The London School of Economics and Political Science

Private credit, public investment and natural disasters: creating and destroying private capital at local level

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Abstract

This thesis explores two main drivers of creation of private capital at local level: private credit, and public investment, using natural disasters as exogenous shocks to private wealth and public policy intervention. It does so by adopting a quasi-experimental approach with case studies set in Italy and the United Kingdom between 2007 and 2019. Theoretical models and literature drawn from economic geography, public economics and finance frame the discussion and the identification designs over the three chapters. The originality of this thesis lays in the novel combination of the research questions addressed, the empirical identification designs and the highly granular datasets from which evidence is obtained. Three main questions are explored using natural disasters, private credit, and public investment alternatively as shocks and conditioning assumptions in the study of private capital development at local level. What is the role of local private capital endowment on the private sector's responsiveness to public investment? How do credit market imperfections affect the firm's response to investment subsidies and the selection of the policy's optimal target group? What is the impact of a negative shock to the entrepreneur's home on their small-medium business? This thesis provides three main novel insights. The first one is the crucial role of private capital stock endowment at local and firm-level in determining the effectiveness of different types of public investment in mobilising private investment and labour demand. The second one is the significant impact of natural disasters on local economies not just through physical destruction and factor relocation, but also through indirect effects generated by credit market imperfections and wealth effects. The third one is the effectiveness of public policy in fostering private capital development at local level, which is shown to be related to the degree of complementarity between the public investment and the pre-existing private capital stock.

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Introduction

I. Overview

This thesis explores two main drivers of creation of private capital at local level: private credit and public investment. It does so by adopting an empirical quasi-experimental approach, with case studies set in the context of Italy and the United Kingdom between 2007 and 2019. Natural disasters are adopted as exogenous shocks in the empirical identification of the different research questions addressed in this paper, representing one time a negative shock to local private capital, another time a trigger for exogenous public investment subsidies and another time a negative shock to household wealth.

Written largely during a global pandemic, the use of natural disasters as exogenous shocks in the identification designs presented here is emblematic and a stimulus for reflection. Natural disasters can cause incredible destruction, loss of human life and disruption to daily life, but we can use them to learn about something new and they can represent an opportunity for growth. We cannot change what has happened, but we can learn from it to shape the future.

Theoretical models and literature drawn from economic geography, public economics and finance frame the discussion and the identification designs over the three chapters. The approach of this thesis allows for contribution to a variety of different literatures and represents an effort towards their cross-fertilization.

The originality of this thesis lays in the combination of the research questions addressed, the empirical identification designs and the highly granular datasets, from which evidence is obtained. Three main questions are explored using natural disasters, private credit and public investment alternatively as shocks and conditioning assumptions in the study of private capital development at local level. What is the role of local private capital endowment on the private sector's responsiveness to public investment? How do credit market imperfections affect the firm's response to interest rate reductions in the form of investment subsidies and the selection of the policy's optimal target group? What is the impact of a negative shock to the entrepreneur's home on their small-medium business? These questions are answered adopting novel and highly granular data sources jointly with innovative quasi-experimental designs, exploiting natural disasters - earthquakes and floods in particular - as exogenous shocks and treatment allocation tools.

Experian data on monthly bank account balances of UK small and medium enterprises (SMEs) and OpenCup, project level data on all public procurement transactions in Italy, provide the backbone of evidence from which this thesis derives its insights, and count only a few other published contributions exploring them, mostly descriptive in nature (for OpenCup: Carlucci et al., 2019; Accetturo et al., 2022; Busetti et al., 2019; for Experian SMEs bank account data: Hurley et al., 2021; Walker and Hurley, 2021).

The empirical and theoretical evidence presented in this thesis points to three main conclusions. The first one is the crucial role of private capital stock endowment at local and firm level in determining the effectiveness of different types of public investment in mobilising private investment and labour demand. The second one is the significant impact of natural disasters on local economies not just through physical destruction and factor relocation, but also through indirect effects generated by credit market imperfections and changes to wealth levels and risk preferences. The practice of secured borrowing in the banking sector (i.e.. pledging an asset as collateral) provides an important of channel of transmission of the negative impact of natural disasters on real estate asset markets further through the economy, with consequences for the credit conditions faced by households and enterprises, in particular SMEs. The destruction of capital and wealth associated to natural disasters also lead to an increase in risk aversion, with consequences for instance for the predisposition to investment and business generation. The third one is the effectiveness of public policy in fostering private capital development at local level by easing constraints from credit market imperfections, supporting local economies in post-disaster recovery, and stimulating private sector's demand for factors of production. This latter channel is shown to be related to the degree of complementarity between the public investment and the pre-existing private capital stock.

The rest of this introductory chapter provides a review of the main themes addressed in the thesis (Section II), a summary of each chapter (Section III), a critical discussion of the methodologies adopted (Section IV) and their limitations (Section V), and a section summarizing the main learnings from this thesis and the direction for future research (Section VI).

Finally, before delving further into the themes discussed in this thesis, I believe it is important to clarify some of the terminology adopted in the sections and chapters that follow for a better understanding of the concepts presented and economic dynamics investigated. The term "capital stock" refers to the outstanding depreciation-adjusted body of government and private owned assets which are used as a means for productivity. The "public capital stock" includes assets such as roads, airports and government-owned buildings such as public hospitals, municipality offices, etc… The "private capital stock" instead refers to assets owned by households and corporates such as real estate, machineries and, in case of corporates, also intangibles. Intangibles and accounts receivables are however excluded from the definition of "physical capital stock", which refers exclusively to tangible assets used for production and whose valuation is vulnerable to physical risk from natural disasters. The concept of "effectiveness" of a public investment on private outcomes is related to the macroeconomics concept of "fiscal multiplier" and is measured as the ratio of a change in private outcomes (attributable to the public investment) to the change in public investment. The "utilization rate of public capital" instead refers to the share of public capital used for productive activity versus the concept of 'available for usage'. In practice, one could consider as an example the case of a stadium which is on average half full: its utilization rate is 50%. If it were filled above its capacity, its utilization rate could go above 100%.

II. Themes

a. Local private capital stock endowment: an important condition for the effectiveness of public investment

Local private capital stock endowments are strongly correlated to broader economic development, access to credit, institutional quality and public sector's investment strategy experience. This correlation has significantly limited the ability to study their individual role in an economic system, especially from an empirical perspective. One of the main themes of this thesis is the role of private capital stock endowments at local level in determining the responsiveness to public investment.

This is done through both a macro/local economy perspective and a micro/firm perspective.

At macro level, private capital stock endowments determine the level of local demand for public capital services (Aschauer, 1998), and as a result, given any level of supply, their utilisation rate (Zhu, 1995). Public capital, adjusted for its utilisation, in turn affects private productivity through the impact it has as a factor in private production (Aschauer, 1989; Gramlich, 1994) and its complementarity with the existing private capital stock (Richardson and Townroe, 1986).

Chapter 1 delves on the role of local private capital stock in the effectiveness of different types of public investment. Direct public investments in infrastructures appear to have a higher effectiveness in areas characterized 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.

Areas with lower levels of private capital stock appear to be more responsive to state-funded investment incentives targeted at production than direct public investments in transport infrastructures. Investment incentives for production, through their ability in increasing the pool of credit eligible applicants, appear to be effective in counterbalancing negative credit implications stemming from a negative capital shock. They thus appear to be effective in increasing the level of physical private capital available at local level also in capital-scarce areas, fostering private productive capacity and, eventually, potential gains in complementarity from public infrastructure. These appear to be favoured over direct public investments in contexts with lower levels of private capital.

These findings provide novel evidence in relation to Commendatore et al. (2008), that posited how, in a New Economic Geography model with two regions (one poor and one rich), an increase in public capital in the poor region was going to increase the share of manufacturing activities in the region. I find that the impact of transport infrastructure investments could be enhanced by providing incentives to private firms for productive investments alongside it. This would increase the private capital of both tradeable and non-tradeable sectors in the poor region, leading to a higher utilisation rate of public capital investments.

At micro/firm-level, private capital stock adopts an additional characterisation as source of collateral to access secured credit in the banking sector. The pecking order financing hypothesis[1] (Bond and Van Reenen, 2007) points to the role of the firm's private capital stock endowment in affecting its investment financing decisions. Internal financing is favoured over external financing but is conditional on the availability of sufficient spare firm's capital. Chapter 2 argues about the existence of a financing gap generated by secured borrowing requirements, which limit the ability of a firm to access external financing, when unable to finance internally. This is due to the lack of sufficient internal collateral. These firms, often small businesses, are shown to present the highest return to productive investment subsidies (i.e. interest rate reductions for borrowing for investment in productive assets).

[1] According to pecking order theory, there exists a hierarchy across financing options, with a preference for internal financing over external financing at firm level. Capital market imperfections make pre-borrowing screening and post-borrowing monitoring costly, and this is associated with a higher cost of capital when financing an investment externally.

b. The economic consequences of natural disasters

Natural disasters affect the economy through direct and indirect channels. This thesis builds on the evidence presented by literature on the direct impacts to explore the indirect ones and the overall consequences for the economy.

The direct economic impacts are the ones associated with the destruction of capital directly associated with the natural disaster event. These direct economic losses are in turn affecting production and consumption in the economy in the short and long run (Kousky, 2014). The destruction of capital associated with natural disasters notably includes both human capital and productive assets such as machinery, real estate and infrastructures. Literature findings informing the patterns of capital destruction and factor relocation associated with earthquakes are discussed in Chapter 1. The network character of public capital, particularly in the case of transport infrastructures (Deng, 2013; Moreno and Lopez-Bazo, 2007; Álvarez-Ayuso et al., 2016), means that the impact of destruction to one part of the network does not remain confined but rather diffuses through the entire network. The destruction effect of private capital instead tends to be more localised, with smaller spatial spillover effects directly associated with the destruction of a firm's machinery or real estate.

Relocation of productive activities and human capital is often observed from the areas affected by elevated natural disaster's destruction. The spatial patterns of such relocation are hard to predict and highly dependent also on whether relocation is considered to be temporary or permanent to start with. The extent to which a temporary relocation becomes permanent in nature is heavily a function of public policy interventions following the disaster (Storr et al., 2015).

This thesis delves deeper into the consequences of natural disasters by exploring their indirect economic effects and their transmission channels in the economy. The findings of the chapters shed insight on a series of related research questions, such as 'Who benefits from post-disaster public investment?', 'Under what circumstances can post-disaster public investment have a greater impact on business outcomes?', 'How do natural disaster shocks transmit across sectors in the economy?'.

In Chapter 1 the asymmetry in the destruction between public and private capital is exploited to investigate how returns from different types of public investment vary depending on the local level of private capital stock. In the five years following the disaster, areas more highly affected by destruction of private capital assets appear to show a lower responsiveness to public investments in transport infrastructure, whilst remain equally receptive to stimulus from public subsidies for productive investments.

In Chapter 1 and 2 emergency public policy interventions following earthquakes are discussed in detail. For the areas affected by seismic destruction, those comprise full state-sponsored reconstruction, public subsidies for private productive investment and subsidies for ameliorations and investments aimed at reducing seismic risk in real estate. Notable are the issues discussed in literature which can hamper state-sponsored reconstruction processes, from delays in reimbursement of claims to corruption and red tape (Özerdem and Rufini, 2013; Hayat and Amaratunga, 2011). In Chapter 2 the asymmetry between eligibility and need for emergency funding is exploited by studying the impact of emergency investment subsidies on firms formally eligible for their receipt but effectively not directly in need, given their lack of damage from the earthquake.

Public policy interventions can however be effective overall in supporting reconstruction and stimulating economic recovery at local level, as the findings presented in Chapter 2 also show. Literature argues that recovery can occur even through a higher growth trajectory, on the back of technological innovation, when public policy interventions are oriented towards "building back better" (Klomp and Valckx, 2014).

The transmission of risks and disruptions stemming from natural disasters across sectors is also explored in this thesis. Chapter 3 studies the effect of a negative shock to the entrepreneur's home valuation from a flood on the activities of their small-medium business. The transmission of the shock from households to the corporate sector occurs through three main channels identified by literature: a 'collateral' channel, a 'wealth' channel, and an 'equity' channel. SMEs are highly likely to be collateral constrained, i.e., lacking enough internal collateral to access financing from the private sector (Bracke et al., 2018). When faced with collateral constraints, the entrepreneur's home equity is commonly used as collateral to obtain credit from the banking sector (Chaney et al., 2012). Home equity extraction is also a possible response to internal financing constraints faced by firms (Reuschke and Maclennan, 2014; Jensen et al., 2022). Finally, the destruction of assets associated to natural disasters inevitably have negative implications on individual wealth, which are associated with an increase in risk aversion among other consequences (Bracke et al., 2018; Paravisini et al., 2016). Findings in Chapter 3 show a significant impact of a flooding shock to the entrepreneur's home onto the SME's ability to access secured credit for at least two years after the shock. This shows the long-lasting indirect effect that a reduction on household physical capital from a natural disaster can have on corporate investment in the economy, and the consequent implications for aggregate productivity. Chapter 3 briefly touches also on the short-term disruption to labour productivity coming from stress associated with the natural disaster experience.

Finally, natural disasters have implications also for sorting of economic activities. These can be both temporary and structural. As it was previously mentioned, forced relocation of activities away from areas harshly hit with destruction from natural disasters can be temporary to start with, and then become more permanent, in the absence of sufficient progress or support for reconstruction. But structural changes in the sorting of economic activities from natural disasters can also be a result of a structural increase in the incidence of natural disasters in a certain region. This could be the direct result of a previous disaster structurally increasing local vulnerability (e.g. a landslide structurally weakening the mountain), or the result of a chronic process, such as in the case of the rise of sea levels and precipitations from climate change. Both cases are bound to have significant implications for the distribution of economic activity at regional level.

This thesis presents initial evidence supporting the incorporation of natural disaster risk in economic geography models. These have been traditionally heavily resting on other factors (such as house prices, costs of labour and capital, and endowments of capital, labour and natural resources) to explain sorting of economic activity and regional growth dynamics. As natural disasters are expected to increase in frequency and intensity, as a result of climate change, and are shown here to have the potential for significantly affecting sorting of economic activities, the case for the incorporation in economic geography models is growing stronger and is one of the avenues for future research stemming from this thesis. Such a step would lay the basis for understanding the implications for regional convergence and the appropriate regional policy response, questions at the forefront of economic geography debates. A permanent increase in the risk of a natural disaster at local level is expected to lower prices of unmovable assets locally, but also decrease expected returns on both public and private investment. This expected to lead to a relocation of business activities away from those areas over time. The speed at which that occurs, however, is likely to depend on the co-location of residential premises, with that increasing the stickiness/persistence.

This creates the space for public policy intervention. On one hand, public policy intervention can mitigate the increase in natural disaster risk and the associated consequences, for instance by building flood defences in the case of coastal and fluvial risk. On the other hand, it can support residential and business relocation at a faster pace than the one occurring in the economy absent any intervention, through measures such as relocation incentives and/or compensation. The calibration of these measures is likely to affect the decision of where to relocate to, either directly (e.g. explicit incentives to relocate to a specific locality) or indirectly (e.g. the compensation amount supporting relocation to a similarly priced area). This thesis does not provide a definite answer on the appropriateness of each of these avenues for policy intervention, but it provides additional evidence on the ‘cost’ of floods, which are part of the assessment of both mitigating measures and active sorting policies.

III. **Summary**

Chapter 1 – When Capital Falls to Pieces: Public Investment and the Role of Private Capital Stock

This paper exploits a negative shock to local private capital to derive insights on the importance of its level in determining the stimulus to local economic growth from different types of public investment interventions. In particular, public investments in transport infrastructure and investment subsidies for R&D and productive investment are considered. The theoretical underpinnings of this chapter rest on the idea of public investment as a service that facilitates private economic activity (Aschauer, 1989) and Zhu's (1995) idea of utilization rate of public capital services, which essentially posits that the local demand for public capital services is a positive function of the level of private capital in the local economy. By determining the utilization rate of public capital services, private capital stock levels therefore affect the gains in private productivity derivable from public capital investment, and, as a consequence, the resulting stimulus to local economic growth.

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 infrastructures. Direct public investments in infrastructures 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. Investment incentives for production, instead, through their ability in increasing the pool of credit eligible applicants, appear to be effective in counterbalancing the negative credit implications stemming from a negative capital shock. They thus appear to be effective in increasing the level of physical private capital available at local level also in capital scarce areas, fostering private productive capacity and, eventually, potential gains in complementarity from public infrastructure.

Overall, these results provide insights applicable to both post-disaster emergency response programs 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 to further foster economic development.

Chapter 2 – Capital Development under Collateral Constraints. Do Investment Subsidies Work?

This chapter studies the impact of productive investment subsidies on firms' capital, labour, output and productivity under credit market frictions. Through the practice of secured borrowing, collateral constraints present a friction in external credit markets, which substantially affects access to credit by smaller firms located in economically depressed areas. Productive investment subsidies are able to smooth out these frictions and stimulate marginal investment by firms which would have otherwise remained unfunded, thus supporting private capital development.

The theoretical model adopted in Chapter 2 draws on Criscuolo et al. (2019) to assess the impact of investment subsidies on firm-level's investment and employment decisions, accounting for the collateral constraints faced by the firm, and models the heterogeneous effects by firm size drawing from Sato (1977).

Empirical evidence is obtained from a productive investment subsidies program part of a post-disaster emergency policy package to support recovery following three major earthquakes in Italy in 2012, 2016 and 2017. The identification design exploits spatial discontinuities in eligibility and in physical damages, and employs a matching algorithm to identify the impact of subsidies across a random sample of firms, including very small firms generally not target of traditional subsidies programs for development. This represents a significant contribution in relation to policy evaluation literature, given the absence of productivity, size or employment-based targeting and conditionality, which allows for a reduction in estimate bias.

The results suggest the effectiveness of investment subsidies in supporting capital development and employment generation in the case of SMEs, with firm's location playing a significant role in determining the relative impact strength. The impact of productive investment subsidies on firm-level capital growth appears to be particularly high for SMEs; for firms operating in manufacturing, retail or hospitality; for areas characterised by a low sectoral business density; and for firms that are generally not targeted by traditional investment subsidies programs. The results estimating the impact of investment subsidies on employment paint a similar picture. The estimated marginal rate of substitution between capital and labour of small firms is above 1, and significantly higher than those of medium and large firms, suggesting stronger impacts on employment from the intervention when targeted to small firms.

Chapter 3 – SMEs under Water. The Impact of Households' Capital Shock on SMEs

This paper contributes to the literature studying the relationship between households and the corporate sector and the transmission of risks from the housing market to the broader economy. Existing literature has discussed how the presence of collateral constraints has led to the widespread use by small-medium enterprises (SMEs) of the entrepreneur's home equity as guarantee to obtain credit from the banking sector. At the same time, residential assets constitute a large part of an individual wealth and shocks to their valuation are shown by literature to affect the individual's risk aversion and, as a consequence, when the individual is an entrepreneur, his business decisions. This has been shown to generate a dependency between the firms' investment behaviour and the valuation of directors' homes, with this relationship being stronger in the case of SMEs. This paper delves deeper on the linkages between housing markets and SMEs' business decisions, through the theoretical channels supported by literature, by studying the impact of a negative shock to SME entrepreneurs' private capital on their SMEs, and exploring its sensitivity to indicators of regional resilience. Empirical evidence is obtained in the context of the United Kingdom, exploiting floods as exogenous shocks to entrepreneurs' residential real estate private capital. Monthly data on SMEs' business current accounts, credit cards and loans at UK major banks is used to assess the impact of the shock on the firms' business continuity, access to credit and medium-term investment behaviour. The results suggest a significant impact of a flooding shock to the entrepreneur's home onto the SME's business activities. Immediately after the shock we observe a temporary reduction in the firms' current account balances, and a temporary increase in firms' borrowing accounts' balances, particularly in the case of collateral backed ones. Over time the firm's revenues revert to counterfactual trends, potentially suggesting a temporary impact of the flood on the entrepreneur's cognitive capabilities. The evidence obtained is consistent with an increase in the entrepreneur's risk aversion motivating precautionary borrowing immediately after the shock, as treated firms' borrowing balances increase. But as this, particularly affects in the case of collateral backed (secured) borrowing accounts, it could also be an indication of anticipation effects of credit rationing, although less likely. Such an increase in borrowing is, however, short-lived and precedes a significant decrease in secured borrowing starting in the second quarter after the flooding shock, and deteriorating further over the course of two years. This can be consistent with a decrease in credit terms and/or supply from the banking sector, as a result of collateral revaluation around six months after the treatment. Indicators of local resilience for the local authority in which the firm operates are found to significantly affect the estimated treatment effect. Higher local unemployment pre-shock is associated with a lower credit limit for unsecured borrowing and lower firm's revenues for treated firms, still persisting two years after the shock. Operating in a rural area is instead associated with a lower current account balance for treated firms two years after the shock and a higher increase in unsecured borrowing straight after the shock, which does not appear to retrace over time.

