local public investments and seismic damages

Official data on public sector investments is obtained from the OpenCup database, the official open data platform of the Italian government for public investments and regularly used in Bank of Italy publications.[17] The platform records all the programmed investments carried out with public funds, be they national, European, regional, local or with private co-funding and it is updated on a monthly basis. It also includes data on the funds distributed following natural disasters.

The CUP code, a unique identifier for each public investment project, is issued at the time the responsible public administration body decides to realise the investment; at that point the project is added to the database under the active status. The status is recorded to be closed once the project is fully realised and the creditors have been paid. If the project is revoked or cancelled, even straight after its planning, the project remains recorded in the database but with a cancelled/revoked status. The breadth of OpenCup's coverage is counterbalanced, however, by the semi-static picture it offers. No progress in the project is registered, except for its cancellation or closure (which sometimes occurs with a delay from the effective closing time[18]) unlike in the case of the two other main open data public investment platforms, OpenCoesione, registering projects aimed at territorial cohesion, and OpenBDAP, a platform which was originally designed to track all public investments but suffered from lack of completeness. These last two data sources, however, present a much more limited data coverage than OpenCup, particularly in the case of Northern regions of Italy, given the lower percentage of cohesion policy investments they receive. Through the CUP code and location references, it is possible to match projects registered on OpenCup to those on OpenBDAP and on OpenCoesione; over the 2007 to 2017 timespan, projects registered on OpenBDAP or/and OpenCoesione for the three regions of interest account for 18% of the total projects registered on OpenCup as having ever been active and for 11% of the closed projects (**Tables A.1-A.2**). Also, the dramatically lower coverage in the case of closed projects, suggests that the inefficiencies detected in updating the project status over time on OpenCup

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[17] "Capital and public investments in Italy: macroeconomic impacts, measurement and regulatory weaknesses", Bank of Italy, n. 520, Oct 2019; "Completion times for public investments and their determinants", Bank of Italy, n.538, Dec 2019.
[18] The latest download of OpenCUP data was carried out on 29th June 2020. The data, therefore, is up-to-date with the second review of OpenCUP status codes , completed on 29th May 2020.

must only account for a small percentage of the difference in records between OpenCup and OpenBDAP-OpenCoesione, whilst the higher coverage of OpenCup is not just fictitious.

Table A.1: Total number of municipality-level public investment projects registered, by starting year

Year	*Emilia-Romagna*		*Lombardia*		*Veneto*	
	OpenCUP	OpenBDAP & OpenCoesione	OpenCUP	OpenBDAP & OpenCoesione	OpenCUP	OpenBDAP & OpenCoesione
2000	401	22	708	12	476	32
2001	705	15	1,429	14	1,522	40
2002	973	30	2,379	37	2,443	68
2003	2,032	81	3,591	106	3,636	114
2004	3,189	144	6,400	228	4,591	163
2005	3,889	120	8,638	368	5,368	183
2006	4,109	121	12,898	358	5,883	252
2007	4,810	285	11,602	419	5,317	323
2008	5,522	1,017	11,833	713	5,484	486
2009	7,396	451	13,459	956	7,025	660
2010	9,249	916	19,946	2,140	8,611	1,503
2011	10,109	1,400	19,028	1,868	8,329	1,918
2012	9,370	4,704	17,218	2,996	5,461	2,377
2013	11,426	3,483	17,876	3,035	5,447	2,727
2014	11,170	4,248	14,668	4,267	6,214	3,171
2015	19,758	3,801	19,587	4,454	17,894	2,787
2016	49,915	3,551	32,702	4,091	22,242	2,764
2017	70,944	4,110	55,768	4,736	44,964	3,914
2018	114,260	4,663	118,057	4,058	91,945	4,447
2019	54,636	2,487	73,496	4,130	63,072	4,181

Source: OpenCUP. One unit represents one unique combination of CUP code and municipality.

Table A.2: Total number of municipality-level public investment projects registered, by closing year

Year	*Emilia-Romagna*		*Lombardia*		*Veneto*	
	OpenCUP	OpenBDAP & OpenCoesione	OpenCUP	OpenBDAP & OpenCoesione	OpenCUP	OpenBDAP & OpenCoesione
2003	22	-	81	-	20	-
2004	227	-	426	-	286	-
2005	635	-	1,012	-	475	-
2006	1,011	-	1,864	-	917	-
2007	1,319	-	2,545	1	1,509	-
2008	1,338	1	6,864	-	2,760	-
2009	1,808	-	10,104	-	1,515	-
2010	2,044	3	6,553	-	2,513	1
2011	4,417	11	6,589	3	2,858	2
2012	3,884	50	8,442	133	2,591	32
2013	4,823	577	8,272	293	2,734	139
2014	20,362	2,528	31,298	2,501	17,452	1,082
2015	5,867	1,602	14,360	2,654	9,956	1,453
2016	8,420	4,815	15,013	6,255	9,447	3,547
2017	5,094	3,494	6,438	2,681	5,077	1,630
2018	5,231	1,587	7,129	2,225	2,636	1,271
2019	5,132	1,718	7,101	2,130	2,551	1,527

Source: OpenCUP. One unit represents one unique combination of CUP code and municipality.

Some adjustments have been carried out over OpenCup raw data for the purposes of this paper. Data contains a number of multiple location projects, which are registered under a unique single CUP, with specified financial resources referring to the total project but which appear multiple times in the data under different geographical locations. Being interested in projects which can be traced back to a single municipality level, I discard projects affecting all the municipalities of a given region.[19] For the remaining multi-location projects affecting several specified municipalities, I split the financial resources assigned to the project equally amongst the municipalities affected; this is done in the interest of retaining a large number of projects[20] without potentially biasing the results.

Data from OpenCUP overall provides project level public investment records detailing the project's year of approval, the year of completion, the total cost, the total public financing, the nature of the public investment (public works, investment incentives or natural disasters emergency funding) and the area of intervention (e.g., real estate, transports, R&D, environment, productive sector, etc).

As mentioned earlier, a problem with data from OpenCup is the often-lagged recording of status updates, from active to closed or revoked/cancelled. The absence of progress information also does not create the grounds for confidently treating active projects as "started". As a solution to the issue of possible measurement error introduced by considering all the projects, instead I consider uniquely the projects with closed status. It is worth mentioning that, even if projects may be recorded as closed later than the effective closing date, the record's closing date reflects the genuine date at which the project is fully realised and the creditors have been paid. This means that the only disadvantage stemming from such an approach is a reduction of the sample size which, as a percentage of the total, is likely to be higher for more recent years. Overall, however, the size of the sample remains substantial and the bias which could possibly characterise more recent data does not represent an issue, given the estimation horizon bound by private sector data availability up to 2017. As the analysis is carried out at municipality level, project-level data is aggregated at municipality level by year.

Table A.3 shows the number of completed projects by year of decision and completion in the regions of interest for the purposes of this paper, Lombardia, Emilia-Romagna and Veneto. Overall, over the 2005 to 2017 time span, a total of 276,400 projects were concluded in those regions (of which 15138 were completed in 2012). Of those, 180583 projects were classified as public works, 92257 as incentives and 3563 as natural disaster emergency funding[21] and were carried out across 2400, 2080 and 79 municipalities, respectively.

[19] A total number of 57,713 records fall into this category for our regions of interest.
[20] Multi-location projects account for 23% of the public investment projects carried out in the treated regions. In total, they amount to 306,491 projects out of the total 1,331,226 sample: 83% of them affect two different municipalities and only 12% of them affect more than four different municipalities.
[21] Consistent with the research design, all the emergency funding was distributed after the 2012 earthquake, with 2013 being the first year in which related projects were being concluded.