IV. **Methodology**

This thesis applies a quasi-experimental approach in answering the research questions of interest. Quasi-experimental approaches primarily aim for the identification of causal nexuses by generally exploiting exogenous shocks affecting a limited and clearly identifiable sample. The choice of this approach is particularly suited when addressing questions characterised by a strong endogeneity, and such is the case in this thesis. Private capital development is highly endogenous, and so are public investment interventions. Private capital stock levels are strongly correlated to broader economic development, access to credit, institutional quality and public sector's investment strategy experience. Public investment interventions, although less so than private capital stock levels, are also hardly exogenous. Electoral interests, quality of institutions and corruption are factors often determining when and where public investment occurs. A comparison between places characterised by different levels of private capital stock, or an assessment of the effectiveness of a public investment intervention, whilst ignoring these underlying differences or drivers, is not going to provide meaningful insights. But controlling for these factors can also be difficult, as some, such as institutional quality, access to credit or corruption, can hardly be measurable.

In this thesis natural disasters constitute the core of the identification designs across the three chapters. The choice of natural disasters stems from both the search of a technical solution for endogeneity and the desire to contribute to a growing literature estimating the economic consequences associated with natural disasters and, relatedly, climate change. Natural disasters are exogenous events, random in time and space at local level, with possible significant consequences over factors of production (capital and labour) and institutional frameworks. This thesis explores different consequences stemming from them. In Chapter 1 a major earthquake is used as an exogenous source of private physical capital destruction to assess the role of private capital endowments on the responsiveness to different types of public investment projects. Chapter 2, instead, explores the impact of an emergency program of subsidies for productive investment following major earthquakes when received by firms not affected by seismic destruction. Finally, Chapter 3 investigates the consequences on SMEs of flooding affecting the home of the entrepreneur.

Natural disasters affect economies following spatial distribution patterns that are unlikely to coincide with administrative regional boundaries, thereby warranting the need for spatial approaches and highly granular data to support them. Data limitations constitute the highest barrier in their use as an exogenous shock more broadly in economic literature. If, in fact, granular data on natural disasters extensions can be sourced relatively easily through geo-physical databases or modelling, statistical offices' capabilities to collect data at municipality or more granular level are harder to come by, especially outside of a developed country context.

The high level of granularity needed in data to accurately work with natural disasters at local level motivated the innovative data work conducted in this thesis. The studies conducted in the first two chapters are based on a novel dataset integrating Italy's public procurement project-level data (sourced from OpenCup, the Italian Public Administration's open data platform) with regional accounts (Chapter 1) and firm-level financial information from Bureau Van Dijk Orbis (Chapter 2). Empirical evidence presented in Chapter 3 is instead drawn from firm-level bank accounts' monthly records from Experian, integrated with firm's ownership information and flood maps, again an entirely novel dataset. The novelty of both datasets does not lay exclusively on the novel combination of different highly granular data sources, but also on the absence, to my knowledge, of pre-existing literature contributions using OpenCup or Experian data as part of empirical identification strategies.

The econometric models adopted in this paper are derived from quasi-experimental literature and are calibrated at firm-level in Chapter 2 and 3 and at municipality-level in Chapter 1. In Chapter 1 the treatment effects are identified through a fuzzy spatial regression discontinuity design. The discontinuity - drawn from civil engineering literature - represents a significant change in the probability of experiencing a change in physical private capital endowment at municipality-level, and treatment effects are estimated through a non-parametric model calibrated within a spatial bandwidth from the discontinuity using epicentral distance as forcing variable. In Chapter 2 and 3 treatment effects are instead estimated through regressions with matching between treated units and control observations from a pool. Matching is conducted in both cases at firm-level minimising the Mahalanobis distance on a series of pre-shock firm-level characteristics. Such matches are also constrained by firm's size, sector and location in both cases, as a way to match within the most relevant control pools.

V. **Limitations**

The choice of a quasi-experimental approach comes with a number of advantages, highlighted in the previous section, but to those are also associated shortfalls.

The main shortfall is associated with the limited external validity of estimates obtained within quasi-experimental designs. The empirical evidence presented in this thesis is derived within the context of Italy and United Kingdom, but the specificity of the identification designs poses caveats to the application of findings, not just outside of those countries, but also within those countries in regions different than the ones object of the case studies analysed and under standard circumstances.

The use of natural disasters as exogenous shocks allows to obtain insights on highly endogenous dynamics, as discussed in the previous section, but leads to the estimation of treatment effects which could be considered as conditioned onto them. One might argue that the impact of a devaluation of the entrepreneur's residential property onto their SME's business from a flood is not the same as when it comes from a downturn in the housing market. In this thesis a lot of effort is put in ensuring that the exogenous shock of interest associated with the natural disaster is accurately isolated from other broader consequences stemming from natural disasters, but this does not perfectly ensure the broader external validity of the results.

This can be a limitation on one hand, but a strength on the other hand, as it allows to directly contribute to literature estimating the economic consequences associated with natural disasters. Such literature has been growing significantly over the past few years as some natural disasters have increased in frequency, and are expected to even more so in the future, as direct consequence of climate change. This is the case for instance for floods, hurricanes, wildfires and droughts. In this thesis, Chapter 3 explores the consequences of floods on households and their transmission on small-medium businesses.

Furthermore, the adoption of quasi-experimental approaches brings a trade-off also in terms of sample size. The satisfaction of numerous conditions to fulfil the quasi-experimental nature of treatment inevitably limits the number of treated observations, and, as a result, the power of the econometric estimation. The trade-off between accuracy and certainty is well-known in econometrics, and the estimates presented here, through quasi-experimental identification designs, are the result of a prioritisation at the margin of accuracy over certainty. Several steps are however taken in this thesis in order to minimise uncertainty within the constraints of a limited treated sample. The most notable is the adoption of a matching technique with replacement, selecting from very large control pools the closest matches to treated observations as control counterfactuals.

Finally, another limitation is represented by the data availability. The empirical identification approaches adopted in this thesis aim for the estimation of causal estimates through quasi-experimental designs and, as such, require very granular data. In Chapter 3, the empirical analysis focuses on UK SMEs' financial data available from 2015 onwards as a result of the Small Business Enterprise & Employment Act. The estimation horizon ends however at the end of 2019 because of the COVID-19 pandemic from 2020 onwards, which had the potential for seriously confounding the results, through the forced suspension of business activities in some cases and the government-backed loans distributed to SMEs. This therefore restricts the shock window to 2017-2018, in order to ensure sufficient pre- and post- treatment observations, thus dramatically limiting the size of the treated sample.

In the case of Chapter 2, the sample size is large and the sample observed is close to the local population of firms. Data limitations however do not allow to instrument treatment with eligibility, thus raising concerns around the endogeneity of treatment. These are however appeased by the adoption of a matching technique in the selection of the control observations, which significantly limits the potential for bias in the final estimates. Furthermore, data limitations do not allow the estimation of a population average treatment effect (ATE) but only an average treatment effect on the treated (ATT). It is argued however that the ATE differs from the ATT only for smaller firms, whilst for medium and large the firms the estimates presented coincide with the ATE.

VI. **Conclusions – What have we learned?**

The body of empirical and theoretical evidence presented over the three chapters of this thesis points to three main conclusions. The first one is the crucial role of private capital stock endowment at local and firm level in determining the effectiveness of different types of public investment in mobilising private investment and labour demand (Chapter 1). The second one is the significant impact of natural disasters on local economies not just through physical destruction and factor relocation, but also through indirect effects generated by credit market imperfections and wealth effects (Chapter 3). The third one is the effectiveness of public policy in fostering private capital development at local level by easing constraints from credit market imperfections through investment subsidies (Chapter 2), supporting local economies in post-disaster recovery through both direct investments and subsidies (Chapter 1 and 2), and stimulating private sector's demand for factors of production (Chapter 1). This latter channel is shown to be related to the degree of complementarity between the public investment and the pre-existing private capital stock.

This thesis' contribution therefore improves the understanding of three main policy-relevant discussions, the first concerns the conditions for the effectiveness of public investment, the second the role of housing markets in a country's economic productive capacity and the third one the impact of natural disasters on the economy and the post-disaster responsiveness of local economies to policy interventions.

Policy-evaluation literature has assessed whether a variety of different public investment programs in different countries worked on not. Notable is the extensive body of literature studying EU Cohesion policy. The contribution of this thesis instead abstracts from program specificities, and aims to derive insights on the conditions that lead to public investment effectiveness, to inform the design of future programs on the basis of that. Attention is granted, in particular, to the local conditioning factors on the receiving end of public investments, rather than the specific technical program features.

I find that complementarity of public investment with pre-existing private capital stock is crucial to maximise its effectiveness. This finding has direct implications on the optimal choice of public investments suitable to local conditions, but it has also, indirectly, implications for the level at which decisions on public investments should be made. The experience of EU Cohesion Policy, for instance, suggests that there is often a lack of capacity from local level authorities in identifying or coming up with investment projects to use the funds for, resulting in a lack of funds usage. But the findings in this thesis suggest that projects dictated from higher-level authorities with less or no local knowledge would be equally a waste of money and could be quite likely to lay unused.

I also find that productive investment subsidies to private firms can be a powerful tool, particularly in areas where private capital is scarce and in firm-level contexts where financial constraints arise due to the lack of sufficient internal capital to be used as collateral. The findings suggest these are likely to arise in three situations: in firms of small size, in investment-prone firms and in firms operating in manufacturing, retail and hospitality when operating in areas characterised by a low sectoral business density as a result of localization economies. These insights reinforce the argument in favour of capital subsidies as a place-based policy tool, but offer a characterisation of their target group different from the one commonly observed in programs around the world. The commonly observed focus on the competitive selection of subsidy receivers on the basis of past productivity metrics and (often false) promises of employment gains associated with subsidy receipt appears to be theoretically and empirically in contrast with a targeting strategy aimed at maximising the value for money of the subsidy and local capital development.

I also find that there is a strong transmission link between the housing market and small-medium businesses (SMEs), as a result of the widely shared practice of using the entrepreneur's home as a guarantee for SME's credit and wealth effects. A sudden negative shock to house prices appears to quickly curtail SMEs borrowing capabilities, with consequences for the level of investment and employment in the economy. The Global Financial Crisis has already been a cautionary tale on the impact sudden changes in the housing market valuation can have on the economies. But, whilst literature has explored extensively its implication for financial stability and its consequences on the real economy through the impact on financial intermediaries' balance sheets driving the 'credit crunch', this thesis points to the importance of the direct transmission channel between the household and the corporate sector. Macro-prudential regulation following the financial crisis has limited the leverage available to households when investing in the housing market but this is in no way a guarantee against the creation, and later collapse, of bubbles in housing market valuations. These findings reinforce evidence on the damages a sudden negative housing market revaluation can cause, and therefore suggest the crucial need also for governments to protect the 'price stability' of their housing market, putting in place mechanisms limiting speculative behaviour on an asset to which – one should not forget – are tied lives and livelihoods.

Finally, I find that investment subsidies for productive investment appear to effectively sustain post-disaster recovery at local level, especially supporting more vulnerable firms generally unable to access credit in the banking sector. I also find that in the five years following the disaster, areas more highly affected by destruction of private capital assets appear to show a lower responsiveness to public investments in transport infrastructure, whilst remain equally receptive to stimulus from public subsidies for productive investments. The findings provide insightful evidence on the dynamics affecting economies after a natural disaster and the most effective policy responses. A visit to L'Aquila this month, the city in Italy infamously almost entirely destroyed by an earthquake in 2009, has brought me to reflect further on the key role played by public policy interventions in the aftermath of the disaster. Nearly 15 years after the disaster around 30-40% of the city centre is still wrapped in scaffolding or reduced to a pile of rubble. Locals admit though that, where completed, reconstruction has been done to a very high standard, with buildings' historical facades and interior structures brought back to their original splendour. But the scarcity of specialised labour to achieve this, coupled with delays in the issuance of funds, has dramatically lengthened reconstruction timelines, with consequences for the social structure of the city. L'Aquila's inhabitants who left the city after the earthquake struggle to recognise the city where they once lived. Not because of the buildings, in which so much effort has gone to bring them back to their original appearance, but because of the social dynamics, entirely transformed by the patterns of displacement and labour market transformation which ensued the earthquake.

But policy intervention should not be limited only to ex-post. In the case of clearly identifiable risks at local level, action plans, mitigating measures and relocation policies should all be considered.

Recent repeated seismic activity in the Campi Flegrei in Italy has led governmental action towards the finalisation of an evacuation plan of the area, with detailed specification of assembly points and relocation destinations by area. That is a textbook example of how action plans should be structured for similar localised natural disaster risks. Furthermore, clear policy guidelines on emergency support after a natural disaster in terms of reconstruction support, production subsidies, etc… help set expectations and reduce uncertainty in the aftermath. Surely, this can increase moral hazard as private individuals have then little incentive in sorting away from areas exposed to natural disaster risk. But this could be mitigated through state disaster risk insurance, as it commonly happens already in countries highly exposed to natural disasters (such as small island states) or other active policy interventions ex-ante. Mitigating measures, for instance, in the form of flood defences or (subsidies for) anti-seismic construction can dramatically lower the risk an area is exposed to, or the consequences from the occurrence of a natural disaster. The costs of the realisation of these and their maintenance should however be carefully considered against the expense mitigation they are expected to grant (i.e. the damages avoided as a result of them), accounting also for future evolution of the risk. In the case of natural disasters related to climate change this is particularly relevant, as, for instance, flood defences built for a specific maximum crest height, might become useless in a few years under increasing sea levels and precipitations' frequency and strength. Policies incentivising relocation to other strategically selected areas might at times present better value for money and be consistent with better structural economic prospects.

The results and the limitations of the research presented in this thesis open several promising avenues for future research.

With regard to the first theme (i.e. the role of local private capital stock endowment in affecting private capital development) this thesis has highlighted the relevance of private capital stock endowments at local level in determining the responsiveness to public investment, through both a macro/local economy perspective and a micro/firm perspective. Chapter 1 has revealed how the effectiveness of different types of public investments in mobilising corporate investment and labour demand depends on private capital stock endowments at local level. The chapter's findings derive from a consideration of private capital stock endowments as determiners of the level of local demand for public capital services, which in turn affect private productivity through the impact they have as a factor in private production and their complementarity with the existing private capital stock. Chapter 1 contributes to the conceptualisation of how public investment affects private productivity by extending Aschauer's (1989) and Zhu's (1995) framework to account for congestion affecting public capital services in the firm-level production function. Future research is however warranted on how different types of public investment enter in the firm-level production function. The derivable insights are going to be instrumental for further research on the characterisation of the degree of complementarity between types of public investment and existing private capital stock endowments, beyond a mere assessment of the capital stock levels. This should focus in particular on obtaining a better understanding of what are the mechanisms driving the complementarity; for instance, does the local sectoral composition matter? Does the level of agglomeration economies or the characterisation of an area as urban or rural matter?

Chapter 2 has shown the effectiveness of productive investment subsidies in increasing private investment both at the intensive and extensive margin, especially in firms characterised by collateral constraints (i.e., lacking sufficient internal capital to be pledged when accessing secured finance through the banking sector). The chapter has shown how the probability of experiencing collateral constraints at firm-level is also tied to local characteristics of the area in which the firm operates. Further empirical investigation of the relationship between regional characteristics and collateral constraints with a larger sample would provide relevant insights for the optimal targeting of subsidy programs and, more broadly, policy strategies for private capital development at local level.

With respect to the second theme (i.e., the economic consequences of natural disasters), this thesis has revealed the significance of the indirect effects in the economy stemming from the destruction and relocation of factors of production associated with natural disasters. Chapter 1 has shown the consequences destruction of physical private capital can have on the responsiveness to public investments at local level and the shift in optimal type of public investment intervention at local level as a result of that. Chapter 2 has provided positive evidence of the effectiveness of productive investment subsidies for economic recovery following a natural disaster. An important extension of this body of research related to natural disasters' destruction and emergency interventions for economic recovery would be represented by an investigation of the extent to which emergency reconstruction aid or subsidy programs support a “building back better” approach (Klomp and Valckx, 2014), and the program-specific and local conditions necessary for that achievement.

Another consequence of natural disasters’ destruction, or expectations around that, has been discussed in Chapter 3, where floods represent a negative valuation shock to residential real estate. The findings in the chapter have revealed the significance of the transmission channels of a wealth shock at household level caused by a natural disaster onto SMEs in the UK. The onset of the global pandemic in 2020 has drastically limited the time series available for this analysis, to avoid the confounding effect of the pandemic related closures and government interventions heavily affecting the UK SMEs object of study. An expansion of the analysis to include post-pandemic data and other types of relevant natural disasters, such as landslides, would offer an enlarged treatment sample which would be beneficial for the exploration of treatment heterogeneity under various dimensions. One of them would be the relevance of initial real estate valuation or, more broadly, household’s wealth. In the chapter, literature provides a series of channels through which the transmission of the shock object of exploration can occur, but the identification design adopted does not allow to allocate the transmission of the negative shock to one channel over the other and further research into this would be desirable. The relevance for the transmission mechanism of regional resilience factors, characterising the environment in which the SME operates in, have been explored in the chapter, but would benefit from further exploration. That would be aimed at deepening the understanding of the channels through which those affect the resilience of SMEs specifically, and condition their recovery. Important insights would arise also from an exploration of the relevance for the transmission mechanisms of regional factors affecting the environment in which households operate. Such investigation would deepen our understanding of the regional conditions affecting the strength of interconnectedness between households and SMEs, and, as a result, the extent of transmission risks from a shock to the household. Finally, a promising avenue for research appears to be the one related to the impact of natural disasters, and their intensification as a result of climate change, on sorting of economic activities. This would be a necessary first step for understanding some of the implications from climate change on regional convergence, and, ultimately, for tailoring the appropriate regional policy response.

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

I. 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 inter-regional inequalities. 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 research and development (R&D).

Years of research on EU Cohesion Policy have shown us that public investment works (Pellegrini et al., 2013; Bondonio, 2016; Giua, 2017; Crescenzi and Giua, 2020), despite concerns about crowding out (Erden and Holcombe, 2005; Erenburg and Wohar, 1995). Aschauer's (1989) theory supports this finding as it attributes to public capital investment the ability to stimulate private productivity, and thus stimulate economic growth. At local level this fosters additional job creation and higher income, improving the competitiveness of the area receiving the investment.

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; Crescenzi and Giua, 2020). These are all factors affecting the supply side of public investment provision. Less rich is the literature analysing demand side factors at play, but empirical evidence, with empty EU-financed Portuguese highways (Wise, 2013) and 'white elephants' (Albalate and Bel, 2011) or 'cathedrals in the desert' (Lipietz, 1980; Rodriguez-Pose, 2017) coming to mind, shows that those are nonetheless very likely to matter too.

In this paper we adopt a different approach from the one just outlined that sees institutions as the main determinants of public investment's effectiveness and think of public investment as a service that facilitates private economic activity. Thus, we draw on Zhu's (1995) idea about the utilization rate of public capital services, which essentially posits that the demand of public capital services (e.g. a bridge, a road, broadband infrastructure, etc…) is a positive function of the level of private capital in the economy. From these theoretical bases this paper looks at the role played by capital stock endowments at local level in the private sector's responsiveness to public investment. By determining the utilization rate of public capital services, private capital stock affects the gains in private productivity derivable 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 a range of other factors affecting fiscal multipliers, which makes answering such questions empirically very challenging. Most literature contributions have adopted a (S)VAR, time-series or panel-data approach (Martinez-Lopez, 2006; Aschauer, 1989), which drastically limit the causal interpretation of their estimates. The lack of data and measurement difficulties for capital stocks, both at public and private level, adds an additional layer of difficulty in the empirical identification of such research question.

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 on the importance of its level 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.

II. **Literature Review**

This paper studies a negative shock to 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 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.

a. Public Investment – Productivity Literature

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.

Aschauer (1989) and Gramlich (1994) theorise the impact of public capital investment on economic growth through the increase in private productivity. 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 stock[2], a net positive impact of public investment is expected to materialise until 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

[2] 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.

is therefore a direct function of the level of private capital stock. Zhu (1995) innovates Aschauer (1989)'s framework, attributing outcomes on private output not to public capital stock directly, but to the use of public capital services. In Zhu (1995)[3] the return to public investment depends also on the private demand for it and, therefore, a-less-than-full utilization 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 (Commendatore et al., 2008; Klien and Moretti, 2014; Ottaviano, 2008). 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 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.

Commendatore et al. (2008) expand Baldwin's (1999) New Economic Geography (NEG) model to allow for capital accumulation and capital mobility between two regions (one rich and one poor). In this model a central government authority allocates productivity enhancing public investments across regions and sectors. They find that the regional and sectoral distribution of public capital investment matters for its impact on private capital, as productivity-enhancing effects are counterbalanced by crowding-out effects at regional and sectoral level. They show that an increase in public capital in the "poor" region is going to increase the share of manufacturing activities in the region if the "rich" region also contributes to the investment financing.

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

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

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.

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; Guild, 2000, Salinas-Jimenez, 2004). 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).

Fratesi and Perrucca (2014) investigate the mechanisms through which territorial capital endowment affects the responsiveness to different types of EU Cohesion policy investments in ten Central and Eastern European countries. Overall, they find a strong predicting power of complementarity of public investment with the regional territorial capital endowment for the effectiveness EU Structural Funds. As territorial capital endowments can differ not only in size but also in composition, different investments can be better suited for different regions, and regions with low territorial capital endowments can still benefit from public investments, as long as they are targeted to their pre-existing conditions. They find that 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. Labour market policies appear to be effective only in regions where there is a presence of high value functions. Regional endowment with human capital appears to be a necessary condition for positive returns from policies aiming at stimulating workforce flexibility, entrepreneurship, innovation and ICT. The effectiveness of investments in tangible assets instead appears to be the highest in regions with intermediate degrees of agglomeration as they can benefit from the increase in agglomeration without incurring in congestion costs, unlike in the case of urban regions. The decreasing returns to agglomeration appear to be conditional however on the existence of some level of urbanisation, as Fratesi and Perrucca (2014) do not find a positive return from investments in tangible assets in rural areas. 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 for those directly related to the establishment of private businesses (e.g., policies targeting SMEs). This is consistent with findings from Bachtrogler et al. (2020), 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 of the investment's location.

b. Natural disasters literature

Natural disasters affect the economy through direct and indirect channels. The direct economic impacts are the ones associated with the destruction of assets directly stemming from 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 productivity growth (Berlemann et al., 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 productivity growth 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 productivity growth 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 et al., 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 disasters, 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.

III. Theoretical Model

This paper studies the role of private capital's complementarity in the impact of public investment on private productivity and local economic growth. It does so by being grounded theoretically in a model of 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, and $\frac{\partial f\prime(L,K,S)}{\partial L} > 0$, $\frac{\partial f\prime(L,K,S)}{\partial K} > 0$, $\frac{\partial f\prime(L,K,S)}{\partial S} > 0$.

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 utilization rate of public capital, G being the stock of public capital available (G^S) and ζ being the congestion factor. The utilization rate, U, is defined within an interval going from 0 (no utilization) to +∞ posing no limit to the overutilization of capital. The concept of utilization rate refers to the share of public capital used for productive activity versus the concept of 'available for usage'. In practice, one could consider as an example the case of a stadium which is on average half full: its utilization rate is 50%. If it were filled above its capacity, its utilization rate could go above 100%. The firm production function can, therefore, be rewritten as $Y = f(L, K, UG^{(1-\zeta)})$. Public capital, which includes assets such as roads, airports and government-owned buildings such as public hospitals, municipality offices, etc…, is used at full capacity when $U = 1$. Congestion occurs upon overutilization 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, φ_t is a shock to public capital stock and δ_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 et al. (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 utilization 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.

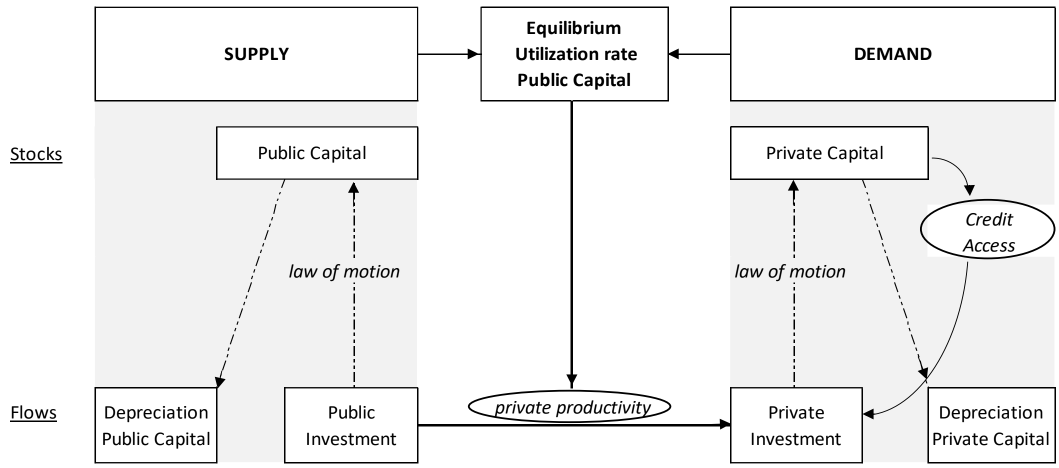
$$U_t \equiv \frac{G_t^D}{G_t} = \frac{f(Y)}{G_t^S}$$

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.[4]

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

Figure 1 summarises the theoretical model just presented.

Figure 1: Theoretical Framework



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

[4] Although the demand for public capital in principle depends on its price (like any other good 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.

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 utilization rate and on the rate of complementarity with private capital stock.

$$\frac{\partial Y_t}{\partial G_t} = \frac{\partial f(L,K,S)}{\partial S_t} \times U_t G_t^{(-\zeta_t)} \times (1-\zeta_t)$$

Where $\frac{\partial f(L,K,S)}{\partial S} > 0$ proxies for the rate of complementarity between public capital and private capital stock, $U_t G_t^{(-\zeta_t)} \geq 0$ with U_t being the utilisation rate and ζ_t is the congestion factor.

b) An exogenous negative shock to private capital stock should decrease the utilization rate of complementary public capital at local level.

$$\frac{\partial U_t}{\partial K_t} = \frac{1}{G_t^S} \times \frac{\partial f(L,K,S)}{\partial K_t} \geq 0$$

Upon no prior congestion (initial steady-state equilibrium, $\zeta_t = 0$ and $U_t \leq 1$) these are expected to decrease the "local fiscal multiplier effect" associated with public investment.

$$\frac{\partial Y_t}{\partial U_t} = G_t^{(1-\zeta_t)} \geq 0$$

c) The sensitivity of the "local fiscal multiplier effect" to private capital stock depends on the type of private investment the public investment aims to stimulate. The higher the complementarity of public investment with prior private capital stock levels, the higher the sensitivity.

$S_t = f(S_{1,t}, S_{2,t}, S_{3,t}, \dots) = f(S_{i,t})$ with $S_{i,t}$ representing different types of public capital

$$\frac{\partial Y_t}{\partial S_{i,t}} = \frac{\partial f(L,K,S)}{\partial S_t} \times \frac{\partial f(S_{i,t})}{\partial S_{i,t}} \geq 0$$

d) In case of prior congestion, a negative private capital shock could reduce congestion, leading to efficiency gains partly offsetting lower private demand.

$$\frac{\partial Y_t}{\partial \zeta_t} = -\frac{\partial f(L,K,S)}{\partial S_t} \times U_t G_t^{(1-\zeta_t)} \ln{(G_t)} \leq 0$$

e) An exogenous negative shock to private capital stock should also directly curtail private investment through the reduction in the value of assets which can be pledged as collateral for investment financing (Chaney et al., 2012). This suggests the existence of second round effects amplifying the initial impact of shocks to private capital.

A couple of real-world examples can be helpful in clarifying these theoretical predictions.

[Prediction **a**] Let's consider the construction of an additional lane of the municipality highway as an example of public investment. The extent to which this stimulates private investment in the municipality depends on:

i) *Whether the municipality businesses are going to benefit from the expansion of transport infrastructure, i.e. the extent to which transport infrastructure is a productive input in the municipality' businesses' production functions with a degree of complementarity to their labour or capital inputs.*

When comparing tradeable with non-tradeable businesses, one can see how an expansion of transport infrastructure for the former is much more directly associated with a possibility of output expansion, mostly through the gains in trade efficiency, than in the latter, where only marginal productivity gains in the labour inputs are likely to derive from the public investment (e.g. as a result of shorter commuting times)

ii) *Whether the public investment is going to ease congestion*

If the highway was experiencing congestion prior to the lane addition, then the public investment would relieve that and private productivity gains would be derivable from that, which would then go and stimulate private sector's output and investment. If the utilization rate of the assets/similar asset was not full instead prior to the investment, i.e. if the highway was rarely populated with cars then one should expected the return of the public investment on private firms' investment and output to be proportional to the asset usage.

iii) *Assuming i) holds, whether the municipality businesses hold or are able to access sufficient capital to expand their production in response to that.*

If the tradeable businesses are already operating at full capacity with no slack in their utilisation of labour and capital inputs, the expansion of transport networks would result in an increase in their production output only if the businesses were able to increase their production inputs, for instance by accessing credit to finance the purchase of additional productive machinery.

[Prediction **c**] Now let's consider another type of public investment, for instance the construction of a bigger football stadium. Clearly the type of private investment such an investment is going to originate is significantly different than the one associated with an additional lane in the municipality' highway. A bigger football stadium is going to stimulate investments in non-tradeable activities, in particular food and accommodation activities, which show a degree of high complementarity with the public investment, as they will be catered towards the higher number of football fans the stadium is going to be able to host.

One can consider a natural disaster, such as an earthquake, as a negative exogenous shock to local capital stock levels.

- [Prediction **b**] The destruction of industrial machinery or broader damage to business premises (i.e. private capital stock) associated, for instance, with the natural disaster is expected to lead to lower tradeable output and a consequent lower usage of local transport infrastructure. If the local transport infrastructure was not experiencing congestion prior to the shock, then such a reduction in the, so called, "utilization rate" of the network is going to be expected to lead to lower returns in terms of economic growth/private output from an additional public investment in the network (i.e. a new road, an additional lane, etc…).
- [Prediction **d**] But if the local transport network was instead insufficient to the pre-shock local demand needs and was experiencing congestion, such a decrease in local private activity as a

result of the destruction of productive capital inputs can actually lead to efficiency gains from the reduction for instance in traffic, road accidents, etc…

- [Prediction **e**] The destruction of private capital assets such a machinery, business premises, etc… however does not have consequences only on the direct output production of the firms affected, but also on their ability of accessing credit. Capital assets are in fact commonly used as collateral when accessing credit by private firms, and their destruction/damage indirectly curtails the ability of the firms affected to access credit from the banking sector to manage their working capital needs affectively or finance productive investments for instance.

IV. Background information on the emergency response to 2012 earthquake

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 an epicentral magnitude of 5.9 and depth of 8.1 km.[5] The human and economic losses generated by these events were officially quantified in 2017.[6] 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 town halls were deemed inaccessible, 570 schools, 16 libraries, 12 theatres and 782 churches were damaged. Overall, public emergency funding covered damages amounting to about €5 billion, of which €4.5 billion was assigned to privates 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

[5] Source: Parametric Catalogue of Italian Earthquakes (CPTI15 v2.0).

[6] Official data and related documents available at https://docsismaemilia.it/

housing solutions, the Civil Protection Department identified 104 eligible municipalities on the basis of the existence of damages directly related to the seismic shocks.[7] For those municipalities the state offered contributions of up to 80% of the cost of repairs and strengthening of private housing real estate[8] and up to 80% of the cost of repairs and strengthening of commercial real estate, the purchase or reparation of machinery damaged by the seismic shock, and any other expenses related to the resumption of productive activity.[9] 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 shock.[10]

V. 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. The change in the number of local units of active enterprises is adopted as a measure of private business generation.

A measure of annual private sector investment at municipality-level, for which no official data is publicly available, is obtained by integrating records from two datasets sourced from the Italian

[7] The list of damaged municipalities eligible for emergency support measures is contained in Annex 1 of 1 June 2012 Decree.
[8] Ordinance n.29 Section 3(1), Regione Emilia-Romagna (28 August 2012)
[9] Ordinance n.57 Section 2-4, Regione Emilia-Romagna (12 October 2012)
[10] Legislative Decree 74, Section 10-11 (6 June 2012)

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). Project-level information is used to construct municipality-level indicators of public investment at annual frequency through a bottom-up approach.

Data on seismic intensity at municipality level for the 2012 earthquake is obtained from the application of Pasolini et al.'s (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**.

VI. Empirical Identification Strategy

A quasi-experimental approach is adopted in this paper, to address the endogeneity associated with private capital stock levels, i.e. the assets owned by households and corporates such as real estate, machineries and, in case of corporates, also intangibles. Destruction from the 2012 earthquake in Northern Italy is used as an exogenous negative shock to physical (i.e. tangible) private capital at local level. Earthquakes with a major destructive power can be considered as random events in time and space.[11] 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 characterised by low seismic risk according to the National Institute of Geophysics and Volcanology (INGV).[12]

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 spatial regression discontinuity design is employed. A spatial regression discontinuity design (RDD) technique (Holmes, 1998; Calonico et al., 2019; Keele and Titiunik, 2015) exploits the existence of a threshold, around which no self-sorting can occur, which leads to exogenous allocation of the observed sample to treatment and control groups.

It is commonplace to observe how earthquake-related physical destruction decreases whilst moving further away from the epicentre. The reason it does so is because of the decreasing seismic intensity experienced further away from the hypocentre. Civil engineering and risk hazard assessment literature (Barbat et al., 2012) identify a seismic intensity threshold for severe damage to buildings from a seismic shock, 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 around 7.25 in Italy (Bindi et al., 2011; Pasolini et al., 2008),

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[11] 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 holding a major destructive power. Furthermore, if one would not agree to 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 epicenter location, but also the depth of the hypocenter 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 hypocenter to the epicenter and the surroundings.

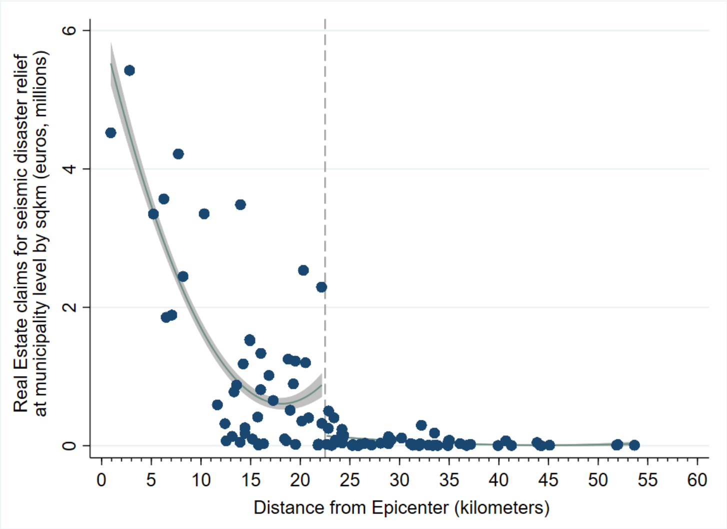
[12] Stucchi M., Meletti C., Montaldo V., Akinci A., Faccioli E., Gasperini P., Malagnini L., Valensise G. (2004). Pericolosità sismica di riferimento per il territorio nazionale MPS04 [Data set]. Istituto Nazionale di Geofisica e Vulcanologia (INGV).

corresponding to a distance of 22.5 kilometers from the epicenter. **Section B of Appendix** contains details on how the evolution of seismic intensity maps to distance from the epicentre in the case of 2012 earthquake.

Theory therefore suggests that for municipalities located more than 22.5km away from the epicentre the seismic damage should be broadly only cosmetic, whilst for those closer to the epicentre the damage should be structural, consistent with significant capital depletion.

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 damages is obtained from the OpenCup database. **Figure 2** shows the average value of those claims by municipality, plotted against the distance from the epicenter 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 epicentral distance falls below 22.5 kilometers, with the difference in the trend below and above the threshold being statistically significant at less than the 1% level. The presence of such a threshold is also detected in data coming from post-2009 L'Aquila earthquake claims, which we do not show here. Additional figures in Section B of the Appendix show the higher robustness of the discontinuity in physical damage claims over the epicentral distance measure presented here relative to the modelled seismic intensity measure, despite the latter representing the underlying mechanism at play justifying the existence of the discontinuity in the first place. This is most likely related to the fact that the experienced seismic intensity measure is a result of modelling and not direct observation, leading to higher uncertainty associated to its value relative to epicentral distance.

Figure 2: Discontinuity in Real Estate damage based on epicentral distance



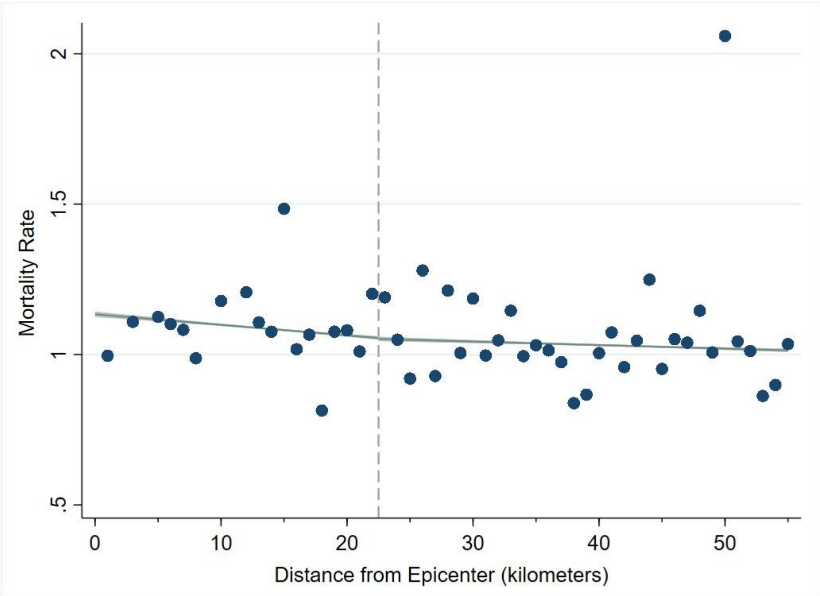
Notes: Data is sourced from Opencup. Shaded area represents 95% confidence intervals.

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.[13] 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.

[13] Legislative Decree 74, Section 3 (1 a-b) (6 June 2012). The compensation amount was exclusively considering the costs of the repairs without factoring in building characteristics or assets depreciation prior to the shock.

The observed discontinuity in physical capital destruction at epicentral distance of 22.5 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 epicentral distance of 22.5, the trend is not significantly different from the one observed below the threshold, suggesting that no discontinuity in human capital occurs at the threshold.

Figure 3: Smoothness of Human Capital around the threshold



Shaded area represented 95% confidence intervals.

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 in other factors affecting production.

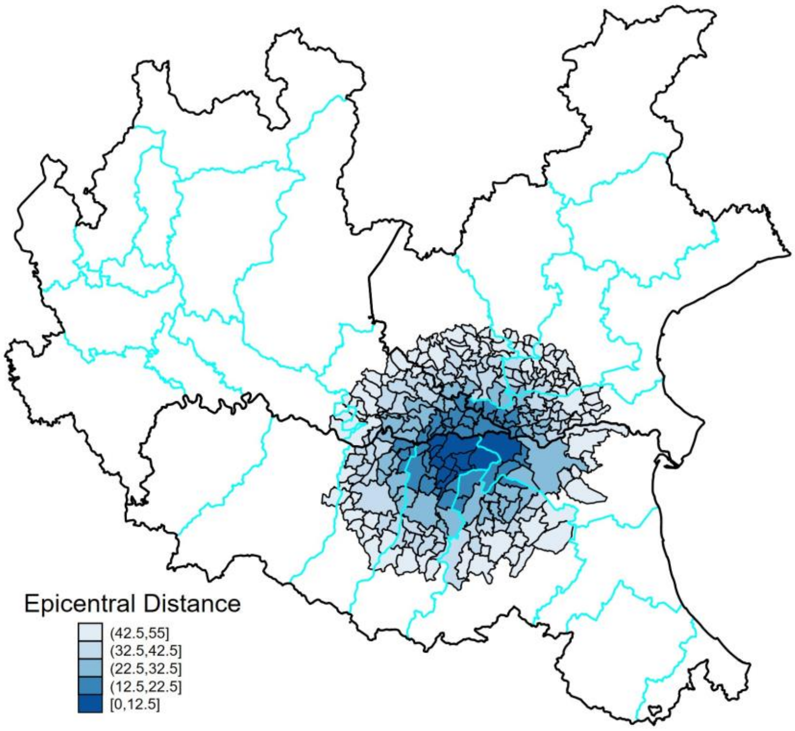
Physical capital encompasses both public and private capital. However, their nature differs and so does the validity of the threshold. The network character of public transport infrastructure capital (Deng, 2013; Moreno and Lopez-Bazo, 2007; Álvarez-Ayuso et al., 2016), which was already discussed in **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 transport infrastructure, 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. Other types of public capital such as schools, hospitals and administrative facilities are also partly characterised by a network character as their sphere of influence tends to go beyond the municipality area. The strength of this characterisation is however less relevant in these types of public capital given their less direct impact on economic activity, which is the main outcome of interest of this paper.