Table A.3: Total number of municipality-level public investment projects currently closed per year, by starting and closing year

Year	*Emilia-Romagna*		*Lombardia*		*Veneto*	
	Opened	Closed	Opened	Closed	Opened	Closed
2000	348		579		406	
2001	458		1,053		914	
2002	745		1,223		1,949	
2003	1,778	22	2,792	81	3,084	20
2004	3,021	229	5,206	447	4,224	293
2005	3,756	640	7,394	1,040	4,832	496
2006	3,859	1,016	10,886	1,877	5,525	936
2007	4,411	1,321	10,456	2,554	4,986	1,525
2008	5,199	1,340	10,851	6,880	5,115	2,767
2009	4,816	1,812	12,062	10,112	5,448	1,525
2010	7,304	2,050	16,396	6,559	6,686	2,522
2011	8,375	4,428	15,285	6,599	6,835	2,867
2012	8,964	3,934	13,442	8,580	6,033	2,624
2013	8,953	5,406	10,238	8,594	5,064	2,879
2014	8,371	22,973	10,362	33,917	5,569	18,641
2015	7,065	7,485	9,647	17,043	4,121	11,443
2016	4,694	13,257	5,044	21,295	3,356	13,036
2017	3,504	8,591	5,482	9,121	2,087	6,715
2018	3,952	6,821	6,113	9,365	1,923	3,910
2019	2,052	6,852	3,440	9,250	1,138	4,086

Source: OpenCUP. One unit represents one unique combination of CUP code and municipality.

A3. Macro-seismic intensity

Epicentral macroseismic and instrumental data for the series of earthquakes occurring in 2012 is obtained from the Parametric Catalogue of Italian Earthquakes (CPTI15 v2.0). Municipality-level geographical coordinates are obtained from the Italian Statistical Office. The availability of macroseismic intensity data from various sources for each seismic shock, if sufficiently granular, would not have made modelling of the attenuation of seismic shocks necessary for the purposes of this paper. But the Italian Macroseismic Database DBMI15 v2.0, the most comprehensive macroseismic database for Italy. is only at an early stage of development and not scientifically reliable.

The seismic waves attenuation law model of Pasolini et al. (2008) is used to obtain estimates of seismic intensity at municipality level[22] for each high intensity seismic shock[23]

[22] Over the period of observation, some changes occur to the administrative borders of municipalities belonging to regions affected by the 2012 earthquake. For municipalities being the result of mergers between already pre-existing municipalities, the seismic intensity is computed as the average of the seismic intensities of the individual municipality's object of the merge. This relies on the often-realistic assumption that the centre of the merged municipality is the centre of the polygon generated by the centres of the original municipalities.
The resulting municipality level estimates are consistent with the INGV Macroseismic report, in which the categorisation is broader. [Arcoraci L., Berardi M., Bernardini F., Brizuela B., Caracciolo C.H., Castellano C., Castelli V., Cavaliere A., Del Mese S., Ercolani E., Graziani L., Maramai A., Massucci A., Rossi A., Sbarra M., Tertulliani A., Vecchi M., Vecchi S. (2012). Rapporto Macrosismico sui terremoti del 20 (ML 5.9) e del 29 maggio 2012 (ML 5.8 e 5.3) nella Pianura Padano-Emiliana. Istituto Nazionale di Geofisica e Vulcanologia (INGV)]
[23] I consider a seismic shock to be of high intensity if its epicentral magnitude is above 5.5.

occurring in 2012, on 20th and 29th May and with the epicentre respectively in Bondeno (province of Ferrara) and Medolla (province of Modena). A seismic attenuation law defines the transmission of seismic waves through a medium as a function of several parameters, amongst which are epicentral intensity, depth and hypocentral distance.[24] The attenuation law model of Pasolini et al (2008) is chosen on account of its calibration on Italian macroseismic data and its specific suitability in estimating seismic intensity at a small distance from the epicentre - as we are likely to do at municipality level - presenting substantial improvements in this respect, when compared to Gasperini (2001) and Albarello and D'Amico (2004). Technical details on the attenuation law's functional form and estimated coefficients are contained in **Box A**.

The choice of adopting a formal attenuation law model, in order to estimate municipality-level seismic intensity rather than a simple measure of epicentral distance, undoubtedly brings higher computational complexity. The benefits are clear, however, when observing the historical heterogeneity in epicentral depth in Italy and how differences in that are associated with notable differences in attenuation radiuses given equal epicentral intensity. A simple epicentral distance measure as a proxy for variation in seismic intensity would have, therefore, led to substantial measurement error.

Given the annual frequency of investment data and the multiplicity of seismic shocks satisfying our requirements in 2012 and over overlapping areas, a further assumption is needed for the measurement of the intensity object of our regression, in the case of municipalities falling within multiple attenuation areas. For the sake of simplicity, for each municipality, I consider the maximum seismic intensity experienced in each given year. This implies that, spatially, attenuation areas drawn for large 2012 intensity seismic shocks, with imperfect coincidental epicentres, will not be circular but equal to the union set of the individual earthquake attenuation areas. Of course, this is a simplification in so far as it does not account for the difference in damage provoked by multiple seismic shocks versus one single shock at the same intensity. However, any attempt to adjust for this would also call into question the time duration of each individual seismic shock and add an increasing layer of complexity, for which I do not believe the benefits outweigh the costs.

[24] The hypocentre or focus is the point within the earth where the earthquake rupture starts. The epicentre is right above the hypocentre, but on the surface. The vertical distance between the hypocentre and the epicentre is called hypocentral or focal depth.

Figure A.1: Spatial evolution of estimated seismic intensity for 2012 Northern Italy earthquake

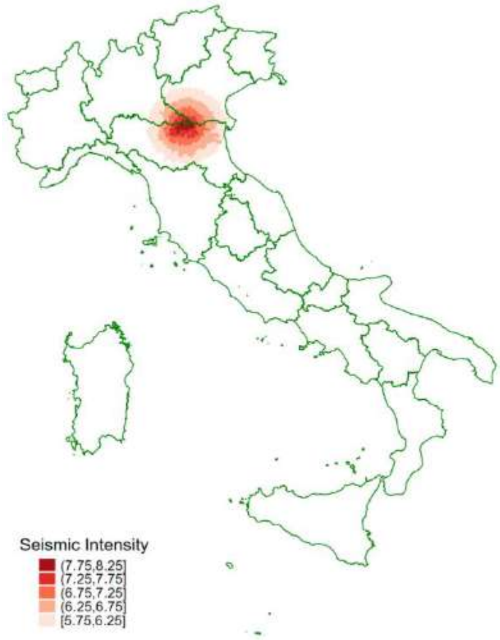


Figure A.1 shows the estimated attenuation areas for 2012 high intensity seismic shocks. Overall, I estimate that a total of 49 municipalities experienced an intensity above 7.25 (the intensity level which will later be used as a threshold in the empirical analysis) distributed across three different regions: 24 in Emilia-Romagna, 11 in Lombardia and 14 in Veneto.

Box A: Pasolini et al (2008) Attenuation law model

In this paper we adopt the log-linear model from Pasolini et al. (2008) to model the attenuation of seismic intensity away from the hypocentre.
The model is specified as follows:

(1) $$I_i = I_E + a(D_i - h) + b(lnD_i - lnh)$$
(2) $$I_E = c + dM_{sw}$$
(3) $$D_i = \sqrt{{R_i}^2 + h^2}$$

Where I_i is the intensity at location I, I_E is the intensity at the epicentre, D_i is the hypocentral distance of location i from the epicentre, h is the depth of the epicentre, M_{sw} is the instrumental magnitude at the epicentre and R_i is the distance (at surface) between location i and the epicentre.

Table A.4 summarises the coefficients estimated by Pasolini et al. (2008) by fitting the model to the full historical Parametric Catalogue of Italian Earthquakes (CPTI04 database).