For the purposes of this identification we, therefore, assume that the threshold in physical capital destruction adopted here refers exclusively to a discontinuity in private capital destruction.

VII. Econometric Modelling Strategy

Figure 4 provides a map of the epicentral distance 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 destruction threshold set at 22.5km from the epicenter, 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 destruction threshold.

Figure 4: Map of epicentral distance 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. Epicentral distance is computed based on the Haversine formula and colour-coded for state financing eligible municipalities.

Figure 2 showed how closer than 22.5km from the epicentre the probability of experiencing damages from the earthquake significantly increases, but further away the probability is also not zero. This is therefore a desirable set up for a fuzzy regression discontinuity design with epicentral distance being the forcing variable.

Being located on either side of the epicentral distance threshold is a strong predictor of the amount of seismic damages the municipality would be affected. This represents the first stage regression.

(1) $K_i = \gamma_0 + \gamma_1 T_i + \theta_i$

Where T_i is a dummy variable indicating the municipality's treatment status, equal to 1 for municipalities located at epicentral distance less or equal to 22.5 (the threshold for severe damage to private capital stock), 0 if above 22.5. K_i is a proxy measure of capital destruction, generated from data on the amount of residential real estate seismic destruction claims by municipality and using the most damaged municipality as a numeraire. This variable, thus defined, is a percentage ranging from 0 to 100, whose highest value is attributed to the municipality most heavily damaged per sqkm. 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, this is a fairly good proxy. 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, is deemed to be satisfied by the evidence presented in **Section VI** and minor sample adjustments.

In the second stage, 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.

$$(2)\quad Y_{i,t} = \alpha_0 + \alpha_1 \widehat{K}_i + \alpha_2 P_t + \alpha_3 I_{i,t} + \alpha_4(P_t\widehat{K}_i) + \alpha_5(\widehat{K}_i I_{i,t}) + \alpha_6(P_t I_{i,t}) + \alpha_7(P_t\widehat{K}_i I_{i,t}) + \alpha_8 D_i + \varepsilon_{i,t}$$

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, 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, with the treatment year excluded from the sample. $I_{i,t}$ 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. D_i is a covariate controlling for the smallest distance between the municipality and the provincial border. This variable is controlled for because of the potential impact it has on the probability of receiving public spending at municipality level (De Siano and D'Uva, 2016). $\widehat{K_i}$ is the first-stage prediction of the physical destruction experienced at municipality level.

The coefficient α_7 represents the main coefficient of interest as it represents the difference in the impact of public investment on private sector outcomes by level of physical destruction experienced differentiating out pre-shock differences in outcomes. The coefficient α_8 captures the average relationship between the distance from the NUTS 3 regional border and private sector outcomes; α_1 captures the relationship between the level of physical destruction experienced during the earthquake and pre-shock private business outcomes in absence of public investment; α_2 captures the average change in private business outcomes after the shock in the absence of physical destruction and public investment; α_3 captures the average impact of public investment on private business outcomes before the shock in municipalities which did not go on experiencing physical capital destruction during the earthquake; α_4 captures the impact of the shock on the relationship between the level of physical destruction experienced during the earthquake and private business outcomes in absence of public investment; α_5 captures the difference in the impact of public investment on private business outcomes before the shock between municipalities which went on experience physical destruction during the earthquake and those which didn't (α_3); α_6 captures the impact of the shock on the impact of public investment on private business outcomes in the absence of physical destruction.

Such 2-stages least square model estimates municipality-specific impacts through a non-parametric approach (i.e., a local linear regression) within a bandwidth around the destruction discontinuity set at epicentral distance of 22.km in each of the provinces including municipalities located on the left side of the threshold. Standard errors are clustered at municipality-level, to control for autocorrelation of the error over the same municipality over time.

The tables presented in **Section VIII** show the results of a non-parametric estimation over epicentral distance bandwidth $[22.5 - 10 \leq Epicentral\ Distance \leq 22.5 + 10]$. The Table of Means (Table 1) in Section VIII shows how restricting the bandwidth to 10km on either side of the threshold leads to a more homogenous sample in terms of pre-shock characteristics than when considering all the municipalities receiving reconstruction funds. The estimates thus derived also 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 sensitivity test results from the adoption of i) a non-fuzzy regression design approach (i.e. a reduced form in which the extent of capital destruction is controlled for directly with the dummy T), ii) a larger estimation bandwidth in epicentral distance, iii) using seismic intensity as the forcing variable with a seismic intensity of 7.25 as threshold and estimation bandwidth $[7.25 - 0.5 \leq Intensity \leq 7.25 + 0.5]$, iv) a fuzzy RDD and OLS equivalent approach on post-shock outcomes exclusively. In this latter model iv) a long difference in the outcome variables between the start of the period (the time of the shock) and the end of the observation window (four years after the shock) is regressed over the same variables of the main specification, except for the time dummy and its interactions. This model is however judged to be less suitable than the baseline specification adopted as a result of i) the significant differences in pre-shock outcomes and characteristics between treated and control municipalities, which the post-shock difference model cannot control for, and ii) the availability of a sufficiently large panel of observations over pre- and post-shock periods, which can support the statistical robustness of the baseline regression model adopted. Table 1 shows, in fact, a statistical difference pre-shock between treated and control municipalities in their industry mix which can affect the effectiveness of public investment interventions post-shock. A comparison of the results between Table 3 & Table C.7, which show respectively the results from the baseline RDD 2SLS 'panel' model and the RDD IV post-shock model, further validates this. There are significant differences in pre-shock growth rates for the outcome variables between treated and control municipalities as shown by the coefficients of the variable *'Kdestruction'* in Table 3, which, when controlled for, suggest an impact of the shock on those (*'post x Kdestruction')*. It appears that the rate of public works at municipality level is stable over time between pre- and post-shock in both treated and control municipalities (as shown by the insignificance of the coefficient of *'Transport public works x Post'* in Table 3), which is a testament to the exogeneity of public investments in transport infrastructure post-shock considered in this paper relative to the shock itself. But the statistical significance of the difference in public works growth rate pre-shock between treated and control municipalities (coefficient of *'Transport public works x Kdestruction'* in Table 3) further suggests the importance of adopting a model able to control for pre-shock outcomes as baseline specification.

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). As just mentioned above, the results of Table 3 provide further reassurance to this end.

VIII. 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 the average values on a series of municipality'[14] characteristics between municipalities located on either side of the threshold both within a 10km bandwidth and the whole sample of municipalities eligible for seismic reconstruction support (broadly falling within 55km from the epicentre), represented respectively, by the second and third concentric circle from the epicentre, and the whole blue shaded circular area in **Figure 4**. We can see how restricting our sample to a 10km bandwidth around the destruction threshold significantly reduces the differences across municipalities located below and above the threshold. Within this bandwidth no significant differences are observed across the threshold in the shares of employment by sector at municipality level. In the municipalities further away from the epicentre however wholesale and retail trade accounts for a slightly larger share in the local business units than in those closest to the epicentre. That is counterbalanced by manufacturing accounting for a slightly smaller share. This suggests the importance to control for pre-shock differences in outcomes and covariates even in a non-parametric regression discontinuity approach.

[14] 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).

Across the discontinuity, municipalities located closer to the epicentre appear to be also 9 sqkm smaller on average than those located further away. This suggests the need to always consider outcomes and covariates on a per-sqkm basis to avoid differences in size confounding the effect. Crucially, however, no significant difference is detected in the per-square kilometre value of public works realised prior to the shock.

Table 1: Table of Means

	12.5≤ED≤32.5			*All firms receiving reconstruction support*		
	ED>22.5	ED≤22.5	Difference	ED>22.5	ED≤22.5	Difference
	45.13	35.71	-9.42 *	38.50	41.86	3.36
Municipality Area (sqkm)	[31.849]	[26.159]	(3.324)	[33.616]	[35.370]	(2.761)
Share of Manufacturing	18.22	20.44	2.22 **	16.57	20.84	4.27 ***
business units	[5.731]	[7.281]	(0.727)	[6.314]	[6.793]	(0.521)
Share of Construction	17.44	17.14	-0.29	18.37	17.01	-1.36 **
business units	[4.819]	[5.244]	(0.565)	[4.580]	[5.010]	(0.446)
Share of Wholesale and	24.89	23.48	-1.40 **	25.11	23.23	-1.88 ***
Retail trade business units	[4.760]	[4.275]	(0.513)	[4.854]	[4.039]	(0.384)
Share of Manufacturing	42.52	43.90	1.38	40.65	45.40	4.75 ***
employment	[14.404]	[14.115]	(1.609)	[15.745]	[13.242]	(1.247)
Share of Construction	11.30	12.09	0.79	12.32	12.36	0.04
employment	[5.335]	[5.931]	(0.631)	[6.480]	[6.266]	(0.524)
Share of Wholesale and	18.77	16.68	-2.09	18.65	16.31	-2.34 ***
Retail trade employment	[7.348]	[6.842]	(0.804)	[7.486]	[6.377]	(0.593)
Public works per sqkm (euro,	14767	21939	7172	18743	21161	2418
millions)	[60877]	[75743]	(7637)	[75156]	[68190]	(6018)
Public incentives per sqkm	244	108	-136	1506	84	-1422
(euro, millions)	[621]	[270]	(56.26)	[17108]	[240]	(1262)
Number of municipalities	45	35		211	46	
Number of observations	180	140		844	184	

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 the other (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 utilization 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 utilization 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 utilization rate. This is expected to lead to lower complementarity with private capital stock 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 and 3** based on the fuzzy RDD model outlined in **Section VII**. The regression model is estimated at provincial level, therefore only provinces presenting municipalities on both sides 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 than those carried out in control municipalities. This is highlighted by the coefficient of the interaction term *'Transport Public Works x Post x Kdestruction'* in **Table 2**, albeit with only the impact on the effectiveness for private investment being significant at 10% level (column 3,6,9,12,15). A percentage point increase in the amount of seismic destruction (‘*Kdestruction’*), consistent with around €54,236 per sqkm in damages to residential properties, is associated with a decrease in the effectiveness of 1% increase in public investment (*‘Transport Public Works x Post'*) in stimulating private investment (‘*GFCF'*) at local level ranging between 0.1% and 0.2% depending by province. Across the municipalities having experienced seismic destruction, the size of the reduction in effectiveness of public investment in transport infrastructure on private investment appears to be positively correlated with the overall post-shock growth differential in private investment growth, relative to the control municipalities, captured by the coefficient of the interaction term *‘Post x Kdestruction’*. Within province, it appears that higher seismic damages are associated with a stronger post-shock private investment growth (*‘Post x Kdestruction’)*, but a smaller responsiveness to public sector investment in transport infrastructures (*‘Transport Public Works x Post x Kdestruction’)*, as we can observe from the results in columns (3,6,9,12,15) in Table 2.

This is consistent with the expected theoretical results. The municipalities not affected by serious private capital destruction (untreated) are able to fully absorb in their private production the benefit given by additional transport infrastructure and, possibly, gain from the resulting reduction in congestion. Congestion could have in fact been generated by the reduction in transport network supply straight after the seismic shock (e.g., through road closures for maintenance of seismic damages) in both treated and untreated municipalities. Instead, municipalities where severe private capital destruction occurred, are likely to have experienced a reduction in the utilization rate of public capital straight after the shock, as the reduction in private demand from private physical capital destruction is expected to have been unable to full absorb the benefits of additional transport infrastructure and the reduction in network congestion. The stronger growth in private investment experienced after the shock in municipalities more strongly affected by capital destruction could instead be associated to reconstruction efforts, thus being overall consistent with a larger decrease in the utilization rate of public capital. Based on the complementarity between public transport investment and physical private capital stock, the results suggest that, in municipalities affected by serious private capital destruction, 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.

Robustness checks of these results by bandwidth size, running variable and model specification are contained in Section C of the Appendix (**Tables C.1-C.3**).

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 markets' demand for goods and services. These concerns are addressed by considering 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 3** 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 on private investment, as captured by the coefficient of the interaction term *'Transport Public Works x Post x Kdestruction'* in columns 10-12 in Table 3. Firms operating in non-tradeable sectors appear to experience a marginally larger reduction in the stimulus from public transport infrastructures investment, as a result of the shock to private capital, than those operating in the tradeable sector, as we can see from comparing the coefficients of the interaction term *'Transport Public Works x Post x Kdestruction'* between columns 10/11 and 12. The difference is however not statistically significant and subject to assumptions on the regression specifications (as tables in Section C of the Appendix suggest), again reinforcing the lack of statistical significance. This suggests that the results presented in Table 2 are unlikely to suffer from a bias associated with a change in local demand for goods and services in the treated municipalities. A comparison of the coefficient associated with the term controlling for post-shock difference between treated and control municipalities (*'Post x Kdestruction'*) between columns (2&3, 6&7, 10&11) suggests that in municipalities more strongly affected by seismic destruction, firms in the construction sector 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. But "reconstruction effects" appear to be well captured and controlled for by the interaction variable between *'Post'* and '*Kdestruction'*, leaving estimates associated to the effectiveness of public investment unbiased by that.

Robustness checks of these results by bandwidth size, running variable and model specification are contained in Section C of the Appendix (**Tables C.4-C.8**). Table C.7 presents the results from the post-shock difference IV model. The results show no significant difference in the effectiveness of public transport investments on private investment at municipality level between treated and control municipalities, and in general a lack of effectiveness of those investments in stimulating business generation and private investment. As discussed however at length in Section VII, the existence of significant differences in pre-shock growth rates of the observed outcomes between treated and control municipalities suggest the potential for a significant bias in estimates obtained not controlling for pre-shock differences, such as those presented in Table C.7.

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

	12.5 ≤ Epicentral Distance ≤ 32.5														
	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	-0.317	-0.302	-0.530	0.766	0.701*	0.293	0.817	0.740*	0.226	0.817	0.740*	0.226	0.714	0.633	0.599
	(0.905)	(0.792)	(1.186)	(0.530)	(0.399)	(0.937)	(0.546)	(0.410)	(0.968)	(0.546)	(0.410)	(0.968)	(0.521)	(0.390)	(0.883)
Kdestruction	-0.233	-0.234	-0.991*	-0.114	-0.0704	-1.307*	-0.143	-0.136	-1.616*	-0.143	-0.136	-1.616*	-0.0899	-0.107	-0.943
	(0.224)	(0.190)	(0.587)	(0.327)	(0.271)	(0.751)	(0.403)	(0.333)	(0.980)	(0.403)	(0.333)	(0.980)	(0.235)	(0.194)	(0.594)
Transport Public works	0.0783	0.0639	0.0437	0.146**	0.130***	0.0782	0.146**	0.129***	0.0721	0.146**	0.129***	0.0721	0.125**	0.109**	0.0720
	(0.0622)	(0.0542)	(0.0846)	(0.0569)	(0.0481)	(0.0858)	(0.0580)	(0.0491)	(0.0878)	(0.0580)	(0.0491)	(0.0878)	(0.0564)	(0.0491)	(0.0832)
Post X Kdestruction	0.271	0.274	1.073*	0.122	0.0986	1.607*	0.0418	0.0710	2.038*	0.0418	0.0710	2.038*	0.0772	0.0947	0.983
	(0.224)	(0.191)	(0.595)	(0.309)	(0.254)	(0.840)	(0.379)	(0.300)	(1.147)	(0.379)	(0.300)	(1.147)	(0.222)	(0.180)	(0.612)
Transport Public works X Post	0.0270	0.0234	0.0316	-0.0832	-0.0787*	-0.0563	-0.0862	-0.0807*	-0.0500	-0.0862	-0.0807*	-0.0500	-0.0781	-0.0707*	-0.0935
	(0.0904)	(0.0787)	(0.125)	(0.0564)	(0.0422)	(0.101)	(0.0578)	(0.0432)	(0.104)	(0.0578)	(0.0432)	(0.104)	(0.0564)	(0.0419)	(0.0968)
Transport Public works X Kdestruction	0.0293	0.0283	0.119*	0.0145	0.00836	0.160*	0.0175	0.0152	0.193*	0.0175	0.0152	0.193*	0.0110	0.0117	0.114*
	(0.0259)	(0.0219)	(0.0667)	(0.0410)	(0.0340)	(0.0909)	(0.0485)	(0.0399)	(0.113)	(0.0485)	(0.0399)	(0.113)	(0.0279)	(0.0228)	(0.0677)
Transport Public works X Post X Kdestruction	**-0.0327**	**-0.0312**	**-0.127***	**-0.0172**	**-0.0121**	**-0.190***	**-0.0113**	**-0.0115**	**-0.235***	**-0.0113**	**-0.0115**	**-0.235***	**-0.0115**	**-0.0119**	**-0.118***
	(0.0255)	**(0.0217)**	**(0.0672)**	**(0.0380)**	**(0.0316)**	**(0.0980)**	**(0.0447)**	**(0.0360)**	**(0.128)**	**(0.0447)**	**(0.0360)**	**(0.128)**	**(0.0260)**	**(0.0211)**	**(0.0691)**
Distance to Provincial Border	4.86e-05	3.88e-05	5.81e-05**	1.57e-05	7.92e-06	3.64e-05	1.38e-05	5.04e-06	3.73e-05	1.38e-05	5.04e-06	3.73e-05	3.62e-05	1.76e-05	5.95e-05**
	(3.37e-05)	(3.02e-05)	(2.92e-05)	(3.25e-05)	(2.86e-05)	(2.89e-05)	(3.41e-05)	(3.01e-05)	(3.04e-05)	(3.41e-05)	(3.01e-05)	(3.04e-05)	(2.93e-05)	(2.55e-05)	(2.70e-05)
Constant	2.729***	1.667***	4.860***	2.131***	1.092**	4.551***	2.141***	1.110**	4.603***	2.141***	1.110**	4.603***	2.321***	1.301**	4.627***
	(0.619)	(0.548)	(0.771)	(0.580)	(0.506)	(0.785)	(0.594)	(0.520)	(0.809)	(0.594)	(0.520)	(0.809)	(0.564)	(0.507)	(0.755)
Observations	345	345	344	307	307	306	298	298	297	298	298	297	339	339	338

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. 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. Distance to Provincial Border is a variable controlling for the smallest distance in kilometers between the municipality' centroid and the border of the NUTS 3 region it is located in. Kdestruction represents the percentage of destruction in physical capital stock coming from the seismic shock. In this 2SLS approach, K destruction is instrumented by Treated is a dummy variable equal to 1 for municipalities with distance from the earthquake epicenter smaller or equal to 22.5 kilometers, 0 if above 22.5.

Table 3: Aggregate fuzzy RDD results for public transport infrastructures by sector's tradeability

	12.5 ≤ Epicentral Distance ≤ 32.5											
	N. Workers				N. Business Units				Gross Fixed Capital Formation			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
VARIABLES	Total	Tradeables	Tradeables excl. construction	Non-Tradeables	Total	Tradeables	Tradeables excl. construction	Non-Tradeables	Total	Tradeables	Tradeables excl. construction	Non-Tradeables
Post	-0.228	-0.0892	0.0900	-0.298	-0.241	-0.184	-0.0905	-0.266	-0.209	-0.180	1.185	-1.137
	(0.817)	(0.751)	(0.810)	(0.886)	(0.714)	(0.599)	(0.638)	(0.764)	(1.080)	(1.949)	(2.363)	(1.107)
Kdestruction	-0.168	-0.0966	-0.0947	-0.224	-0.161	-0.0411	-0.0149	-0.219	-0.698*	-0.612	-0.614	-0.767*
	(0.151)	(0.141)	(0.155)	(0.191)	(0.128)	(0.108)	(0.130)	(0.149)	(0.371)	(0.582)	(0.660)	(0.435)
Transport Public works	0.0717	0.0800	0.0978	0.0604	0.0576	0.0603	0.0772*	0.0528	0.0492	-0.0162	0.0617	0.00542
	(0.0577)	(0.0570)	(0.0649)	(0.0607)	(0.0506)	(0.0419)	(0.0439)	(0.0545)	(0.0792)	(0.165)	(0.196)	(0.0934)
Post X Kdestruction	0.193	0.119	0.119	0.249	0.186	0.0661	0.0383	0.244	0.748**	0.639	0.620	0.815*
	(0.153)	(0.144)	(0.158)	(0.192)	(0.130)	(0.112)	(0.135)	(0.150)	(0.377)	(0.595)	(0.680)	(0.435)
Transport Public works X Post	0.0164	-0.00422	-0.0161	0.0283	0.0168	0.00160	-0.00817	0.0238	-0.00445	0.0342	-0.105	0.0813
	(0.0828)	(0.0777)	(0.0849)	(0.0888)	(0.0717)	(0.0607)	(0.0652)	(0.0765)	(0.116)	(0.216)	(0.258)	(0.120)
Transport Public works X Kdestruction	0.0210	0.0131	0.0139	0.0267	0.0194	0.00591	0.00420	0.0259	0.0857**	0.0797	0.0819	0.0940*
	(0.0179)	(0.0165)	(0.0183)	(0.0225)	(0.0152)	(0.0127)	(0.0155)	(0.0176)	(0.0425)	(0.0670)	(0.0750)	(0.0503)
Transport Public works X Post X Kdestruction	**-0.0230**	**-0.0143**	**-0.0152**	**-0.0293**	**-0.0210**	**-0.00689**	**-0.00441**	**-0.0277**	**-0.0900****	**-0.0824**	**-0.0816**	**-0.0979***
	(0.0176)	**(0.0163)**	**(0.0181)**	**(0.0221)**	**(0.0149)**	**(0.0126)**	**(0.0155)**	**(0.0173)**	**(0.0430)**	**(0.0682)**	**(0.0766)**	**(0.0500)**
Distance to Provincial Border	5.89e-05**	3.90e-05	3.62e-05	7.10e-05**	4.29e-05*	2.28e-05	2.25e-05	5.09e-05*	6.84e-05***	-6.92e-06	3.11e-05	8.83e-05***
	(2.83e-05)	(2.69e-05)	(3.06e-05)	(3.14e-05)	(2.53e-05)	(1.99e-05)	(2.13e-05)	(2.74e-05)	(2.56e-05)	(4.38e-05)	(4.28e-05)	(3.20e-05)
Constant	2.803***	2.101***	1.617***	2.120***	1.743***	0.677*	-0.225	1.347**	4.850***	4.253***	2.950*	4.356***
	(0.570)	(0.548)	(0.620)	(0.612)	(0.509)	(0.410)	(0.430)	(0.551)	(0.711)	(1.404)	(1.750)	(0.864)
Observations	395	395	395	395	395	395	395	395	394	376	341	394

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.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. Distance to Provincial Border is a variable controlling for the smallest distance in kilometers between the municipality' centroid and the border of the NUTS 3 region it is located in. Kdestruction represents the percentage of destruction in physical capital stock coming from the seismic shock. In this 2SLS approach, K destruction is instrumented by Treated is a dummy variable equal to 1 for municipalities with distance from the earthquake epicenter smaller or equal to 22.5 kilometers, 0 if above 22.5.

We now move to consider the impact of private capital stock levels on the elasticity of private investment and employment outcomes to state-funded investment subsidies. State-funded investment subsidies can vary significantly in scope, ranging from those aimed at supporting Research & Development activities, to those partly financing productive investments, and the complementarity of these subsidized investments with the existing private capital stock varies widely. In this section we present first the aggregate results without distinguishing by type of subsidy, whilst in the next section we present individual results for R&D and productive investment subsidies.

When studying the stimulus to private sector's activity from investment subsidies, the discontinuity in physical private capital stock destruction affects the fiscal multiplier effect no more through the complementarity/private demand for 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 - 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. But on the other hand, destruction of private capital, such as the one associated to an earthquake, reduces the amount of collateral available in the economy.

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 epicentral distance smaller than 22.5 on each side. But treated municipalities experience a larger reduction in collateral size than control municipalities. This, on one hand suggests an expected larger impact of investment subsidies over private sector employment, business generation and investment through the larger pool of marginal investments which can be stimulated, on the other hand the negative shock to private capital deteriorates the amount of collateral available in the economy, which can be become insufficient for access to credit even in the presence of interest rate subsidies.

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

Columns 1 to 3 in **Table 4** contain the aggregate results for total investment incentives. Sensitivity tests by bandwidth, running variable and model specification are also contained in the Appendix (**Section D Table D.4**). Overall, the treated municipalities experiencing serious private capital destruction do not show post-shock a significantly different response, than those which didn't, to investment incentives in terms of net business creation, net employment creation and fixed capital investment, as captured by the coefficient on the interaction term *'Incentives x Post x Kdestruction'*. The results suggest a strongly significant impact of investment subsidies on private employment, net business creation and gross fixed capital, which are stimulated on average by 0.15%, 0.14% and 0.18% per 1% increase in investment subsidies (coefficient of *'Incentives'*).

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.7 in Section D of the Appendix**).

Table 4: Fuzzy RDD results for investment incentives

	12.5 ≤ Epicentral Distance ≤ 32.5								
	Total			*Productive*			*R&D*		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	N.Workers	N.BU	GFCF	N.Workers	N.BU	GFCF	N.Workers	N.BU	GFCF
Post	-0.0943	-0.0270	0.0710	0.708**	0.633**	0.579	-1.072**	-1.031***	-0.0659
	(0.406)	(0.363)	(0.410)	(0.297)	(0.274)	(0.421)	(0.448)	(0.384)	(0.497)
Kdestruction	-0.136	-0.0778	-0.121	-0.0812	-0.0462	-0.0776	-0.272	-0.210*	0.00326
	(0.132)	(0.102)	(0.106)	(0.120)	(0.0957)	(0.105)	(0.175)	(0.116)	(0.360)
Incentives	0.155**	0.136**	0.189***	0.279***	0.235***	0.265***	-0.0589	-0.0678	0.218**
	(0.0735)	(0.0688)	(0.0689)	(0.0595)	(0.0579)	(0.0798)	(0.0784)	(0.0708)	(0.0973)
Post X Kdestruction	0.0996	0.0541	0.0917	0.0461	0.0217	0.0406	0.384	0.299	0.0255
	(0.113)	(0.0893)	(0.104)	(0.113)	(0.0906)	(0.110)	(0.237)	(0.184)	(0.353)
Incentives X Post	-0.0451	-0.0481	-0.102	-0.181***	-0.159***	-0.190**	0.277***	0.264***	-0.0847
	(0.0732)	(0.0671)	(0.0716)	(0.0534)	(0.0510)	(0.0766)	(0.107)	(0.0944)	(0.111)
Incentives X Kdestruction	0.0196	0.0101	0.0222	0.0103	0.00482	0.0151	0.0447	0.0347*	0.00206
	(0.0205)	(0.0157)	(0.0163)	(0.0187)	(0.0149)	(0.0162)	(0.0289)	(0.0187)	(0.0635)
Incentives X Post X Kdestructior	**-0.0160**	**-0.00704**	**-0.0195**	**-0.00735**	**-0.00199**	**-0.0113**	**-0.0982**	**-0.0743**	**-0.0231**
	(0.0187)	**(0.0146)**	**(0.0163)**	**(0.0183)**	**(0.0145)**	**(0.0169)**	**(0.0611)**	**(0.0491)**	**(0.0639)**
Distance to provincial border	2.36e-05	1.40e-05	3.13e-05	2.09e-05	1.21e-05	3.41e-05*	2.88e-05	3.00e-05	3.10e-05
	(2.23e-05)	(1.97e-05)	(1.92e-05)	(2.07e-05)	(1.82e-05)	(1.85e-05)	(3.36e-05)	(3.22e-05)	(2.83e-05)
Constant	2.894***	1.727***	4.596***	2.269***	1.225***	4.213***	4.142***	2.809***	5.021***
	(0.409)	(0.389)	(0.377)	(0.337)	(0.340)	(0.422)	(0.417)	(0.343)	(0.493)
Observations	662	662	661	627	627	626	182	182	181
R-squared	0.061	0.072	0.068	0.097	0.103	0.075	0.018	0.089	0.098

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. 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. In this 2SLS approach, K destruction is instrumented by Treated is a dummy variable equal to 1 for municipalities with distance from the earthquake epicenter smaller or equal to 22.5 kilometers, 0 if above 22.5.

Table 4 presents also the results of investment incentives by type. 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.

The results are reported only for Research and Development-oriented incentives and Productive activity incentives however, as they are the only ones paid to a significant share of the municipalities object of observation. The estimates for the coefficient on the interaction term *'Incentives x Post x Kdestruction'* obtained for Production and R&D incentives are also not statistically different from zero, suggesting so significant difference in the responsiveness to incentives from treated versus control municipalities. Both types of investment incentives however appear to significantly stimulate private investment (coefficient on 'Incentives' in column 6 and 9), whilst only incentives from production are associated to positive gains in terms of employment and new business generation at municipality level (columns 4-5). Estimates from the post-shock differences IV regression model contained in the Appendix (**Tables D.5 – D.6 in in Section D**) also show no significant difference in the effectiveness of the investment subsidies between treated and control municipalities, but they also record a complete lack of effectiveness overall – differently from the estimates presented in Table 4 and broader literature on the topic. This again is likely linked to a bias associated with the absence for a control for pre-shock differences in outcomes' growth rates between treated and control municipalities.

As previously discussed, theoretically the impact of a negative capital shock on the effectiveness of investment subsidies on employment, investment and business generation at local level is unclear, as on one hand that means that a larger pool of marginal investments is available for financing, but on the other hand less collateral is available in the economy. These results do not provide evidence in favour of one of the two effects dominating, but provide evidence supporting the value of state-funded investment incentives as "enablers" for credit access and business investment *even* in areas where private capital is scarce or which suffered a negative capital shock.

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, investment subsidies seem to be more cost-effective than direct investments, as they allow private capital to develop through credit access, which supports business creation and, ultimately, employment.

IX. 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 on the importance of its level 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 utilization 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. The adoption of a quasi-experimental design, exploiting an exogenous shock to private capital, allows to derive insights on a relationship whose understanding is crucial for the development of effective local development policies, but whose endogeneity and measurement difficulties had dramatically limited previous research on the topic.

Second, it provides insight on the ramifications of destruction from natural disasters and the local response to public policy interventions post-disaster. Whilst most previous literature on the topic focuses on the quantification of damages, this paper sheds light on some of the structural changes occurring in areas affected by natural disasters, particularly related to the loss of public and private capital assets, and how those impact the areas' responsiveness to public policy interventions.

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.

Investment incentives for production, through their ability in increasing the pool of credit eligible applicants, appear to be effective in counterbalancing the negative credit implications stemming from a negative capital shock. They thus appear to be effective in increasing the level of physical private capital available at local level also in capital scarce areas, fostering private productive capacity and, eventually, potential gains in complementarity from public infrastructure. These appear therefore to be more cost-effective than direct public investments in contexts with lower levels of private capital.

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. Likewise, when tailoring policies to areas having recently suffered from a natural disaster, policy makers need to be mindful of the impact that had on public and private capital assets and should prioritise interventions that adequately respond to the needs and demands of local capital endowments.

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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"[15]. 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

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

used to integrate the SBS for the credit sector[16] 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. 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

[16] 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.

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[17] 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) $$I_{ji,t} = X_{kj,t}\left(I_{jk,t}\right)$$

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

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

[17] 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 $\Delta UL_{ji,t} = UL_{ji,t} - UL_{ji,t-1}$. 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 are 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.[18] 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

[18] "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.

with a delay from the effective closing time[19]) unlike in the case of the two other main opendata 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 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.

[19] 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.

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.[20] 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[21] 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

[20] A total number of 57,713 records fall into this category for our regions of interest.
[21] 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.

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 15,138 were completed in 2012). Of those, 180,583 projects were classified as public works, 92,257 as incentives and 3,563 as natural disaster emergency funding[22] and were carried out across 2400, 2080 and 79 municipalities, respectively.

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

[22] 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.

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[23] for each high intensity seismic shock[24] 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.[25] 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**.

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

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[23] 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 municipalities 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)]
[24] I consider a seismic shock to be of high intensity if its epicentral magnitude is above 5.5.
[25] The hypocentre or focus is the point within the earth where the earthquake rupture starts. The epicentre is right above the hypocentre but on surface. The vertical distance between the hypocentre and the epicentre is called hypocentral or focal depth.

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 2012 high intensity seismic shocks, having non perfectly 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.

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

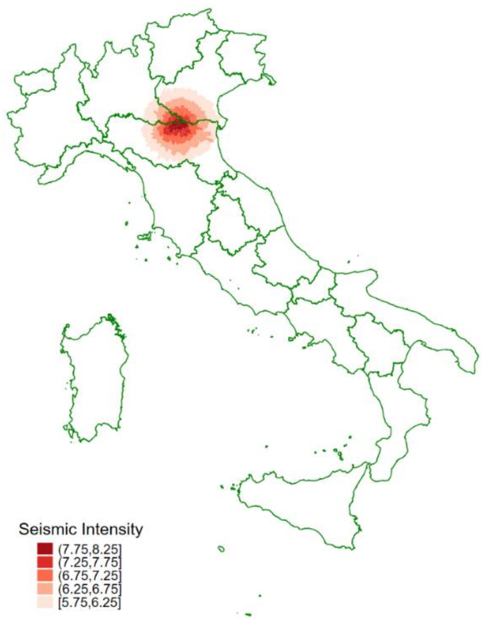


Figure A.1 shows the estimated attenuation areas for 2012 high intensity seismic shocks. Overall, I estimate that a total of 49 municipalities experienced an intensity above 7.25 (the intensity level around which a discontinuity in physical destruction should be experienced) distributed across three 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 $long_E$).

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

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[26], 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 is holding equal 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

[26] 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.

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.[27] Through mechanical calculations, combining the models of Bindi et al. (2011) and Pasolini et al. (2008)[28], 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[29] 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 broadly smoothly away from the epicentre, as empirically estimated attenuation laws (Pasolini 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

[27] 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.

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

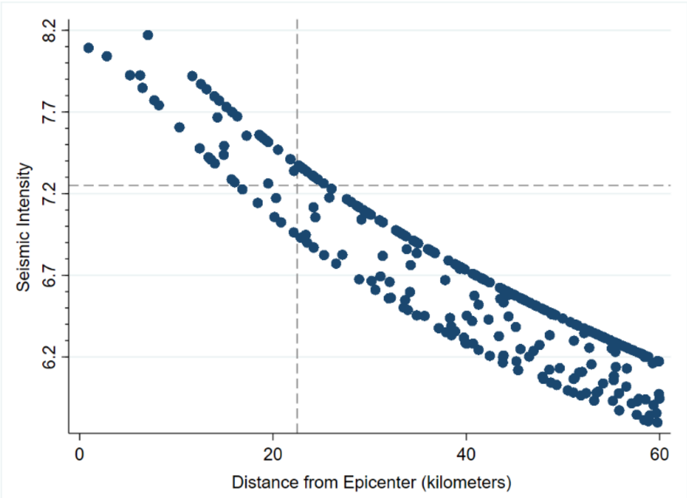
[29] A MMIS intensity level of 7 describes shaking as "very strong" and damage as "negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken". A MMIS intensity level 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".

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

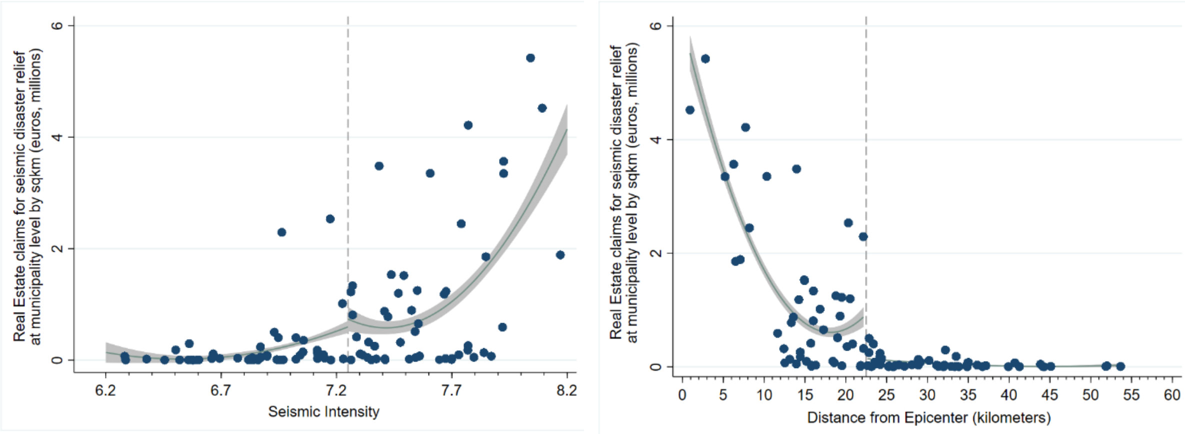
Plotting the estimated seismic intensity against the distance from the epicentre for the municipalities affected by the 2012 earthquake we can see how a seismic intensity of 7.25 corresponds to an epicentral distance of 22.5km on average.

Figure B.1: Mapping Seismic Intensity to Epicentral Distance



I then move on testing the robustness of each of these two measures and proposed threshold values in predicting a discontinuity in earthquake related physical destruction. From Figure B.2 below it is possible to observe the superiority of the measure of epicentral distance and threshold value of 22.5 relative to the seismic intensity measure. Below 22.5km from the epicentre the values of claims for seismic relief reconstruction funds by sqkm dramatically increases, with the discontinuity being significant at less than 1% level.

Figure B.2: Testing Discontinuity in Destruction across threshold measures



The figures below present several robustness tests of the discontinuity in additional to the one presented in Figure 3.

Figure B.3: Kernel density at threshold

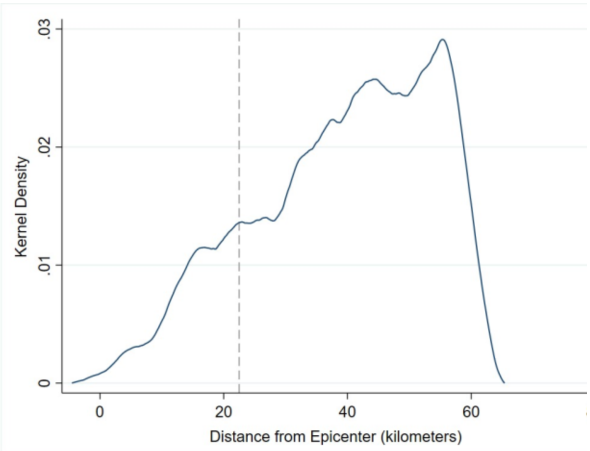


Figure B.4: Total Area affected

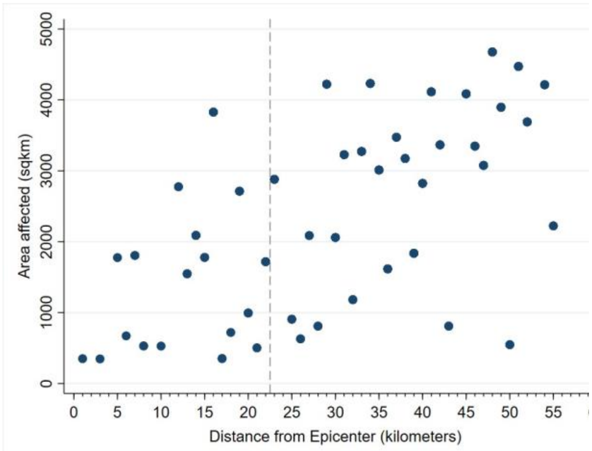


Figure B.5: Average Number of people employed in the private sector before the earthquake by sqkm

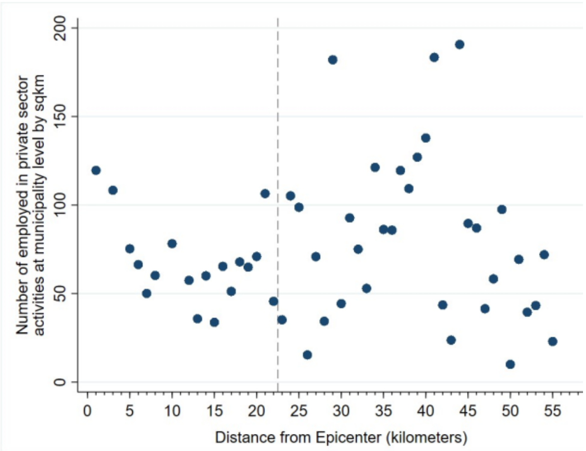


Figure B.6: Average Number of private sector business units before the earthquake by sqkm