Table A.4: Pasolini et al. (2008) attenuation law model estimates

Parameter	*Estimate*
c	-1.147 ± 0.096
d	+1.567 ± 0.012
a	-0.0104 ± 0.0007
b	-0.912 ± 0.039
h	+4.155 ± 0.511
σ	0.79

Pasolini et al. (2008) treat h as a semi-free coefficient, conditioning the estimates based on a sample-derived average. Although they use an earlier version of the CPTI catalogue to obtain their estimates, the model is calibrated on data starting in year 1000, providing long-term structural estimates which are also supposedly consistent with the last decade of observation.
In our case, h and M_{sw} are obtainable from data directly from the CPTI15 v2.0 database. The distance (at surface) between municipality i and the epicentre (R_i) is obtained through an application of the Harversine formula to the geographical coordinates of latitude and longitude of the centre of each municipality i (respectively lat_i and $long_i$) and the earthquake epicentre (respectively lat_E and $long_E$).

(4) $$R_i = 2r\, arcsin\left(\sqrt{sin^2\left(\frac{lat_i - lat_E}{2}\right) + cos(lat_E)cos(lat_i)sin^2\left(\frac{long_i - long_E}{2}\right)}\right)$$

From equations (1) to (4), through numerical approximation, it is possible to obtain the maximum surface radius conditional on a chosen intensity.

Section B – Identification Strategy

B.1 Severe Destruction Threshold for Regression Discontinuity Design

As the interest in seismic shocks for the purposes of this paper stems from the capital destruction that they can generate and from where it is generated, this section discusses in detail what is the mechanism through which this happens and what constitutes the basis of the identification strategy adopted in this paper. Although commonly associated with the magnitude of an earthquake, according to civil engineering and risk hazard assessment literature[25], buildings and infrastructure destruction is more closely related to the size of horizontal displacement they are subject to during the seismic shock, than the energy content of that shock indicated by magnitude. Of course, this gives equal consideration to the quality, materials and structural specifications of building and infrastructure construction, which all play a role. as well in determining their resistance to a seismic shock of a given intensity. Peak Ground Acceleration (PGA) and Peak Ground Velocity (PGV) are used as indicators of horizontal displacement, whilst seismic intensity, measured in Modified Mercalli Intensity Scale, is a direct indicator of the extent of structural damages and perception of the seismic shock.

Empirical evidence suggests a non-linearity in the relationship between horizontal ground displacement and building resistance.[26] Through mechanical calculations, combining the models of Bindi et al. (2011) and Pasolini et al. (2008)[27], it is possible to check that the severe damage threshold estimated by Barbat et al. (2012) is consistent with a seismic intensity of 7.25 for Italy, on average corresponding to a magnitude of 5.5 in the soil conditions characterising the areas affected. This is consistent with the description associated with Modified Mercalli Intensity Scale levels equal to 7 and 8[28] and with INGV macroseismic report, which attributes significant structural damages (including destruction of parts of buildings, fallen roofs and building structural failures) to municipalities in Italy, classified as 7-8 in seismic intensity and widespread but with moderate damage akin to fallen chimneys and cracks in walls to an intensity equal to 7.

Therefore, even if the numerical values of both PGA and seismic intensity decay move broadly smoothly away from the epicentre, as empirically estimated attenuation laws (Pasolini

[25] Tiberti and Milani (2017) discuss the relationship between horizontal ground acceleration and building collapse in the case of three building structures in Finale Emilia, destroyed by the earthquake in 2012.

[26] Barbat et al. (2012) find a non-linear relationship between the expected spectral displacement (ESD) of reinforced concrete building structures and its standard deviation, which leads to the identification of a severe damage threshold at PGA around 0.15g and an "extensive-to-collapse" threshold at 0.23-0.24g. One can identify a severe damage threshold when the relationship between the volatility of ESD and ESD becomes the steepest. That is estimated by the authors to occur at ESD=0.15m corresponding to PGA around 0.15g. An "extensive-to-collapse" threshold is instead identified at ESD=0.22m corresponding to PGA equal to 0.23-0.24g.

[27] Formal derivations are contained in Box B in Section A of the Appendix.

[28] A MMIS intensity level of 7 describes shaking as "very strong" and damage as "negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken". A MMIS intensity level of 8 describes shaking as "severe" and damage as "slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Fall in chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned".

et al., 2008) and ground motion prediction equations (Bindi et al., 2011) may suggest, seismic related destruction - in terms of real value of damages - does not. Thus, a value of 7.25 in seismic intensity can be interpreted as a threshold in this case. I would like to stress further that, although the existence of a non-linearity between PGA and destruction is a more general finding, the value at which this occurs is more country- and area-specific, as it largely depends on the soil composition and quality and structural features of buildings. Buildings and infrastructures are, indeed, built being "stress-tested" against resistance to expected shocks, amongst which there is horizontal displacement. If the experienced shock is larger than what the building was being built to face, severe damage is expected.