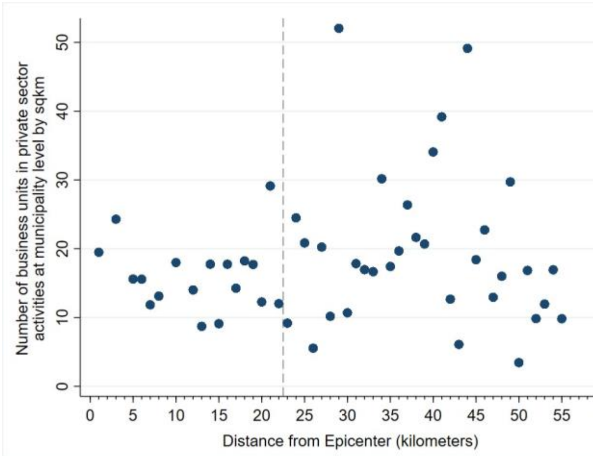


Figure B.7: Total State spending on public works before the earthquake by sqkm

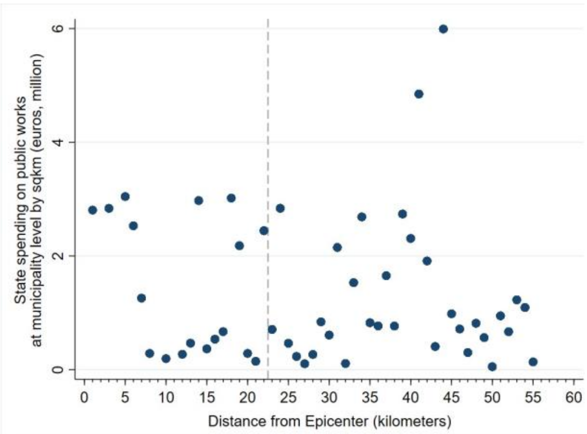


Figure B.8: State spending on private incentives before the earthquake by sqkm

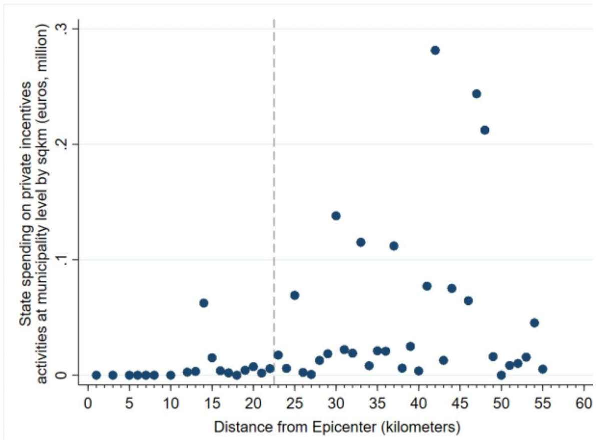


Table B.1 First-Stage Regression by Instrument

VARIABLES	K destruction	
	(1)	(2)
Treated [Seismic intensity ≥ 7.25]	11.44***	
	(2.430)	
Treated [Epicentral distance ≤ 22.5]		13.49***
		(2.505)
Constant	0.0850**	0.0303***
	(0.0333)	(0.00789)
Observations	27,071	27,016
R-squared	0.264	0.441

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Section C - Robustness tables for infrastructure analysis

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

	12.5 ≤ Epicentral Distance ≤ 32.5														
	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	-0.242	-0.225	-0.250	0.783	0.722*	0.682	0.787	0.727*	0.688	0.787	0.727*	0.688	0.723	0.654*	0.924
	(0.884)	(0.774)	(1.126)	(0.509)	(0.385)	(0.896)	(0.513)	(0.387)	(0.902)	(0.513)	(0.387)	(0.902)	(0.492)	(0.367)	(0.841)
Treated	-0.406	-0.581	-2.556	-0.155	-0.186	-2.730*	-0.179	-0.365	-2.663	-0.179	-0.365	-2.663	-0.183	-0.505	-2.238
	(0.982)	(0.868)	(1.890)	(0.815)	(0.681)	(1.586)	(0.898)	(0.754)	(1.750)	(0.898)	(0.754)	(1.750)	(0.881)	(0.728)	(1.907)
Transport Public works	0.0859	0.0711	0.0741	0.149***	0.132***	0.113	0.149***	0.132***	0.112	0.149***	0.132***	0.112	0.128**	0.113**	0.109
	(0.0588)	(0.0512)	(0.0768)	(0.0538)	(0.0457)	(0.0791)	(0.0538)	(0.0458)	(0.0788)	(0.0538)	(0.0458)	(0.0788)	(0.0520)	(0.0453)	(0.0751)
Post X Treated	1.464	1.667	4.847**	0.153	0.395	5.284**	-0.406	-0.00718	5.349*	-0.406	-0.00718	5.349*	-0.0991	0.245	2.883
	(1.159)	(1.039)	(2.303)	(0.880)	(0.710)	(2.271)	(0.861)	(0.649)	(2.704)	(0.861)	(0.649)	(2.704)	(0.863)	(0.680)	(2.084)
Transport Public works X Post	0.0176	0.0145	-0.00291	-0.0867	-0.0816**	-0.104	-0.0861	-0.0812**	-0.105	-0.0861	-0.0812**	-0.105	-0.0807	-0.0738*	-0.133
	(0.0879)	(0.0765)	(0.118)	(0.0537)	(0.0402)	(0.0963)	(0.0540)	(0.0405)	(0.0968)	(0.0540)	(0.0405)	(0.0968)	(0.0531)	(0.0392)	(0.0926)
Transport Public works X Treated	0.0706	0.0809	0.348*	0.0245	0.0215	0.348**	0.0266	0.0383	0.342*	0.0266	0.0383	0.342*	0.0278	0.0517	0.313
	(0.103)	(0.0904)	(0.204)	(0.0908)	(0.0754)	(0.175)	(0.0961)	(0.0805)	(0.188)	(0.0961)	(0.0805)	(0.188)	(0.0943)	(0.0782)	(0.203)
Transport Public works X Post X Treated	**-0.171**	**-0.175**	**-0.564****	**-0.0416**	**-0.0509**	**-0.602****	**0.00271**	**-0.0220**	**-0.609****	**0.00271**	**-0.0220**	**-0.609****	**-0.0198**	**-0.0419**	**-0.374***
	(0.119)	**(0.107)**	**(0.243)**	**(0.0888)**	**(0.0726)**	**(0.233)**	**(0.0860)**	**(0.0668)**	**(0.273)**	**(0.0860)**	**(0.0668)**	**(0.273)**	**(0.0910)**	**(0.0721)**	**(0.218)**
Distance to Provincial Border	5.08e-05	4.04e-05	6.44e-05**	1.60e-05	7.85e-06	4.02e-05	1.52e-05	5.55e-06	4.42e-05	1.52e-05	5.55e-06	4.42e-05	3.63e-05	1.72e-05	6.29e-05**
	(3.39e-05)	(3.02e-05)	(2.94e-05)	(3.33e-05)	(2.93e-05)	(2.92e-05)	(3.47e-05)	(3.06e-05)	(3.01e-05)	(3.47e-05)	(3.06e-05)	(3.01e-05)	(3.01e-05)	(2.61e-05)	(2.75e-05)
Constant	2.663***	1.604***	4.595***	2.107***	1.078**	4.277***	2.108***	1.084**	4.267***	2.108***	1.084**	4.267***	2.292***	1.265***	4.311***
	(0.594)	(0.525)	(0.699)	(0.566)	(0.495)	(0.732)	(0.569)	(0.500)	(0.730)	(0.569)	(0.500)	(0.730)	(0.534)	(0.479)	(0.679)
Observations	345	345	344	307	307	306	298	298	297	298	298	297	339	339	338
R-squared	0.065	0.064	0.083	0.047	0.046	0.069	0.055	0.055	0.071	0.055	0.055	0.071	0.056	0.049	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 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 with distance from the earthquake epicenter smaller or equal to 22.5 kilometers, 0 if above 22.5. 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. Distance to Provincial Border is a variable controlling for the smallest distance in kilometers between the municipality' centroid and the border of the NUTS 3 region it is located in.

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

	9.5 ≤ Epicentral Distance ≤ 37.5														
	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	-0.0518	-0.0632	-0.0953	0.782	0.715*	0.483	0.817	0.742*	0.226	0.817	0.742*	0.226	0.400	0.420	0.104
	(0.872)	(0.770)	(1.087)	(0.522)	(0.394)	(0.919)	(0.547)	(0.410)	(0.968)	(0.547)	(0.410)	(0.968)	(0.577)	(0.425)	(0.926)
Kdestruction	-0.0246	-0.0243	-0.217	-0.0695	-0.0586	-0.560	-0.143	-0.136	-1.616*	-0.143	-0.136	-1.616*	-0.111	-0.121	-0.994
	(0.0677)	(0.0600)	(0.184)	(0.184)	(0.151)	(0.524)	(0.403)	(0.333)	(0.980)	(0.403)	(0.333)	(0.980)	(0.240)	(0.197)	(0.618)
Transport Public works	0.101*	0.0872*	0.0741	0.147***	0.130***	0.0951	0.146**	0.129***	0.0721	0.146**	0.129***	0.0721	0.113**	0.101**	0.0470
	(0.0600)	(0.0527)	(0.0733)	(0.0555)	(0.0470)	(0.0828)	(0.0580)	(0.0491)	(0.0878)	(0.0580)	(0.0491)	(0.0878)	(0.0570)	(0.0485)	(0.0837)
Post X Kdestruction	0.0654	0.0602	0.296	0.0618	0.0648	0.755	0.0408	0.0683	2.038*	0.0408	0.0683	2.038*	0.109	0.116	1.050*
	(0.0713)	(0.0647)	(0.197)	(0.175)	(0.141)	(0.614)	(0.380)	(0.301)	(1.147)	(0.380)	(0.301)	(1.147)	(0.228)	(0.184)	(0.638)
Transport Public works X Post	-0.00291	-0.00368	-0.0121	-0.0849	-0.0799*	-0.0772	-0.0862	-0.0809*	-0.0500	-0.0862	-0.0809*	-0.0500	-0.0466	-0.0490	-0.0419
	(0.0891)	(0.0787)	(0.114)	(0.0554)	(0.0414)	(0.0990)	(0.0579)	(0.0432)	(0.104)	(0.0579)	(0.0432)	(0.104)	(0.0622)	(0.0456)	(0.101)
Transport Public works X Kdestruction	0.00582	0.00473	0.0347	0.00950	0.00703	0.0763	0.0175	0.0152	0.193*	0.0175	0.0152	0.193*	0.0131	0.0131	0.119*
	(0.0101)	(0.00887)	(0.0232)	(0.0252)	(0.0208)	(0.0655)	(0.0485)	(0.0399)	(0.113)	(0.0485)	(0.0399)	(0.113)	(0.0285)	(0.0232)	(0.0704)
Transport Public works X Post X Kdestruction	**-0.00954**	**-0.00750**	**-0.0418***	**-0.0106**	**-0.00878**	**-0.0963**	**-0.0112**	**-0.0112**	**-0.235***	**-0.0112**	**-0.0112**	**-0.235***	**-0.0149**	**-0.0142**	**-0.125***
	(0.00969)	**(0.00858)**	**(0.0242)**	**(0.0229)**	**(0.0188)**	**(0.0727)**	**(0.0448)**	**(0.0361)**	**(0.128)**	**(0.0448)**	**(0.0361)**	**(0.128)**	**(0.0267)**	**(0.0216)**	**(0.0720)**
Distance to Provincial Border	6.45e-05**	5.44e-05*	6.66e-05**	1.52e-05	7.58e-06	3.35e-05	1.37e-05	4.99e-06	3.73e-05	1.37e-05	4.99e-06	3.73e-05	5.08e-05*	2.88e-05	7.60e-05***
	(3.26e-05)	(2.94e-05)	(2.81e-05)	(3.26e-05)	(2.87e-05)	(2.94e-05)	(3.41e-05)	(3.01e-05)	(3.04e-05)	(3.41e-05)	(3.01e-05)	(3.04e-05)	(2.63e-05)	(2.27e-05)	(2.53e-05)
Constant	2.529***	1.463***	4.594***	2.124***	1.090**	4.419***	2.141***	1.110**	4.603***	2.141***	1.110**	4.603***	2.409***	1.359***	4.826***
	(0.598)	(0.532)	(0.669)	(0.572)	(0.499)	(0.762)	(0.594)	(0.520)	(0.809)	(0.594)	(0.520)	(0.809)	(0.564)	(0.493)	(0.760)
Observations	370	370	369	313	313	311	298	298	297	298	298	297	357	357	356

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. 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. Distance to Provincial Border is a variable controlling for the smallest distance in kilometers between the municipality' centroid and the border of the NUTS 3 region it is located in. Kdestruction represents the percentage of destruction in physical capital stock coming from the seismic shock. In this 2SLS approach, K destruction is instrumented by Treated is a dummy variable equal to 1 for municipalities with distance from the earthquake epicenter smaller or equal to 22.5 kilometers, 0 if above 22.5.

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Section D - Robustness tables for investment incentives

Table D.1: RDD results for investment incentives

	12.5 ≤ Epicentral Distance ≤ 32.5			*6.75 ≤ Seismic Intensity ≤ 7.75*		
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	N.Workers	N.BU	GFCF	N.Workers	N.BU	GFCF
Post	-0.0245	0.00883	0.135	0.147	0.0931	0.114
	(0.378)	(0.342)	(0.387)	(0.372)	(0.336)	(0.390)
Treated	-0.830	-0.280	-1.591**	-0.984	-0.708	-1.791***
	(0.818)	(0.698)	(0.720)	(0.690)	(0.592)	(0.633)
Incentives	0.166**	0.142**	0.202***	0.168**	0.136**	0.191***
	(0.0694)	(0.0657)	(0.0657)	(0.0674)	(0.0633)	(0.0634)
Post X Treated	0.515	0.0343	1.351	0.313	0.220	1.514*
	(0.739)	(0.643)	(0.848)	(0.671)	(0.572)	(0.767)
Incentives X Post	-0.0559	-0.0527	-0.114*	-0.0690	-0.0554	-0.104
	(0.0689)	(0.0638)	(0.0681)	(0.0672)	(0.0620)	(0.0667)
Incentives X Treated	0.0977	0.00209	0.324***	0.133	0.0864	0.364***
	(0.137)	(0.118)	(0.123)	(0.118)	(0.103)	(0.109)
Incentives X Post X Treated	**-0.0710**	**0.0315**	**-0.307****	**-0.0728**	**-0.0325**	**-0.341*****
	(0.132)	**(0.115)**	**(0.136)**	**(0.118)**	**(0.102)**	**(0.122)**
Distance from provincial border	2.39e-05	1.40e-05	3.26e-05*	3.64e-05*	2.45e-05	4.55e-05**
	(2.22e-05)	(1.97e-05)	(1.90e-05)	(2.19e-05)	(1.90e-05)	(1.94e-05)
Constant	2.814***	1.682***	4.520***	2.761***	1.677***	4.524***
	(0.374)	(0.364)	(0.349)	(0.362)	(0.347)	(0.332)
Observations	662	662	661	693	693	692
R-squared	0.131	0.119	0.086	0.157	0.137	0.096

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 with distance from the earthquake epicenter smaller or equal to 22.5 kilometers, 0 if above 22.5; or equal to 1 for municipalities that experienced seismic intensity larger or equal to 7.25, 0 if below 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. Distance to Provincial Border is a variable controlling for the smallest distance in kilometers between the municipality' centroid and the border of the NUTS 3 region it is located in.

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Table D.7: Robustness check for share of incentive financing

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Capital Development under Collateral Constraints

Do Investment Subsidies Work?

I. Introduction

Do investment subsidies work in stimulating additional capital investment by private firms? Do they also lead to higher demand for labour? Which type of firms are going to be the most responsive to this incentive? How do credit market imperfections affect the response to investment subsidies and the selection of the optimal target group?

These are the questions this paper aims to provide an answer to through an innovative quasi-experimental approach using an emergency programme following a natural disaster as tool for identification.

Public industrial subsidies have been used extensively in multiple countries and situations, attracting large amounts of public financial resources. The widespread use of subsidies, as a tool of public industrial policy, has fostered the development of a rich policy-evaluation literature (Bernini and Pellegrini, 2011; Bernini et al. 2017; Hart et al, 2008; Criscuolo et al, 2019; Busso et al., 2013; Kilen and Moretti, 2014 a-b). Overall, public subsidy programmes for investment have been shown to generate an increase in firms' capital, employment, and output (Bernini and Pellegrini, 2011; Criscuolo et al, 2019). There are, however, limitations to the findings derivable from policy evaluations of capital investment subsidy programmes. The first one is their inability to test the average treatment effect given the often-specific targeting of a policy programme. The second one is the bias introduced by conditionality clauses often present in those programmes, specifically in the context of estimating the impact on employment.

The first contribution this paper aims to make is in response to the above-mentioned limitations of policy-evaluation literature. Empirical evidence is obtained in the context of Italy, exploiting the allocation of investment subsidies as a post-emergency response following three major earthquakes. The purely place-based nature of the policy intervention which is the object of study in this paper, facilitates the testing of the policy impact over a local population of firms, absent any productivity, size or employment-based targeting and conditionality. The sample of firms in this analysis ranges across different sizes and sectors and on a broader set of dimensions than has been explored in previous contributions to the literature.

The identification design adopted allows a deeper delve into the optimal targeting of public investment subsidies, studying the policy effect in the context of credit market frictions, particularly those arising from secured access to credit.

Investment subsidies affect the cost of capital incurred by the firm, which, as Bond and Van Reenen (2007) discuss in their pecking order theory, is higher when the investment project cannot be financed internally and the firm has to resort to external financing. Criscuolo et al. (2019) show how, following a similar investment subsidy, firms which must resort to external funding to finance their investment projects ("pecking order constrained"), experience a larger increase in capital than firms internally financing. Smaller firms, they argue, have a higher probability of lacking internal financing capacity and therefore falling into this so-called "pecking order constrained" category.

As Small and Medium Enterprises (SMEs) play a central role in the economy, and particularly so in Italy where they account for 76% of total employment and 64% of total value added (versus 68% and 59% for OECD average; OECD, 2021), a credible assessment of optimal targeting of investment subsidies for regional firm development, cannot be divorced from the specific challenges faced by SMEs' access to credit.

The constraint that SMEs face in credit markets is not just represented by a higher cost of financing, but also by the need, in most cases, to pledge assets as collateral to their borrowing, a practice referred to as secured borrowing. In the US, arguably one of the most developed capital markets in the world, an analysis of supervisory level data suggests that secured borrowing accounts for more than 95% of credit lines to SMEs, whilst up to 70% of credit lines to large and very large companies are unsecured (Chodorow-Reich et al., 2021). Similar differences are also detected across firm sizes for term loans (Avery et al. 1998). The importance of collateral is even higher in the European economies where around 77% of loans are secured (Fan et al., 2020).

Thus, this leads to another characterisation of constraints in credit markets, collateral constraints. When it comes to estimating the impact of investment subsidies on firms' capital these are not a substitute for the pecking order constraints investigated by Criscuolo et al. (2019) but act alongside them.

The second contribution of this paper consists in investigating the impact that such collateral constraints have on the effectiveness of investment subsidies, both from a theoretical and empirical standpoint. This has as an objective, an assessment of the ability of investment subsidies, in solving credit market imperfections associated with secured financing, and the development of a framework for their optimal targeting to this end. Collateral constraints – we show – are a function, particularly in the case of SMEs, also of local characteristics. The targeting framework for investment subsidies presented here supports their role as a place-based policy tool and thus contributes to the wider debate on place-based policies.

Finally, this paper contributes also to natural disaster literature providing an insight into the effectiveness of a post-disaster emergency response. The investment subsidy programme studied here was part of a package of emergency interventions for communities affected by seismic destruction, and the investment subsidies were specifically aimed at supporting the local economy's recovery. The gains made in some directions of the empirical identification from such empirical strategy relative to past literature, which were already discussed, come at a cost in terms of generality of the results derivable. But, as the frequency and intensity of natural disasters and associated destruction is expected to increase from climate change, the results from this paper can certainly help to shape the policy response in such contexts.

The paper is organised as follows: Section II provides a short summary of the relevant literature debates and findings; Section III sketches out the theoretical model acting as a framework for the impact of investment subsidies under imperfect credit markets; Section IV presents the empirical identification set up and the econometric modelling strategy; Section V details the data sources. Empirical results are presented in Section VI, with conclusions contained in Section VII. The Appendix contains additional detail on the theoretical model derivation, dataset generation and robustness analysis.

II. **Literature Review**

The research questions addressed and the methods adopted make the contribution of this paper directly related to three main streams of literature: i. Policy evaluation literature of investment subsidies programmes, ii. Credit markets imperfections literature, iii. Natural disasters literature. This section will provide a summary of the main findings and open debates of these literature strands and how this paper fills those gaps.

A. Policy-evaluation literature of capital investment subsidies programmes

The long-standing use of public capital investment subsidies has led to the development of a rich policy-evaluation literature discussing their impact on firms' output, employment and capital. Notable examples of capital investment subsidy programmes, used as an object of policy evaluation studies, are the L. 488 investment subsidies' programme in Italy running from 1997 to 2007 (Bernini and Pellegrini, 2011; Bernini et al. 2017), the Regional Selective Assistance (RSA) programme in the UK

(Hart et al, 2008; Criscuolo et al, 2019,; Harry and Robinson, 2001) - later rebranded as Selective Finance for Investment for England - running from 1972 to 2008 and later followed by the Grant for Business Investment and the Regional Growth Fund programmes, the US Empowerment Zones (Busso et al. 2013) and Tennesse Valley Authority Policy (Kilen and Moretti 2014 a-b), the NUTEK regional policy subsidies in Sweden (Bergstrom, 2000) , the Irish Industrial Development grant schemes (Girma et al., 2007; Cassidy, 2002; Cassidy and Strobl, 2004) and the Czech Operational Programme Enterprise and Innovation (Dvoulety et al., 2021).