B.2 Robustness checks for RDD

Figure B.1: Area affected

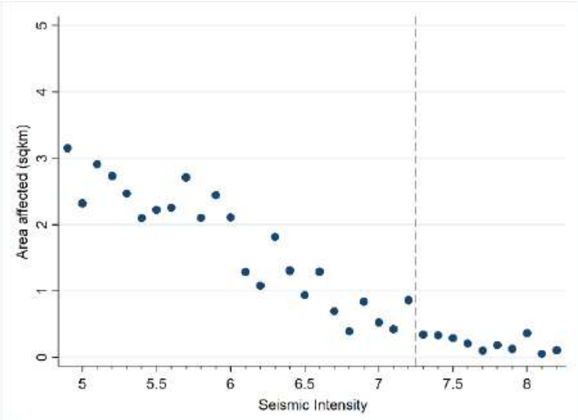


Figure B.2: Number of employed in the private sector

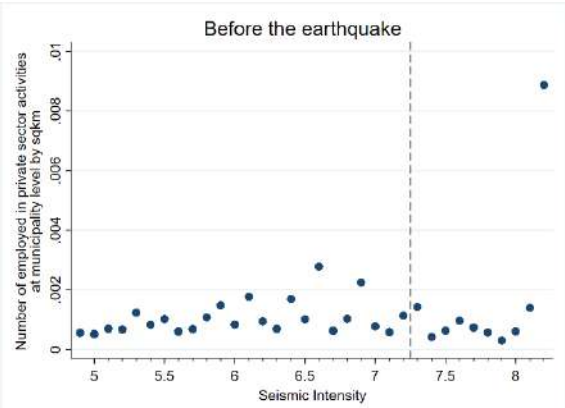


Figure B.3: Number of private sector business units

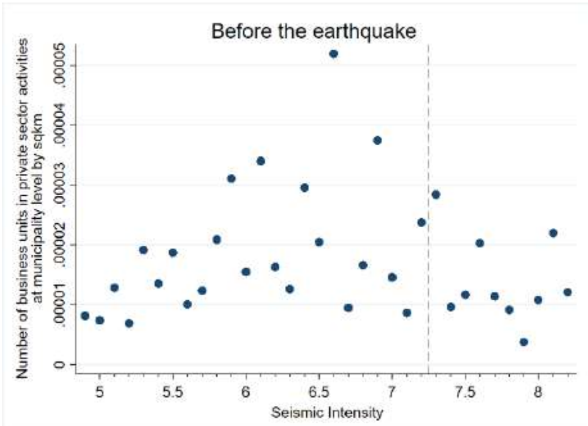


Figure B.4: State spending on public works

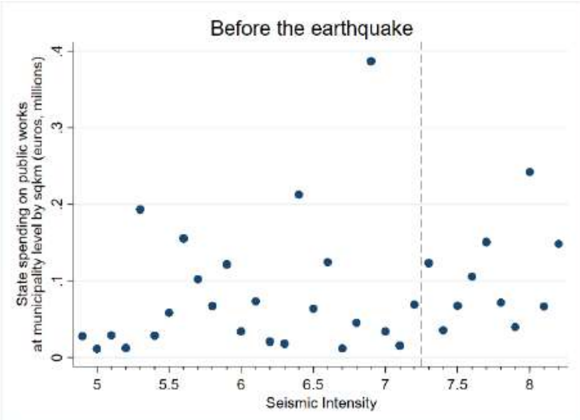
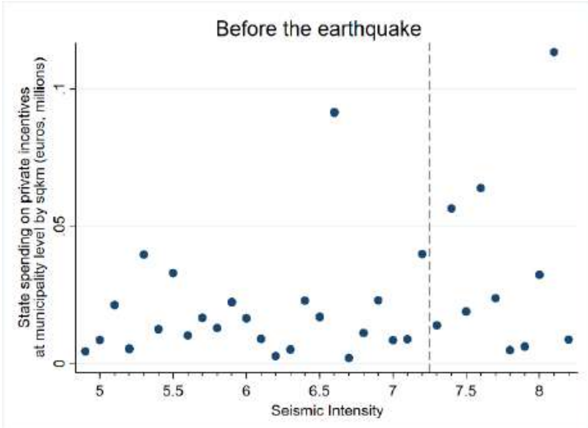


Figure B.5: State spending on private incentives



Section C – Robustness tables for infrastructure part analysis

Table C.1: Within-province RDD results for transport public infrastructures

	6.25 ≤ Seismic Intensity ≤ 8.25														
	Modena			Ferrara			Mantova			Rovigo			Bologna		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
VARIABLES	N.Workers	N.BU	GFCF	N.Workers	N.BU	GFCF	N.Workers	N.BU	GFCF	N.Workers	N.BU	GFCF	N.Workers	N.BU	GFCF
Post	0.395	0.302	0.539	0.404	0.297	0.580	0.441	0.343	0.597	0.441	0.343	0.597	0.328	0.243	0.548
	(0.447)	(0.411)	(0.417)	(0.463)	(0.426)	(0.427)	(0.465)	(0.427)	(0.430)	(0.465)	(0.427)	(0.430)	(0.461)	(0.423)	(0.419)
Treated	-1.724***	-1.680***	-3.058*	-2.509***	-2.188***	-4.145***	-2.334***	-2.069***	-5.029***	-2.334***	-2.069***	-5.029***	-2.287***	-1.971***	-4.784***
	(0.560)	(0.479)	(1.567)	(0.473)	(0.427)	(1.193)	(0.391)	(0.369)	(1.102)	(0.391)	(0.369)	(1.102)	(0.473)	(0.421)	(1.460)
Post X Treated	0.662	0.963*	2.602	0.819	0.980*	3.726**	0.503	0.713	5.053***	0.503	0.713	5.053***	0.932	0.868	4.168**
	(0.579)	(0.543)	(2.074)	(0.526)	(0.545)	(1.633)	(0.481)	(0.521)	(1.208)	(0.481)	(0.521)	(1.208)	(0.558)	(0.545)	(1.738)
Int.- 7.25	1.268***	1.078***	1.429***	1.207***	1.025***	1.386***	1.235***	1.052***	1.413***	1.235***	1.052***	1.413***	1.244***	1.057***	1.417***
	(0.336)	(0.303)	(0.314)	(0.336)	(0.304)	(0.314)	(0.339)	(0.306)	(0.318)	(0.339)	(0.306)	(0.318)	(0.333)	(0.300)	(0.312)
Transport Public works X Post	-0.0466	-0.0363	-0.0900**	-0.0407	-0.0298	-0.0904**	-0.0466	-0.0360	-0.0964**	-0.0466	-0.0360	-0.0964**	-0.0384	-0.0288	-0.0890**
	(0.0437)	(0.0383)	(0.0374)	(0.0451)	(0.0394)	(0.0374)	(0.0452)	(0.0395)	(0.0378)	(0.0452)	(0.0395)	(0.0378)	(0.0450)	(0.0393)	(0.0375)
Transport Public works X Treated	0.112**	0.127***	0.292**	0.177***	0.162***	0.367***	0.149***	0.141***	0.460***	0.149***	0.141***	0.460***	0.164***	0.143***	0.492***
	(0.0447)	(0.0418)	(0.126)	(0.0290)	(0.0259)	(0.0879)	(0.0106)	(0.0120)	(0.0601)	(0.0106)	(0.0120)	(0.0601)	(0.0377)	(0.0294)	(0.130)
Transport Public works X Post X Treated	-0.0577	-0.0828	-0.273	-0.0935*	-0.0989**	-0.355**	-0.0635	-0.0736*	-0.498***	-0.0635	-0.0736*	-0.498***	-0.114**	-0.0926*	-0.466***
	(0.0620)	(0.0570)	(0.190)	(0.0458)	(0.0439)	(0.150)	(0.0439)	(0.0419)	(0.0906)	(0.0439)	(0.0419)	(0.0906)	(0.0522)	(0.0489)	(0.158)
Transport Public works X (Int.- 7.25)	-0.134***	-0.118***	-0.144***	-0.134***	-0.118***	-0.145***	-0.135***	-0.119***	-0.145***	-0.135***	-0.119***	-0.145***	-0.132***	-0.117***	-0.145***
	(0.0278)	(0.0246)	(0.0254)	(0.0281)	(0.0249)	(0.0257)	(0.0282)	(0.0250)	(0.0258)	(0.0282)	(0.0250)	(0.0258)	(0.0278)	(0.0247)	(0.0255)
Transport Public works X (Int.- 7.25) X Treated	0.0965*	0.0443	0.109	0.118	0.0841	0.207	0.126	0.0933	0.175	0.126	0.0933	0.175	0.0567	0.0463	0.0519
	(0.0532)	(0.0495)	(0.0819)	(0.0966)	(0.0821)	(0.172)	(0.0994)	(0.0848)	(0.162)	(0.0994)	(0.0848)	(0.162)	(0.0981)	(0.0794)	(0.141)
Transport Public works X (Int.- 7.25) X Post	0.0139*	0.0122*	0.00770	0.0161*	0.0141**	0.00882	0.0153*	0.0135*	0.00742	0.0153*	0.0135*	0.00742	0.0145*	0.0127*	0.00830
	(0.00771)	(0.00645)	(0.00826)	(0.00810)	(0.00671)	(0.00893)	(0.00806)	(0.00668)	(0.00875)	(0.00806)	(0.00668)	(0.00875)	(0.00761)	(0.00634)	(0.00831)
Transport Public works X (Int.- 7.25) X Treated X Post	-0.0927***	-0.0786***	-0.147	-0.101	-0.0937	-0.312**	-0.1000	-0.0952	-0.281**	-0.1000	-0.0952	-0.281**	-0.0672	-0.0726	-0.175
	(0.0173)	(0.0155)	(0.0854)	(0.0904)	(0.0846)	(0.146)	(0.0924)	(0.0908)	(0.129)	(0.0924)	(0.0908)	(0.129)	(0.0686)	(0.0730)	(0.108)
Constant	4.324***	2.951***	6.270***	4.139***	2.796***	6.117***	4.200***	2.847***	6.188***	4.200***	2.847***	6.188***	4.294***	2.922***	6.221***
	(0.286)	(0.251)	(0.255)	(0.275)	(0.242)	(0.269)	(0.278)	(0.246)	(0.266)	(0.278)	(0.246)	(0.266)	(0.271)	(0.237)	(0.242)
Observations	5,842	5,842	5,786	5,737	5,737	5,680	5,693	5,693	5,637	5,693	5,693	5,637	5,808	5,808	5,752
R-squared	0.141	0.151	0.110	0.145	0.156	0.112	0.145	0.155	0.112	0.145	0.155	0.112	0.144	0.154	0.111

Robust standard errors clustered at municipality level in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Post is a dummy variable equal to 1 for 2012<year<2017 , 0 for 2007<year<2012 - the treatment year is excluded from the sample. Treated is a dummy variable equal to 1 for municipalities that experienced seismic intensity larger or equal to 7.25, 0 if below 7.25. (Int. - 7.25) represents the difference between seismic intensity and the threshold intensity of 7.25. All the dependent variables (private firms' number of business units, number of workers and gross fixed capital investment) are per square kilometres and expressed in natural logarithm. Also public investments in transport infrastructures (Transport Public works) are per square kilometre and expressed in natural logarithm.

Table C.2: Within-province RDD results for transport public infrastructures with proxy for capital stock levels

	6.25 ≤ Seismic Intensity ≤ 8.25														
	Modena			Ferrara			Mantova			Rovigo			Bologna		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
VARIABLES	N.Workers	N.BU	GFCF	N.Workers	N.BU	GFCF	N.Workers	N.BU	GFCF	N.Workers	N.BU	GFCF	N.Workers	N.BU	GFCF
Post	-2.963***	-2.668***	-3.084***	-2.970***	-2.683***	-3.085***	-2.973***	-2.678***	-3.097***	-2.973***	-2.678***	-3.097***	-2.995***	-2.697***	-3.086***
	(0.159)	(0.138)	(0.182)	(0.161)	(0.140)	(0.184)	(0.161)	(0.140)	(0.185)	(0.161)	(0.140)	(0.185)	(0.160)	(0.140)	(0.183)
Treated	-1.330***	-1.333***	-2.471**	-2.227***	-1.949***	-3.815***	-2.265***	-1.989***	-4.977***	-2.265***	-1.989***	-4.977***	-2.167***	-1.858***	-4.556***
	(0.443)	(0.391)	(1.165)	(0.527)	(0.457)	(1.235)	(0.686)	(0.580)	(1.061)	(0.686)	(0.580)	(1.061)	(0.566)	(0.485)	(1.100)
Post X Treated	3.795***	3.696***	5.919***	4.073***	3.856***	7.406***	3.963***	3.796***	9.157***	3.963***	3.796***	9.157***	4.271***	3.846***	8.042***
	(0.473)	(0.433)	(1.275)	(0.679)	(0.549)	(1.730)	(0.882)	(0.708)	(1.525)	(0.882)	(0.708)	(1.525)	(0.641)	(0.498)	(1.239)
Int.- 7.25	0.00874	-0.0353	0.0169	-0.0326	-0.0692**	-0.0215	-0.0192	-0.0576*	-0.00923	-0.0192	-0.0576*	-0.00923	0.00374	-0.0395	0.00565
	(0.0365)	(0.0319)	(0.0368)	(0.0366)	(0.0319)	(0.0371)	(0.0367)	(0.0320)	(0.0372)	(0.0367)	(0.0320)	(0.0372)	(0.0360)	(0.0316)	(0.0363)
Transport Public works X Post	0.266***	0.241***	0.267***	0.268***	0.243***	0.268***	0.268***	0.242***	0.268***	0.268***	0.242***	0.268***	0.269***	0.244***	0.268***
	(0.0146)	(0.0126)	(0.0169)	(0.0147)	(0.0127)	(0.0170)	(0.0147)	(0.0127)	(0.0171)	(0.0147)	(0.0127)	(0.0171)	(0.0146)	(0.0127)	(0.0169)
Transport Public works X Treated	0.0658	0.0803*	0.241*	0.156**	0.140**	0.369***	0.155**	0.140**	0.485***	0.155**	0.140**	0.485***	0.146**	0.127**	0.456***
	(0.0543)	(0.0485)	(0.129)	(0.0641)	(0.0561)	(0.139)	(0.0768)	(0.0659)	(0.120)	(0.0768)	(0.0659)	(0.120)	(0.0627)	(0.0550)	(0.121)
Transport Public works X Post X Treated	-0.368***	-0.355***	-0.633***	-0.416***	-0.390***	-0.787***	-0.398***	-0.379***	-0.963***	-0.398***	-0.379***	-0.963***	-0.431***	-0.385***	-0.870***
	(0.0530)	(0.0489)	(0.137)	(0.0677)	(0.0559)	(0.177)	(0.0851)	(0.0692)	(0.154)	(0.0851)	(0.0692)	(0.154)	(0.0697)	(0.0548)	(0.133)
Transport Public works X Kdestruction	-0.00603	-0.00857**	0.00461	-0.00644**	-0.00940***	0.00711	-0.00716**	-0.0100***	0.00641	-0.00716**	-0.0100***	0.00641	-0.00113	-0.00247**	0.00384***
	(0.00394)	(0.00357)	(0.00472)	(0.00297)	(0.00258)	(0.00468)	(0.00301)	(0.00263)	(0.00461)	(0.00301)	(0.00263)	(0.00461)	(0.000874)	(0.000967)	(0.000566)
Transport Public works X Kdestruction X	0.00717*	0.00923***	-0.00327	0.00774**	0.0105***	-0.00277	0.00844***	0.0109***	-0.00182	0.00844***	0.0109***	-0.00182	0.00222	0.00310*	0.000679
Treated	(0.00395)	(0.00358)	(0.00477)	(0.00322)	(0.00289)	(0.00543)	(0.00324)	(0.00289)	(0.00542)	(0.00324)	(0.00289)	(0.00542)	(0.00165)	(0.00159)	(0.00275)
Transport Public works X Kdestruction X	0.00577**	0.00722***	-0.00648	0.00678***	0.00856***	-0.00960	0.00693***	0.00867***	-0.00940	0.00693***	0.00867***	-0.00940	0.00212***	0.00233***	-0.00287***
Post	(0.00251)	(0.00229)	(0.00656)	(0.00210)	(0.00175)	(0.00732)	(0.00213)	(0.00177)	(0.00731)	(0.00213)	(0.00177)	(0.00731)	(0.000731)	(0.000877)	(0.000770)
Transport Public works X Kdestruction X	-0.00598**	-0.00723***	0.00600	-0.00691**	-0.00808***	0.00637	-0.00864***	-0.00926***	0.00559	-0.00864***	-0.00926***	0.00559	-0.00307**	-0.00239*	-0.000654
Treated X Post	(0.00253)	(0.00230)	(0.00658)	(0.00272)	(0.00235)	(0.00805)	(0.00261)	(0.00218)	(0.00821)	(0.00261)	(0.00218)	(0.00821)	(0.00155)	(0.00139)	(0.00303)
Constant	4.425***	3.040***	6.237***	4.289***	2.928***	6.111***	4.334***	2.967***	6.154***	4.334***	2.967***	6.154***	4.408***	3.025***	6.197***
	(0.0955)	(0.0844)	(0.0942)	(0.0957)	(0.0839)	(0.0960)	(0.0957)	(0.0844)	(0.0959)	(0.0957)	(0.0844)	(0.0959)	(0.0947)	(0.0843)	(0.0940)
Observations	5,842	5,842	5,786	5,737	5,737	5,680	5,693	5,693	5,637	5,693	5,693	5,637	5,808	5,808	5,752
R-squared	0.081	0.090	0.061	0.085	0.095	0.062	0.084	0.093	0.062	0.084	0.093	0.062	0.085	0.093	0.062

Robust standard errors clustered at municipality level in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Post is a dummy variable equal to 1 for 2012<year<2017 , 0 for 2007<year<2012 - the treatment year is excluded from the sample. Treated is a dummy variable equal to 1 for municipalities that experienced seismic intensity larger or equal to 7.25, 0 if below 7.25. (Int. - 7.25) represents the difference between seismic intensity and the threshold intensity of 7.25. All the dependent variables (private firms' number of business units, number of workers and gross fixed capital investment) are per square kilometres and expressed in natural logarithm. Also public investments in transport infrastructures (Transport Public works) are per square kilometre and expressed in natural logarithm. Kdestruction represents the percentage of destruction in physical capital stock coming from the seismic shock.