Public programmes of subsidies for capital investment are often structured as national calls for tender for incentives, in which subsidies are awarded to projects on a competitive basis, upon satisfaction of minimum requirements. The subsidies are often in the form of grants (Irish Industrial Development scheme, UK RSA, L. 488 in Italy) partly covering the investment cost. The exact workings of the tendering process can vary, but they often favour projects proposing higher shares of co-financing and higher increases in employment (e.g., L.488). As a result, “local champions” tend to be the main receivers of subsidies (Bernini et al., 2017; Peng et al., 2021; Aubert et al., 2011), which are generally medium sized firms more competitive than the local average and already providing significant employment at local level.

Sometimes employment creation is not just a variable affecting the probability of being awarded the subsidy, but is also an outright conditionality associated with the participation in the programme. This the case for instance for the Regional Selective Assistance programme in the UK, in which firms awarded capital subsidies had to commit to increase employment, or at least keep it unchanged relative to the level they would have had absent the subsidy. Similarly, businesses receiving grant subsidies from the Industrial Development Agency or Forbairt in Ireland need to show as a pre-condition for eligibility that the financed project would be able to generate employment or maintain existing employment in Ireland. Such formal employment conditionality clauses are hard to monitor and enforce, but there is suggestive evidence that smaller firms may be more bound by those than larger firms (Criscuolo et al., 2019).

Overall, public subsidies for capital investment have been shown to generate an increase in firms' capital, employment and output (Bernini and Pellegrini, 2011; Criscuolo et al., 2019; Cassidy and Strobl, 2004). Both Bergström (2000) and Pellegrini and Muccigrosso (2016), respectively studying the Swedish and Italian programme of public subsidies, find that the receipt of subsidies also positively affects the chances of survival and growth prospects of the beneficiary firms. Girma at al. (2007) find that that is the case in Ireland only when the beneficiary firms are domestic, not in the case of multinationals.

Evidence on the extent of the subsidies' stimulus on marginal investments is, however, contrasting. Bronzini and De Blasio (2006) find that L.488 investment subsidies do not seem to have stimulated marginal but rather inframarginal investments to some extent, as firms appear to have brought forward investments originally planned for a later period, in order to take advantage of the incentives.

The impact on productivity is also mixed. Girma et al. (2007) find a positive effect on productivity from Irish government subsidies that support productivity enhancing activities (R&D, capital and training, technology acquisition). A positive impact on productivity is also found from the UK Regional Selective Assistance (Harris and Robinson, 2001). Bergström (2000) instead does not find that assisted firms in Sweden were able to significantly boost their productivity. Bernini et al. (2017) obtain evidence of a short term negative effect but medium-long term positive effect of L.488 subsidies in Italy. The stark divergence in the estimated impact on productivity of subsidies programmes across countries could be due to differences in programme features, including the process for subsidies allocation and the conditionality associated with them, but also to the characteristics of the treated firms and the environment in which they operate. Literature also finds limited spatial spillovers in the short term, although it concedes that those could be more easily coming from start-ups which in some cases are excluded, whilst already established large firms might crowd out employment from other non-subsidised players (Bernini and Pellegrini, 2011). Criscuolo et al. (2019) do not find spatial crowding out or employment mobility to be associated with subsidies but rather to unemployment reduction. Finally, the impact of investment subsidies appears to be larger when firms are small (Criscuolo et al., 2019; Dvoulety et al., 2021).

Whilst a positive effect of subsidies on output and capital is consistent with theory and across empirical evidence, the effect on employment is unclear theoretically. The net effect on employment is, in fact, determined by the balance between scale effects (the increase in output as a consequence of higher capital bequests more labour inputs) and the substitution effects (determined by the decrease of the user cost of capital vs the cost of labour).

The design features of capital subsidies programmes make an unbiased empirical assessment of their outcomes challenging. As already pointed out, beneficiary firms are hardly randomly picked. Eligibility conditions and allocation systems lead to a correlation between the probability of treatment and pre-treatment indicators of competitiveness, size and relevance for local employment. This is addressed in literature typically through the application of difference-in-difference designs with propensity score matching techniques (Dvoulety et al., 2021; Bernini and Pellegrini, 2011) or regression discontinuity designs (Cerqua and Pellegrini, 2014; Pellegrini and Muccigrosso, 2016) when assessing the impact of subsidies. Propensity score matching techniques are effective in identifying the relevant firm characteristics influencing the probability of being treated, and matching treated firms to control firms exhibiting the same features except for treatment.

A series of other issues, however, remain in policy evaluation studies of public capital subsidies programmes. Takalo and Tanayama (2010) show that success in obtaining government subsidies, in instances in which those are awarded competitively through ex-ante screening, represents an informative signal for external investors positively affecting the probability of accessing external finance later (Narayanan et al., 2000). This clearly has implications for the post-treatment output and investment observed in the beneficiary firms, and brings into question whether the impact observed on these two variables is directly attributable to the subsidy programme itself or the signalling associated with it.

The empirical assessment of the impact of investment subsidies on employment through policy evaluation studies is particularly challenging. The design of subsidy programmes itself could be directly influencing the mostly positive detected impacts of subsidies on employment. This is straightforward in the case of conditionality clauses, and differences in firms' soft power could also be explaining the higher employment gains detected for smaller firms (Criscuolo et al. 2019). But it is also relevant in the cases in which the subsidies' allocation system favours projects generating employment (Cassidy and Strobl, 2004).

The challenges surrounding the estimation of an impact of the subsidies on employment inevitably also affect the estimated impact on productivity. As a result of the allocation systems previously discussed, the programme design often directly or indirectly leads to hiring more employees than optimal. The negative impact of productivity, often detected in policy evaluation studies, could therefore be simply a by-product of that. But it could, equally, be a consequence of lower screening and generally lower-quality investment projects entered by the firm given the reduced cost associated with them, in short, a result of moral hazard.

Finally, the empirical assessment of investment subsidies programmes, as part of development policies, holds, inevitably, limited ability in testing the average treatment effect, given the selection bias in subsidy award. This limits the external validity of estimates, even when obtained through exogenous shocks to allocation, such as score thresholds exploited in discontinuity designs (Pellegrini and Muccigrosso, 2016; Bernini and Pellegrini, 2011; Bernini et al. 2017).

B. *Credit Markets Imperfection Literature*

The lack of complete information on borrowers is a source of adverse selection and, in turn, motivates rationing in credit markets (Stiglitz and Weiss, 1981; Jaffee and Russell, 1976). Collateral requirements, defining the practice of secured borrowing, originate as a market solution to this problem, reducing the need for rationing (Bester, 1985) and improving overall welfare efficiency (Blinder and Stiglitz, 1983).

The type of collateral pledged for secured credit access depends on the credit facility. SMEs' credit lines are mostly backed by account receivables and inventory (AR&I). Half of term loans to SMEs have real estate backing instead, whilst fixed assets backing is more prevalent for larger firms (Chodorow-Reich et al., 2021). This suggests that the extent of collateral constraints also depends more heavily on the firm's location in the case of small businesses. If, upon default, a fixed asset's resale value is quite independent from the firm's location (assuming transport costs to be marginal relative to the asset value), the real estate's resale value instead largely depends on the attractiveness of the location for the business sectors that the real estate asset can accommodate.

Collateral has been shown to act as a screening device to attenuate adverse selection in borrowers (Bester, 1985; Besanko and Thakor, 1987), and as an incentive reducing ex-post borrowing moral hazard (Boot and Thakor, 1994) and contract's enforcement costs (Albuquerque and Hopenhayn, 2004). Yet, despite the significant role of collateral in reducing credit rationing, substantial limits in access to credit persist for small and medium-sized businesses and they are considered one of the main barriers to their growth (Felsenstein and Schwartz, 1993, Schiffer and Weder, 2001; Pissarides et al., 2003; Beck et al., 2005).

Contributions investigating how capital subsidies interact with credit market frictions are scarce (Criscuolo et al., 2019; Girma et al., 2007). The body of literature is substantially more developed instead for the interaction of financial constraints with R&D investment subsidies (Colombo et al., 2013; Cerulli and Poti, 2012; Gonzalez and Pazo, 2008; Gonzalez et al. 2005; Almus and Czarnitzi, 2003; Czarnitzki, 2006; Czarnitzki et al. 2007; Grilli and Murtinu, 2012; Dai and Cheng, 2015).

Girma et al. (2007) explore the interaction of subsidies financing productivity-enhancing activities (R&D, capital and training, technology acquisition) with financial constraints, proxied by the firm pre-treatment debt-to-equity ratio. They find that the productivity-enhancing effect of subsidies positively correlates with the financial constraints the firm faces, with the effect steadily increasing up until when the debt-to-equity ratio of the firm reaches 100.

Criscuolo et al. (2019) study more in depth how investment subsidies interact with credit market frictions, both from an empirical and theoretical perspective. As investment subsidies reduce the cost of capital, they are expected to ease credit constraints at the margin. Criscuolo et al. (2019) focus on the impact this has on firms' internal and external financing, and how this impacts the pecking order hypothesis on the margin. They show that capital subsidies have a larger impact on firms having hit internal financing capacity and, therefore, financing investment externally.

Criscuolo et al. (2019) find a larger impact of subsidies on smaller firms and posit that that could be associated with capital market frictions more strongly affecting them, but do not investigate this further. A similar finding is observed in several literature contributions - among which a programme evaluation for R&D investment subsidies implemented in Northern Italy (Bronzini and Iachini, 2014) – and remains an open question in the literature.

Looking at the problem focusing exclusively on SMEs, literature has shown that, when accessing external credit, they are not subject exclusively to a pecking order friction but also to the fulfilment of collateral requirements. It is in line with this framework that this paper aims to contribute to the existing literature.

C. Natural Disasters Literature

There is a growing number of literature contributions investigating the impact of natural disasters and the policy interventions which follow them. The interest in this literature has been growing recently, as a result of the relevance of its findings in studying the consequences of climate change and the appropriate policy responses. Whilst this is directly relevant to contributions studying the consequences of floods (Bernard and Cook, 2015), hurricanes (Mitsova et al., 2018), tsunamis (Biran et al., 2014), dam disasters, and wildfires, and other natural disasters likely going to increase in frequency as a result of climate change, works studying other natural disasters – such as earthquakes - can still be provide valuable insights in defining response frameworks to events causing large scale destruction of private and public capital.

Mari (2022) provides an extensive review of literature contributions studying the impact of earthquakes. Out of the various natural disasters, earthquakes are found to have the greatest negative impact on economies and, crucially, they are unpredictable and unpreventable (Vere-Jones, 1995). Overall, high intensity earthquakes generate large scale destruction of buildings and infrastructures, with an elevated number of casualties and a significant damage also to the ecological environment (Xie et al., 2018). This clearly leads to large direct economic losses, lower levels of capital development and, frequently, also relocation of economic activities and human capital away from the affected areas. The extent to which such relocation is temporary or permanent in nature often heavily depends on the prospects of economic recovery and the actions taken by government to support it.

A more limited number of literature contributions have provided insights on the disaster recovery of businesses and local economies, with attention to both short and long-term recovery patterns and the impact of reconstruction support and broader policies for recovery (Chang and Rose, 2012; Hosoya, 2016).

Crucial in supporting economic recovery appears the prompt provision of sufficient funds for reconstruction. Xie et al. (2018) find that increased investment levels and accelerated timing of repair and reconstruction following the Wenchuan earthquake could have reduced the lost output from business interruption by 47.4% during the four years after the earthquake, and could have shortened the recovery period by one year.

The recovery rate and the speed of recovery achieved can be influenced however by a wider range of factors beyond the size of recovery funds for reconstruction. The governance of such funds in particular appears to play a significant role. Sardana and Dasanayaka (2013) estimated that recovery from a tsunami in Sri Lanka's Galle district was only 64.8%, as a result of poor governance and targeting, despite an abundance of funds available. A more successful story was instead the one of Aceh in Indonesia. High standards in the coordination and distribution of recovery aid ensured that the region returned to its pre-tsunami growth path and the new investments triggered a wave of industrialization and development of the formal sector to levels not seen prior to the tsunami, with a consequent reduction in poverty (Vidyattama et al. 2021).

Celil et al (2022) note the significant role also played by an expansion of credit from the local banking sector to corporate borrowers. Post disaster cities that experienced greater credit expansion from Chinese regional state-owned City-Commercial Banks (CCBs) enjoyed stronger economic recoveries overall. The intervention studied by Celil et al (2022) is similar in nature to the one object of study in this paper. The expansion of credit from CCBs is in fact not largely dissimilar from a state guaranteed subsidy operating through private banks.

III. Theoretical Model

We draw on Criscuolo et al. (2019) to develop a model helping to assess the impact of investment subsidies on firm-level's investment and employment decisions accounting for the collateral constraints faced by the firm and adequately equipped in modelling the heterogeneous effects by firm size.

III.a Impact of interest rate subsidies on Capital K

As in Criscuolo et al. (2019), investment subsidies can be considered as reductions in the cost of capital faced by the firm using the Hall-Jorgenson cost of capital framework (King 1947), so that

(1) $$\rho = \delta + \frac{r(1-\varphi-\theta\tau)}{1-\tau}$$

Where ϕ is the investment grant in percentage of the total investment, δ is the depreciation rate, τ is the statutory corporate tax rate, r is the interest rate and θ is the depreciation tax allowance. The cost of capital is falling in the generosity of the investment grant.

An investment subsidy corresponds to a decrease in the tax-adjusted user cost of capital (ρ) which leads to a downward shift of the supply of funds curve. This generates an increase in the equilibrium level of capital, assuming a downward sloping marginal revenue productivity of capital curve.

In the absence of credit market frictions, the supply of funds curve is horizontal as the cost of capital is assumed to be constant at different capital levels, as illustrated in Criscuolo et al. (2019) (**Panel A in Figure 1**).

Figure 1: Criscuolo et al. (2019) credit model

But capital markets are not perfect, and most notably, there exists a hierarchy across financing options, with a preference for internal financing over external financing at firm level, as argued in Bond and Van Reenen's pecking order financing hypothesis (Bond and Van Reenen, 2007; Myers and Majluf, 1984). Criscuolo et al. (2019) integrate this credit market friction into their model, in which a firm is "unconstrained" if it can finance the capital investment internally. Instead, it is "constrained" if it needs to resort to external debt or capital markets to finance the investment. This latter financing option implies a higher cost of capital, increasing with the amount of capital the firm needs to raise in external capital markets (hence the upward sloping curve in **Panel B of Figure 1**). In this framework, the "unconstrained" firm MRPK curve crosses the cost of capital curve in the flat part, whilst the "constrained" one crosses it in the upward sloping part. It follows that these "constrained" firms are subject to amplification effects and the same reduction in the cost of capital is associated with a higher increase in capital for the "constrained" firms than the "unconstrained" firms, thus specified. In the framework of Criscuolo et al. (2019), the credit access constraint arises from accumulation of capital beyond what can be financed internally. This framework implies that the firm always finances the project if the project's Net Present Value (NPV) >0, or if MRPK>r but, within sector, small or investment-prone firms are more likely to hit internal financing constraints than larger or investment-scarce firms and, consequently, more likely to experience a higher cost of financing due to "pecking order" frictions.

Whilst this is a sufficient approximation for large firms located in markets with ease of direct access to financial markets, like the US, it does not consider frictions in accessing external financing due to secured borrowing requirements which, as already discussed in the previous section, are extremely relevant for small and medium firms and, more generally, firms located in markets where access to external financing still mostly occurs through financial intermediation and not directly through bond or equity markets.

In this paper, the Criscuolo et al.'s (2019) credit friction model is extended to account for constraints to the firm's investment demand, posed by the banking sector's secured lending rule. This aims to model the firm's inability to externally finance positive NPV projects when it lacks sufficient collateral to pledge against the investment loan.

In this model, the banking sector lends (secured) if two conditions pertaining to the investment project are satisfied: 1) the project presents a positive NPV, 2) the secured borrowing condition is satisfied, meaning that repossession sales – a function of assets pledged as collateral - are larger than or equal to expected losses, where $Expected\ Losses\ (EL) = financing\ exposure \times Probability\ of\ Default$

The Secured Borrowing Condition is obtained through the following building blocks:

A. *Repossession Sales*

(2) $$RPS = \nu C$$

(3) $$C = \mathrm{cK}$$

(4) $$\nu = \alpha\bar{\nu} + (1-\alpha)\nu_l$$

Where ν is the recovery rate (i.e., the percentage of the collateral value obtainable upon liquidation net of the costs of liquidation), *C* is the collateral asset which is a positive ($c > 0$) share of the total capital of the firm, *K*. The recovery rate ν can be decomposed into a recovery rate for "tradeable"/ "movable capital" $\bar{\nu}$ applicable to the share of capital assets which are movable (α) and a location-dependent recovery rate ν_l applicable to unmovable assets (e.g., industrial real estate, heavy industrial machinery, access to location specific natural resources etc.).

B. *Expected Losses*

(5) $$EL = \Delta K(1+r) \times \pi$$

(6) $$\Delta K = \theta K$$

(7) $$\pi = \max\left[\pi_{sovereign}\, , (1-b)\pi_l + b\pi_f\right]$$

Where ΔK is the capital investment which can be thought of as a positive and unbounded share (θ, with θ>*c*) of the existing firm capital, and is fully financed by the firm through secured borrowing in the banking sector. r is the interest rate, π is the banking sector's perceived probability of default associated with the firm. The firm's perceived probability of default is lower bounded by the probability of default of the sovereign in which a given firm operates. It is otherwise a function of the location specific probability of default (π_l) adjusted for the firm-specific default probability (π_f). The extent of such adjustment depends on the factor *b*, *b* ∈[0,1), with *b*=0 generally for distant transaction lenders and b>0 for local lenders for established firms, as they have better access to firm specific information (Inderst and Mueller, 2006). Assuming a competitive banking market, firms request financing from local lenders only if the information value of the local knowledge positively contributes to the probability of being successful in obtaining a financing. This implies that b>0 only if $\pi_l > \pi_f$, otherwise firms would rather be financed by transaction lenders than by local lenders if they can get a better rate there (Inderst and Mueller, 2006). In the empirical testing of this model, I will later assume that i) the market is large enough $\pi_l \neq f(\pi_f)$, i.e., the average location specific default probability is exogenous to the firm specific probability of default, ii) the screening is possible but difficult given we study SMEs for which balance sheet accounts are often untransparent and less reliable, which implies that $0 < b \ll 1$; hence π is largely exogenous to the single firm characteristics.

Therefore, the Secured Borrowing Condition can be expressed as follows:

$$\nu c K \geq \theta K(1+r)\pi$$

$$K - \frac{\theta}{c} K(1+r)\frac{\pi}{\nu} \geq 0$$

Which becomes,

(8) $$K\left(1 - \frac{\theta\pi}{c\nu}(1+r)\right) \geq 0$$

It is then possible to derive the marginal effects, later constituting the proposed testing hypotheses for the model:

[C.1] $$\frac{\partial SBC}{\partial K} = \left(1 - \frac{\theta\pi}{\nu}(1+r)\right) = \frac{\nu - \theta\pi(1+r)}{\nu}$$

$$\nu \geq 0$$

$\nu \geq \theta\pi(1+r)$ by construction in SBC

Hence $\frac{\partial SBC}{\partial K} \geq 0$. The higher the initial capital, the lower the probability of constraint to secured credit access.

Assuming K=1 for simplification:

[C.2] $$\frac{\partial SBC}{\partial \theta} = -\frac{\pi}{cv}(1+r) \leq 0$$

Hence, the larger the investment share, the higher the probability of constraint to secured credit access.

[C.3] $$\frac{\partial SBC}{\partial \pi} = -\frac{\theta(1+r)}{cv} \leq 0$$

Hence, the higher the probability of default, the higher the probability of constraint to secured credit access.

[C.4] $$\frac{\partial SBC}{\partial r} = -\frac{\theta\pi}{cv} \leq 0$$

Hence, the higher the interest rate, the higher the probability of constraint to secured credit access.

[C.5] $$\frac{\partial SBC}{\partial v} = \frac{\theta\pi(1+r)}{cv^2} \geq 0$$

Hence, the higher the recovery rate, the lower the probability of constraint to secured credit access.

[C.6] $$\frac{\partial SBC}{\partial c} = \frac{\theta\pi(1+r)}{c^2 v} \geq 0; \qquad \frac{\partial^2 SBC}{\partial c^2} \leq 0$$

Hence, the higher the size of collateral pledged, the lower the probability of constraint to secured credit access. Furthermore, there is a decreasing marginal gain in the reduction of constraint probability with an increase in collateral size.