Section D - Robustness tables for investment incentives

Table D.1: Robustness check for share of incentive financing

	Incentive financing share/sqkm			
	6.75 ≤ Seismic Intensity ≤ 7.75		6.25 ≤ Seismic Intensity ≤ 8.25	
VARIABLES	(1)	(2)	(3)	(4)
Post	0.313***	0.160***	0.299***	0.124***
	(0.0109)	(0.0294)	(0.0109)	(0.0281)
Treated	0.0404	0.0615	0.0364	0.0173
	(0.0645)	(0.110)	(0.0641)	(0.109)
Post X Treated	-0.0723	-0.00140	-0.0747	0.0717
	(0.0605)	(0.104)	(0.0605)	(0.105)
Int.- 7.25		0.00254		0.0153*
		(0.00795)		(0.00869)
Treated X (Int.- 7.25)		-0.103		-0.0582
		(0.288)		(0.283)
Post X (Int.- 7.25)		-0.0664***		-0.0793***
		(0.0106)		(0.0103)
Post X Treated X (Int.- 7.25)		0.392		0.174
		(0.241)		(0.265)
Constant	0.245***	0.250***	0.255***	0.285***
	(0.00802)	(0.0185)	(0.00860)	(0.0211)
Observations	5,912	5,912	6,118	6,118
R-squared	0.079	0.088	0.073	0.083

Robust standard errors clustered at municipality level in parentheses
*** p<0.01, ** p<0.05, * p<0.1*

Post is a dummy variable equal to 1 for year>2012, 0 for year<2012 - the treatment year is excluded from the sample. Treated is a dummy variable equal to 1 for municipalities that experienced seismic intensity larger or equal to 7.25, 0 if below 7.25. (Int. - 7.25) represents the difference between seismic intensity and the threshold intensity of 7.25. Incentives financing share/sqkm represents the share of the total project cost financed by the state per sqkm.

Table D.2: Within-province RDD results for incentives

	6.75 ≤ Seismic Intensity ≤ 7.75														
	Modena			Ferrara			Mantova			Rovigo			Bologna		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
VARIABLES	N.Workers	N.BU	GFCF	N.Workers	N.BU	GFCF	N.Workers	N.BU	GFCF	N.Workers	N.BU	GFCF	N.Workers	N.BU	GFCF
Post	1.151***	0.950***	0.863***	1.184***	0.980***	0.876***	1.184***	0.980***	0.876***	1.184***	0.980***	0.876***	1.188***	0.982***	0.860***
	(0.191)	(0.164)	(0.213)	(0.189)	(0.162)	(0.214)	(0.189)	(0.162)	(0.214)	(0.189)	(0.162)	(0.214)	(0.188)	(0.162)	(0.213)
Treated	-1.700***	-1.296***	-2.763***	-1.915***	-1.485***	-3.005***	-1.915***	-1.485***	-3.005***	-1.915***	-1.485***	-3.005***	-1.739***	-1.325***	-2.879***
	(0.576)	(0.493)	(0.650)	(0.541)	(0.461)	(0.616)	(0.541)	(0.461)	(0.616)	(0.541)	(0.461)	(0.616)	(0.552)	(0.476)	(0.607)
Post X Treated	-0.976*	-0.914**	0.432	-0.835*	-0.743*	0.392	-0.874*	-0.773*	0.432	-0.874*	-0.773*	0.432	-0.809*	-0.723*	0.539
	(0.545)	(0.450)	(0.753)	(0.483)	(0.395)	(0.699)	(0.491)	(0.403)	(0.698)	(0.491)	(0.403)	(0.698)	(0.484)	(0.404)	(0.655)
Int.- 7.25	0.940***	0.813***	1.010***	0.936***	0.809***	1.021***	0.935***	0.809***	1.021***	0.935***	0.809***	1.021***	0.927***	0.802***	0.996***
	(0.0984)	(0.0872)	(0.112)	(0.0992)	(0.0879)	(0.113)	(0.0992)	(0.0879)	(0.113)	(0.0992)	(0.0879)	(0.113)	(0.0971)	(0.0859)	(0.111)
Incentives	0.0547	0.0442	-0.000408	0.0605*	0.0498	-0.00331	0.0606*	0.0498	-0.00329	0.0606*	0.0498	-0.00329	0.0676*	0.0546*	0.00937
	(0.0362)	(0.0329)	(0.0402)	(0.0363)	(0.0331)	(0.0410)	(0.0363)	(0.0331)	(0.0410)	(0.0363)	(0.0331)	(0.0410)	(0.0357)	(0.0324)	(0.0405)
Incentives X Post	-0.167***	-0.140***	-0.132***	-0.175***	-0.148***	-0.137***	-0.175***	-0.148***	-0.137***	-0.175***	-0.148***	-0.137***	-0.171***	-0.145***	-0.134***
	(0.0305)	(0.0266)	(0.0337)	(0.0298)	(0.0259)	(0.0337)	(0.0298)	(0.0259)	(0.0337)	(0.0298)	(0.0259)	(0.0337)	(0.0296)	(0.0257)	(0.0336)
Incentives X Treated	0.322***	0.253***	0.614***	0.348***	0.276***	0.632***	0.347***	0.276***	0.632***	0.347***	0.276***	0.632***	0.313***	0.244***	0.631***
	(0.0976)	(0.0814)	(0.0992)	(0.0940)	(0.0778)	(0.100)	(0.0940)	(0.0778)	(0.100)	(0.0940)	(0.0778)	(0.100)	(0.0964)	(0.0807)	(0.101)
Incentives X Post X Treated	0.0119	0.0440	-0.312***	-0.0438	-0.0124	-0.312***	-0.0485	-0.0177	-0.327***	-0.0485	-0.0177	-0.327***	-0.0247	0.00293	-0.340***
	(0.0955)	(0.0804)	(0.114)	(0.0842)	(0.0687)	(0.113)	(0.0868)	(0.0708)	(0.112)	(0.0868)	(0.0708)	(0.112)	(0.0840)	(0.0693)	(0.107)
Incentives X (Int.- 7.25)	-0.177***	-0.158***	-0.187***	-0.177***	-0.157***	-0.189***	-0.177***	-0.157***	-0.189***	-0.177***	-0.157***	-0.189***	-0.174***	-0.155***	-0.183***
	(0.0146)	(0.0133)	(0.0170)	(0.0148)	(0.0134)	(0.0171)	(0.0148)	(0.0134)	(0.0171)	(0.0148)	(0.0134)	(0.0171)	(0.0144)	(0.0131)	(0.0169)
Incentives X Treated X (Int.- 7.25)	-0.215*	-0.223**	-0.333***	-0.177*	-0.190**	-0.275***	-0.177*	-0.190**	-0.275***	-0.177*	-0.190**	-0.275***	-0.178*	-0.188**	-0.302***
	(0.110)	(0.0974)	(0.115)	(0.103)	(0.0933)	(0.0938)	(0.103)	(0.0933)	(0.0938)	(0.103)	(0.0933)	(0.0938)	(0.102)	(0.0917)	(0.100)
Incentives X Post X (Int.- 7.25)	0.00823	0.00692	0.0145**	0.00667	0.00549	0.0134*	0.00667	0.00549	0.0134*	0.00667	0.00549	0.0134*	0.00828	0.00673	0.0138**
	(0.00571)	(0.00514)	(0.00704)	(0.00561)	(0.00504)	(0.00701)	(0.00561)	(0.00504)	(0.00701)	(0.00561)	(0.00504)	(0.00701)	(0.00546)	(0.00489)	(0.00692)
Incentives X Treated X Post X (Int.- 7.25)	0.173**	0.149**	0.243**	0.220***	0.211***	0.215**	0.206***	0.199***	0.209**	0.206***	0.199***	0.209**	0.158**	0.163**	0.203**
	(0.0837)	(0.0731)	(0.0960)	(0.0790)	(0.0708)	(0.0933)	(0.0775)	(0.0689)	(0.0952)	(0.0775)	(0.0689)	(0.0952)	(0.0757)	(0.0685)	(0.0915)
Constant	3.462***	2.242***	5.676***	3.423***	2.205***	5.695***	3.423***	2.204***	5.695***	3.423***	2.204***	5.695***	3.399***	2.186***	5.643***
	(0.227)	(0.202)	(0.253)	(0.227)	(0.203)	(0.258)	(0.227)	(0.203)	(0.258)	(0.227)	(0.203)	(0.258)	(0.224)	(0.200)	(0.255)
Observations	5,785	5,785	5,768	5,755	5,755	5,738	5,747	5,747	5,730	5,747	5,747	5,730	5,823	5,823	5,806
R-squared	0.265	0.270	0.159	0.268	0.273	0.161	0.269	0.274	0.161	0.269	0.274	0.161	0.265	0.271	0.159

Robust standard errors clustered at municipality level in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Post is a dummy variable equal to 1 for year>2012, 0 for year<2012 - the treatment year is excluded from the sample. Treated is a dummy variable equal to 1 for municipalities that experienced seismic intensity larger or equal to 7.25, 0 if below 7.25. (Int. - 7.25) represents the difference between seismic intensity and the threshold intensity of 7.25. All the dependent variables (private firms' number of business units, number of workers and gross fixed capital investment) are per square kilometres and expressed in natural logarithm. Also state-funded incentives for private firms (Public investment incentives) are per square kilometre and expressed in natural logarithm.

Table D.3: Within-province RDD results for incentives with proxy for capital stock levels

	6.75 ≤ Seismic Intensity ≤ 7.75							
	Modena			Ferrara			Mantova	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	N.Workers	N.BU	GFCF	N.Workers	N.BU	GFCF	N.Workers	N.BU
Post	0.716***	0.557***	0.408*	0.764***	0.600***	0.431*	0.764***	0.600***
	(0.204)	(0.177)	(0.221)	(0.200)	(0.173)	(0.222)	(0.200)	(0.173)
Treated	0.792	0.944**	-0.156	0.619	0.775*	-0.331	0.620	0.775*
	(0.536)	(0.469)	(0.572)	(0.493)	(0.425)	(0.526)	(0.493)	(0.425)
Post X Treated	-0.241	-0.291	1.176	-0.155	-0.103	1.151*	-0.308	-0.230
	(0.578)	(0.496)	(0.730)	(0.524)	(0.440)	(0.651)	(0.518)	(0.431)
Int.- 7.25	-0.238***	-0.236***	-0.205***	-0.243***	-0.240***	-0.208***	-0.243***	-0.240***
	(0.0325)	(0.0299)	(0.0338)	(0.0324)	(0.0298)	(0.0338)	(0.0324)	(0.0298)
Incentives	0.409***	0.359***	0.372***	0.416***	0.365***	0.375***	0.416***	0.365***
	(0.0281)	(0.0243)	(0.0300)	(0.0275)	(0.0237)	(0.0301)	(0.0275)	(0.0237)
Incentives X Post	-0.127***	-0.103***	-0.103***	-0.135***	-0.110***	-0.107***	-0.135***	-0.110***
	(0.0288)	(0.0252)	(0.0312)	(0.0281)	(0.0245)	(0.0312)	(0.0281)	(0.0245)
Incentives X Treated	-0.103	-0.144*	0.114	-0.0651	-0.111	0.132	-0.0651	-0.111
	(0.0894)	(0.0830)	(0.105)	(0.0779)	(0.0740)	(0.102)	(0.0779)	(0.0740)
Incentives X Post X Treated	-0.0493	0.00150	-0.326***	-0.0928	-0.0521	-0.335***	-0.0685	-0.0322
	(0.101)	(0.0897)	(0.117)	(0.0871)	(0.0760)	(0.102)	(0.0857)	(0.0746)
Incentives X Kdestruction	0.0139***	0.00712	0.0245***	0.0144***	0.00759*	0.0249***	0.0144***	0.00759*
	(0.00432)	(0.00439)	(0.00510)	(0.00437)	(0.00445)	(0.00511)	(0.00437)	(0.00445)
Incentives X Treated X Kdestruction	-0.0141***	-0.00682	-0.0235***	-0.0157***	-0.00773	-0.0231***	-0.0157***	-0.00773
	(0.00441)	(0.00447)	(0.00524)	(0.00475)	(0.00484)	(0.00557)	(0.00475)	(0.00484)
Incentives X Post X Kdestruction	-0.0241***	-0.0180***	-0.0360***	-0.0254***	-0.0192***	-0.0373***	-0.0254***	-0.0192***
	(0.00493)	(0.00426)	(0.00655)	(0.00519)	(0.00446)	(0.00698)	(0.00519)	(0.00446)
Incentives X Treated X Post X Kdestruction	0.0255***	0.0186***	0.0364***	0.0282***	0.0213***	0.0381***	0.0262***	0.0196***
	(0.00501)	(0.00432)	(0.00663)	(0.00557)	(0.00485)	(0.00737)	(0.00530)	(0.00460)
Constant	1.133***	0.172	3.276***	1.077***	0.120	3.247***	1.076***	0.120
	(0.196)	(0.170)	(0.210)	(0.190)	(0.164)	(0.210)	(0.190)	(0.164)
Observations	5,785	5,785	5,768	5,755	5,755	5,738	5,747	5,747
R-squared	0.221	0.227	0.129	0.225	0.230	0.130	0.226	0.231

	6.75 ≤ Seismic Intensity ≤ 7.75						
	Mantova	Rovigo			Bologna		
	(9)	(10)	(11)	(12)	(13)	(14)	(15)
VARIABLES	GFCF	N.Workers	N.BU	GFCF	N.Workers	N.BU	GFCF
Post	0.431*	0.764***	0.600***	0.431*	0.783***	0.619***	0.431*
	(0.222)	(0.200)	(0.173)	(0.222)	(0.199)	(0.172)	(0.221)
Treated	-0.330	0.620	0.775*	-0.330	0.692	0.854**	-0.339
	(0.526)	(0.493)	(0.425)	(0.526)	(0.499)	(0.432)	(0.513)
Post X Treated	1.123*	-0.308	-0.230	1.123*	-0.181	-0.140	1.248**
	(0.664)	(0.518)	(0.431)	(0.664)	(0.503)	(0.424)	(0.606)
Int.- 7.25	-0.208***	-0.243***	-0.240***	-0.208***	-0.230***	-0.232***	-0.196***
	(0.0338)	(0.0324)	(0.0298)	(0.0338)	(0.0316)	(0.0288)	(0.0330)
Incentives	0.375***	0.416***	0.365***	0.375***	0.416***	0.365***	0.374***
	(0.0301)	(0.0275)	(0.0237)	(0.0301)	(0.0274)	(0.0236)	(0.0300)
Incentives X Post	-0.107***	-0.135***	-0.110***	-0.107***	-0.137***	-0.112***	-0.107***
	(0.0312)	(0.0281)	(0.0245)	(0.0312)	(0.0280)	(0.0243)	(0.0311)
Incentives X Treated	0.132	-0.0651	-0.111	0.132	-0.0855	-0.128*	0.142
	(0.102)	(0.0779)	(0.0740)	(0.102)	(0.0796)	(0.0734)	(0.0962)
Incentives X Post X Treated	-0.331***	-0.0685	-0.0322	-0.331***	-0.0709	-0.0338	-0.351***
	(0.104)	(0.0857)	(0.0746)	(0.104)	(0.0844)	(0.0730)	(0.0965)
Incentives X Kdestruction	0.0249***	0.0144***	0.00759*	0.0249***	0.00225	6.57e-05	0.00755***
	(0.00511)	(0.00437)	(0.00445)	(0.00511)	(0.00189)	(0.00128)	(0.00262)
Incentives X Treated X Kdestruction	-0.0231***	-0.0157***	-0.00773	-0.0231***	-0.00324	-0.000218	-0.00529
	(0.00557)	(0.00475)	(0.00484)	(0.00557)	(0.00255)	(0.00217)	(0.00356)
Incentives X Post X Kdestruction	-0.0373***	-0.0254***	-0.0192***	-0.0373***	-0.00227	-0.00145	-0.00843**
	(0.00698)	(0.00519)	(0.00446)	(0.00698)	(0.00327)	(0.00250)	(0.00424)
Incentives X Treated X Post X Kdestruction	0.0369***	0.0262***	0.0196***	0.0369***	0.00379	0.00261	0.00824*
	(0.00737)	(0.00530)	(0.00460)	(0.00737)	(0.00348)	(0.00277)	(0.00472)
Constant	3.246***	1.076***	0.120	3.246***	1.109***	0.140	3.288***
	(0.210)	(0.190)	(0.164)	(0.210)	(0.188)	(0.162)	(0.209)
Observations	5,730	5,747	5,747	5,730	5,823	5,823	5,806
R-squared	0.131	0.226	0.231	0.131	0.223	0.228	0.128

Robust standard errors clustered at municipality level in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Post is a dummy variable equal to 1 for year>2012, 0 for year<2012 - the treatment year is excluded from the sample. Treated is a dummy variable equal to 1 for municipalities that experienced seismic intensity larger or equal to 7.25, 0 if below 7.25. (Int. - 7.25) represents the difference between seismic intensity and the threshold intensity of 7.25. All the dependent variables (private firms' number of business units, number of workers and gross fixed capital investment) are per square kilometres and expressed in natural logarithm. Also state-funded incentives for private firms (Public investment incentives) are per square kilometre and expressed in natural logarithm. Kdestruction represents the percentage of destruction in physical capital stock coming from the seismic shock.

Table D.4: RDD results for investment incentives

			6.25 ≤ Seismic Intensity ≤ 8.25				
	(1)	(2)	(3)		(4)	(5)	(6)
VARIABLES	N.Workers	N.BU	GFCF	VARIABLES	N.Workers	N.BU	GFCF
Post	1.061***	0.872***	0.698***	Post	0.690***	0.538***	0.318
	(0.186)	(0.160)	(0.209)		(0.198)	(0.172)	(0.217)
Treated	-1.407**	-1.003**	-2.505***	Treated	0.751	0.930*	-0.284
	(0.587)	(0.507)	(0.634)		(0.551)	(0.478)	(0.564)
Post X Treated	-0.866	-0.808*	0.458	Post X Treated	-0.0861	-0.150	1.299*
	(0.532)	(0.450)	(0.725)		(0.558)	(0.484)	(0.665)
Int.- 7.25	0.865***	0.735***	0.910***	Int.- 7.25	-0.192***	-0.203***	-0.169***
	(0.0978)	(0.0880)	(0.108)		(0.0307)	(0.0279)	(0.0318)
Incentives	0.0935**	0.0820**	0.0360	Incentives	0.404***	0.356***	0.360***
	(0.0379)	(0.0353)	(0.0385)		(0.0276)	(0.0239)	(0.0293)
Incentives X Post	-0.150***	-0.127***	-0.106***	Incentives X Post	-0.123***	-0.100***	-0.0889***
	(0.0297)	(0.0259)	(0.0327)		(0.0281)	(0.0245)	(0.0305)
Incentives X Treated	0.254**	0.187**	0.577***	Incentives X Treated	-0.124	-0.162*	0.129
	(0.100)	(0.0846)	(0.0994)		(0.0915)	(0.0826)	(0.100)
Incentives X Post X Treated	-0.00629	0.0302	-0.348***	Incentives X Post X Treated	-0.0480	0.000709	-0.345***
	(0.0938)	(0.0788)	(0.110)		(0.0973)	(0.0866)	(0.109)
Incentives X (Int.- 7.25)	-0.159***	-0.141***	-0.166***	Incentives X Kdestruction	0.00419**	0.00190	0.00937***
	(0.0150)	(0.0139)	(0.0163)		(0.00211)	(0.00174)	(0.00243)
Incentives X Treated X (Int.- 7.25)	-0.219**	-0.216**	-0.356***	Incentives X Treated X Kdestruction	-0.00425*	-0.00156	-0.00821***
	(0.0974)	(0.0856)	(0.105)		(0.00227)	(0.00192)	(0.00275)
Incentives X Post X (Int.- 7.25)	0.00965*	0.00729	0.0154**	Incentives X Post X Kdestruction	-0.00355	-0.00230	-0.00974***
	(0.00541)	(0.00487)	(0.00669)		(0.00231)	(0.00173)	(0.00278)
Incentives X Post X Treated X (Int.- 7.25)	0.293***	0.249***	0.419***	Incentives X Post X Treated X Kdestruction	0.00494**	0.00292	0.0102***
	(0.0840)	(0.0740)	(0.0969)		(0.00245)	(0.00188)	(0.00303)
Constant	3.328***	2.088***	5.531***	Constant	1.294***	0.287*	3.450***
	(0.232)	(0.211)	(0.244)		(0.191)	(0.165)	(0.206)
Observations	6,118	6,118	6,101	Observations	6,118	6,118	6,101
R-squared	0.252	0.259	0.150	R-squared	0.215	0.222	0.126

Robust standard errors clustered at municipality level in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Robust standard errors clustered at municipality level in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Post is a dummy variable equal to 1 for year>2012, 0 for year<2012 - the treatment year is excluded from the sample. Treated is a dummy variable equal to 1 for municipalities that experienced seismic intensity larger or equal to 7.25, 0 if below 7.25. (Int. - 7.25) represents the difference between seismic intensity and the threshold intensity of 7.25. All the dependent variables (private firms' number of business units, number of workers and gross fixed capital investment) are per square kilometers and expressed in natural logarithm. Also state-funded incentives for private firms (Public investment incentives) are per square kilometer and expressed in natural logarithm. Kdestruction represents the percentage of destruction in physical capital stock coming from the seismic shock.

ABOUT EMANES

The Euro-Mediterranean and African Network for Economic Studies (EMANES) is a network of research institutions and think tanks working on socio-economics policy in Europe, the Mediterranean and Africa. EMANES is coordinated by the Euro-Mediterranean Economists Association (EMEA).

The research conducted by EMANES Researchers, Associates and Fellows aims to design sound and innovative socio-economic models that are inclusive, sustainable and employment creative, to devise new models for regional integration and to provide policy recommendations towards this goal.

EMANES research agenda is organized around the following mutually reinforcing and interconnected themes led by EMANES researchers, associates and fellows:

- Governance, institutions and institutional reforms;
- Macroeconomic policies and employment creation;
- Private sector, micro, small and medium –sized enterprises development, entrepreneurship and social business;
- Digital economy;
- Healthcare policy;
- Human capital development, education, innovation, skill mismatch and migration;
- Labor markets, employment and employability;
- Finance, financial inclusion and the real economy;
- Sustainable development;
- Regional integration;
- Euro-Mediterranean economic partnership;
- Scenarios analysis and foresight.

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