In the more detailed SBC specification, additional marginal conditions can be derived:

$$[\alpha\bar{v} + (1-\alpha)v_l]cK \geq \theta K(1+r)[(1-b)\pi_l + b\pi_f]$$

$$K\left(1-\frac{\theta[(1-b)\pi_l+b\pi_f]}{c[\alpha\bar{v}+(1-\alpha)v_l]}(1+r)\right)\geq 0$$

[C.7] $$\frac{\partial SBC}{\partial\alpha}=+\frac{\theta}{c}(1+r)[(1-b)\pi_l+b\pi_f]\frac{1}{[\alpha\bar{v}+(1-\alpha)v_l]^2}(\bar{v}-v_l)$$

[C.7a] $$\frac{\partial SBC}{\partial\alpha}\geq 0\ if\ \bar{v}\geq v_l$$

[C.7b] $$\frac{\partial SBC}{\partial\alpha}< 0\ if\ \bar{v}< v_l$$

If the movable capital recovery rate is higher than the local recovery rate for unmovable assets, then the higher the share of unmovable capital, the higher the probability of constraint to secured credit access.

[C.8] $$\frac{\partial SBC}{\partial b}=-\frac{\theta}{c}(1+r)\frac{1}{[\alpha\bar{v}+(1-\alpha)v_l]}(\pi_f-\pi_l)$$

[C.8a] $$\frac{\partial SBC}{\partial b}\leq 0\ if\ \pi_f\geq\pi_l$$

[C.8b] $$\frac{\partial SBC}{\partial b}> 0\ if\ \pi_f<\pi_l$$

If the firm specific probability of default is higher than the local probability of default, the higher the local banking dependence, the higher the probability of constraint to secured credit access.

In the Secured Borrowing Condition, defined as in eq.(7), upon a loan request θK from a firm endowed with *K*, there are two choice parameters for the financial lending institution: the interest rate and the size of collateral, respectively *r* and *c*.

As the SBC marginal conditions C.4 and C.6 suggest, an increase in the size of collateral (c) is associated with an increase in the likelihood of satisfying the borrowing condition, as it increases the revenues from repossession sales if the borrower were to default. An increase in interest rate (r) is instead associated with a reduced likelihood of satisfying the borrowing condition, given the higher debt servicing costs deriving from it and, therefore, the higher expected loss. This is consistent with the common stylised facts associated with monetary policy on access to credit, according to which a lower interest rate increases access to credit and stimulates investment. This does not refute the concept of risk-adjusted returns and risk premiums in lending rates, but it highlights the trade-off between risk reward and borrower's solvency, which financial institutions need to balance, given the endogeneity of default probabilities and banks' balance sheet management. This suggests, therefore, that banks use standard/fixed interest rates to all customers but adjust to individual risk through the size of the collateral they require when trying to satisfy the SBC.

Holding the other parameters as exogeneous, upon a loan request θK from a firm endowed with K, any bank can satisfy its SBC demanding a certain collateral size $c^D \in (0, +\infty]$. Firms are considered as price-takers in this model and, whilst the collateral demanded can be larger than the firm's capital, i.e., c^D can be above 1, firms can pledge at most their full capital as collateral, thus $c^S \in (0,1]$. This suggests, therefore, a non-continuous function in capital (K) for firms' access to investment with a discontinuity located between the internal and external financing supply. Panels A, B and C of Figure 2 show step-by-step how different assumptions on frictions and endogeneity of capital financing markets affect the analytical definition of the supply of capital faced by firms.

When a firm is able to finance the investment internally, the cost of capital is constant, consistent with a flat supply of funds curve such as the one observed in perfect capital markets (Figure 1, Panel A). Under exogenous internal financing limits, the internal financing option is capped at K_1' as shown in both Panel A and B of Figure 1. But as the internal cost of capital changes (for instance as a result of a change in the base interest rate observed in the economy), so does the maximum internal financing capability in practice, increasing as the cost of money decreases (Panel C, Figure 2).

Under imperfect capital markets, when firms have to resort to external financing (as already shown in Figure 1 Panel B), the cost of capital faced by the firm is not constant but increasing with the amount of capital supplied/demanded, consistent with an upward sloping supply of capital curve (Panel B and C, Figure 2).

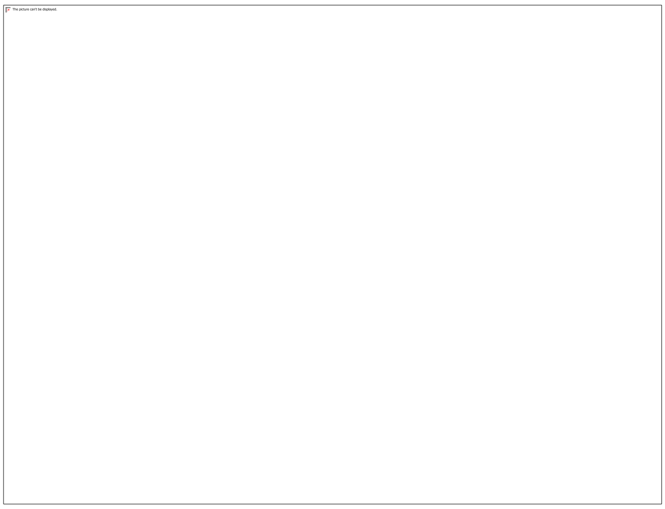
But when external financing is needed, not every firm is able to access it. There is a financing gap in which borrowing costs rise abnormally to satisfy the Secured Borrowing Condition in the absence of sufficient collateral. This financing gap affects a range of capital values above the internal financing limit and the below the minimum value necessary to be able to access external financing (Figure 2). As internal financing limits are endogenous to the cost of capital, the size of the financing gap also varies with it. The lower the interest rates in the economy, the smaller the financing gap (Panel C, Figure 2). This implies that, as interest rates rise in the economy, so does the share of firms unable to obtain secured credit.

Figure 2: Effect of investment subsidies in imperfect capital markets with secured borrowing

Panel A: Collateral requirement as only friction between internal and external financing

Panel B: i) Collateral requirement and ii) increasing cost of capital as frictions between internal and external financing

Panel C: i) Collateral requirements and ii) increasing cost of capital as frictions between internal and external financing, iii) endogenous internal financing limit



In the most comprehensive model represented in *Panel C,* firms are faced with credit market frictions leading to collateral requirements upon borrowing and an increasing cost of capital in external financing. Furthermore, their internal financing limit is endogenous, meaning that it is dependent on the cost of capital. In this model for collateral constrained firms, a decrease in the cost of capital results in a larger capital increase than for unconstrained firms internally financing their investments and for firms "pecking order" constrained (i.e., financing their capital investments via capital markets). The relative impact of a decrease in the cost of capital between unconstrained firms internally financing their investments (ΔK) and firms "pecking order" constrained (ΔK'') is uncertain and depends on a number of factors: holding the "capital inflection point" (i.e., the level of capital corresponding to the internal financing limit – K'1 in *Panel B*) unaltered from a change in the cost of capital, the steeper the external cost of capital function the smaller ΔK'' relative to ΔK. That is offset, however, by a responsiveness in the internal financing capability limits to changes in the cost of capital (*Panel C*). The balance between these two effects determines the relative impact of the change in the cost of capital, Δρ, on capital changes for these two groups of firms.

These findings can be derived analytically as follows. Additional detail on the derivation of the supply of funds curves and the associated proofs is contained in **Section A of the Appendix**.

All the firms face the same Marginal Revenue Product of Capital, i.e., the demand for capital curve, which is assumed to be downward sloping with the parameters q and x generically defining its features.

$$MRPK \quad \rho^D = q - xK$$

For unconstrained firms internally financing, the supply of capital is horizontal, perfectly elastic with respect to the cost of capital ρ

$$\rho^S = \rho$$

$$\rho^{S\prime} = \rho + \Delta\rho$$

Hence, a change in the cost of capital, $\Delta\rho$, is associated with the following change in capital, ΔK

$$\Delta K = -\frac{\Delta\rho}{x} = \Delta K^U = \Delta K$$

For constrained firms, instead, the impact of a reduction in the cost of capital changes depending on the frictions considered in the model. We will show here how the impact differs between the model presented in Panel B and the one in Panel C, with the latter being the most comprehensive model, providing the theoretical grounding for the rest of the paper.

In the model of *Panel B* firms face internal financing limits, independent from the cost of capital.

These, so called "Pecking Order" constrained, firms face the following supply of capital curve beyond their exogenous internal financing limit generically defined by parameter η

$$\rho^S = \rho - \eta m + \gamma K$$

The supply of capital for pecking-order constrained firms is upward sloping with gradient γ. The larger γ, the higher are frictions from external financing capital investments.

Hence, a reduction in the cost of capital, $\Delta\rho$, shifts down the supply of capital curve

$$\rho^{S\prime} = \rho + \Delta\rho - \eta m + \gamma K$$

And is associated with the following change in capital, ΔK

$$\Delta K = -\frac{\Delta\rho}{\gamma + x} = \Delta K^{PC} = \Delta K"$$

It is therefore possible to see how the larger γ, i.e., the steeper the supply of capital is in external markets is, the smaller ΔK^{PC} is relative to ΔK^{U}.

In the model of *Panel C*, with firms are "Pecking-Order" constrained and their internal financing limit η is no more exogenous but depends endogenously on the cost of capital.

To start, these firms face the same supply of capital curve faced by the pecking-order constrained firms

$$\rho^{S} = \rho - \eta m + \gamma K$$

But, in this case, a reduction in the cost of capital Δρ is associated with a $\Delta\eta$ increase in the internal financing limit. Therefore, a reduction in the cost of capital Δρ is associated with both a downward and leftward shift of the supply of capital curve.

$$\rho^{S\prime} = \rho + \Delta\rho - (\eta + \Delta\eta)m + \gamma K$$

$$\Delta K = -\frac{\Delta\rho - m\Delta\eta}{\gamma + x} = \Delta K^{PC+} = \Delta K"$$

Hence, it is possible to see the relationship between the parameters $\Delta\eta$ and *m* and the elasticity of capital to a change in cost of financing relative to *Panel B* model. $\Delta\eta$ represents the responsiveness of internal financing limits to changes in the cost of capital. $\Delta\eta \geq 0$ when $\Delta\rho \leq 0$, and $\Delta\eta < 0$ when $\Delta\rho > 0$. The parameter *m>0* is instead positively related to the steepness of the supply of capital curve as follows

$$m = \tan\left(tan^{-1}(\gamma)\right) = \tan\left(\arctan(\gamma)\right)$$

The steeper is the supply of capital curve, defined by gradient γ, the larger is *m.*

We can see that the greater is the responsiveness to internal financing limits from a change in the cost of financing and the steeper the supply of capital is in external markets, the larger is the increase in capital from a decrease in the cost of capital relative to the model with exogenous internal financing limits (*Panel B*).

Furthermore, in *Panel C* the relative size of $\Delta K''$ (the change in capital for pecking order constrained firms) relative to ΔK (the change in capital for firms internally financing) depends on the balance between $\Delta\rho \times \frac{\gamma}{x}$ and $m \times \Delta\eta$. With

$$\Delta K'' \geq \Delta K \; if \; \Delta\rho \frac{\gamma}{x} \geq -m\Delta\eta$$

$$\Delta K'' < \Delta K \; if \; \Delta\rho \frac{\gamma}{x} < -m\Delta\eta$$

III.b Impact of Interest rate subsidies on Employment and Output: a non-homothetic preferences approach

A standard production function Y=F(K,L) with Constant Elasticity of Substitution (CES) between Labour and Capital, homothetic preferences and perfect competition in all markets, is generally assumed in the existing body of literature empirically investigating the impact of investment subsidies on private allocation of production factors and output (Criscuolo et al. , 2019; Bernini and Pellegrini, 2011; Bernini et al., 2017). Whilst a reduction in the cost of capital is unequivocally associated with an increase in capital, as previously discussed, from the Marshallian conditions of derived demand, the impact on employment of a change in the cost of capital ($\partial L/\partial\rho$) depends on the elasticity of substitution between labour and capital (σ), the share of capital in total costs (s_K) and the absolute price elasticity of product demand (Hamermesh, 1990). Thus, the sign of the net effect on employment depends on the relative size of the scale effect (ϕ) and the substitution effect (σ), with the effect being amplified when capital accounts for a larger share of production factors (s_K).

$$\frac{\partial L}{\partial \rho} = s_K(\sigma - \varphi)$$

Under the assumption of homogeneous preferences across firm size, this framework suggests a linear expansion path in output and, therefore, a directionally homogeneous impact of a reduction in the cost of capital on employment and an optimal mix of capital and labour factors, largely dependent on their relative prices.

Criscuolo et al. (2019), Bernini and Pellegrini (2011) and Bernini et al. (2017) find that in general investment subsidies increase employment, thus suggesting that the scale effect is dominating the substitution effect. Leaving aside considerations related to the practical difficulties faced in obtaining an unbiased estimate of impact on employment given the employment conditionality clauses generally associated with the subsidy programmes[30], based on the reasoning illustrated above, this finding should be homogeneous across firm size, to be consistent with the theoretical model generally chosen to back the empirical analysis. However, larger firms are found to increase their employment, as a result of the subsidies, by less than the smaller firms, if at all. One proposed explanation of this finding is that large firms could be better at "gaming the system" and less subject to scrutiny (Criscuolo et al. 2019).

This paper investigates an alternative explanation which could help explain the empirical results found in literature across different countries, programmes and levels of institutional quality. The relaxation of the homotheticity assumption for production factor preferences is hereby tested as a more appropriate theoretical framework for investigating changes in factor prices on factor allocations and output across firms of different sizes, including also small firms.

[30] The UK RSA programme analysed by Criscuolo et al. (2019) conditions the fund to the creation or safeguard of jobs; in the L.488 subsidies programme in Italy analysed by Bernini and Pellegrini (2011) and Bernini et al. (2017) instead the number of jobs created increases the chances of obtaining the investment subsidies through the auction mechanism.

Empirically the capital-to-labour ratio has been shown to vary - even at constant price ratio (del Rio and Lores, 2018) and across firm size and sector (Leonardi, 2007). But the difficulty in the reconciliation of the result of the theoretical model with the empirical evidence is matched by an equal mismatch between the assumptions underlying homothetic preferences between labour and capital allocation and the empirically observed firm structure.

Simply put, there cannot be a firm without workers. In the most extreme case, a sole-tradership still counts one worker, the self-employed. In some sectors, regulatory and scale-barriers mean that the minimum number of workers to operate in the business is actually more than one. This implies that flexibility around factor composition reduces as the firm size shrinks, given the greater likelihood of hitting operational workforce constraints.

Homothetic preferences do not allow accounting for such constraints when assessing changes in factor allocation, in response to changes in factor prices. Sato (1977) shows that a relaxation of homotheticity allows for this and there exists a class of non-homothetic production functions still characterized by CES, of which standard homothetic CES functions are a special case. NH-CES production functions are characterised by a variable marginal rate of substitution even at constant factor prices, translating into a non-linear expansion path of preferences, as opposed to the linear expansion path of H-CES traditional production functions.

This model suggests that the balance between scale and substitution effect changes with the firm’s output level. Given a decrease in the cost of capital relative to the cost of labour, the model suggests that the substitution effect is going to be stronger in large firms than small firms. This implies that scale effects in response to that are more likely to dominate substitution effects in the context of small firms than large firms, where factor reallocation is more sensitive to changes in relative prices.

Such findings are consistent with empirical evidence presented by literature and constitute therefore a valid alternative explanation grounded in theory.

III.c Summary of Theoretical Model Results

Overall, these theoretical models provide several predictions later tested in the empirical analysis.

First, the investment subsidy (considered as an interest rate reduction) is expected to have a positive effect on investment and, therefore, capital accumulation. Secured borrowing frictions amplify the impact of investment subsidies for firms unable to finance the investment internally nor externally, as lacking sufficient amount of collateral. The theoretical model suggests that the share of firms so called “secured borrowing constrained” increases as interest rates are higher in the economy.

The impact of investment subsidies, at local level (in which *r* and *b* are constant), is expected to be related to drivers of collateral constraint, which - based on the model outlined in the previous section - means that is negatively related to the initial capital stock (i.e., size of the firm), and positively related to the firm’s probability of default (firm specific π_f, and location-sector specific $\pi_{s,l}$) and the relative size of the investment subsidised (θ). The impact of investment subsidies is also expected to be related to the share of unmovable assets $(1-\alpha)$, with the sign of their relationship depending on how the location of the business ranks in terms of demand for industrial real estate at national level (ν_l). The effect is expected to be greater, the larger the share of unmovable assets in areas with lower industrial density (associated with a less liquid market and, hence, lower recovery rate from bank repossession sales).

Second, the investment subsidy will have a positive effect on employment, if the scale effect outweighs the substitution effect. In the non-homothetic preferences model presented, this is more likely to occur in the case of smaller firms, given the smaller substitution effect they are likely to experience from a reduction in the cost of capital relative to larger firms. Furthermore, given the higher capital increase small firms are expected to experience relative to larger firms (due to size and probability of default as just discussed), scale effects are also going to be stronger for smaller firms. This suggests that, whilst uncertainty remains over the sign of the net effect on employment, the adoption of a theoretical model without homogenous preferences would suggest that investment subsidies should result in a larger increase/lower decrease in employment for small firms relative to larger firms. Likewise, the impact on output should be positive and larger for smaller firms.

IV. Empirical Identification Strategy

This paper exploits the exogenous receipt of capital subsidies, as part of a post-disaster emergency policy intervention, to derive causal estimates of the impact of investment subsidies on firms' capital, labour, output and productivity. In particular, it aims to empirically derive estimates of heterogeneous treatment effects of investment subsidies by size and other drivers of collateral constraint.

Investment subsidies have been part of the post-disaster policy toolkit in Italy since 2012, alongside long-standing state-sponsored reconstruction funding for the areas affected by natural disasters. By not being part of a specific development policy, but an emergency response to stimulate economic recovery in the areas affected by natural disasters, there is no centralised regulation defining the policy's eligibility requirements and implementation. Instead, investment subsidies are legislated in each of the emergency decrees listing post-disaster interventions. Despite the lack of a permanent programme regulation, the subsidies programme has, however, remained largely consistent and unvaried since its introduction, allowing for a comparison of outcomes across different disaster events.

This paper considers the investment subsidies provided following major earthquake disasters since 2012. This includes the 2012 earthquake in Northern Italy, the 2016 event in Central Italy and the 2017 occurrence in Abruzzo, with the subsidy programmes regulated respectively by Art. 11 D.L. 74, Art. 20 D.L. 189 and Art. 18 D.L. 8. Although major floods and landslides have also benefited from such an emergency responses, restricting the analysis to earthquakes ensures consistency in disaster dynamics across the events and leverages the destruction modelling already presented in Mari (2020) for the 2012 earthquake.

The programme provides a state-sponsored reduction in interest rate on loans undertaken to finance investments in the areas affected by the earthquake, with priority given to firms headquartered or operating in those territories, until exhaustion of the resources allocated to the local administrations. No conditionality is associated with the loans, which have a term limit of 15 years and are capped at €25 million per firm. For most municipalities the location of the investment project within that municipality constitutes the only formal eligibility requirement to access the programme, except for a few in which additional proof of damage is required. As the interest rate reduction occurs on loans financed through the banking sector, by implication, eligibility for credit from the banking sector is also associated with the programme.

In the programmes considered the eligibility for the investment subsidy extends well beyond the areas located in the near proximity of the epicentre and generally covers all municipalities that experienced a seismic intensity of at least 6 in one of the seismic shocks. The eligible municipalities without conditionality are shaded in red in **Figure 3**. In large municipalities located at the "policy border", eligibility is conditional upon additional proof of damage to business' property attributable to the seismic shock – these municipalities are shaded in green in **Figure 3**.

Figure 3: Eligibility for Investment Subsidies by NUTS 4

In this paper we exploit the exogenous receipt of these subsidies to study their impact on firm-level outcomes. In order to avoid any confounding impact associated with earthquake related disruption we consider as treated exclusively those firms which did not experience damages from the earthquake. This means that only firms receiving subsidies in municipalities in which receipt is unconditional (shaded in red in **Figure 3**) are considered treated as a start. But within those, surely the firms located nearby the epicentre have experienced destruction. A discontinuity in physical destruction is then exploited to identify those that are unlikely to have suffered from any destruction of physical capital. Looking at official data on claims for seismic disaster relief, Mari (2020) shows that below an experienced seismic intensity of 7.25 a municipality is unlikely to have experienced physical damages (**Figure 4**). We therefore consider as treated the firms located in municipalities with unconditional eligibility for subsidies but having experienced a seismic intensity of less than 7.25, thus unlikely to have suffered any physical damage to their property. This restriction crucially weakens the link between eligibility and post-earthquake business side effects (e.g., caused by a loss of productive assets, loss of customers, etc...). Concerns around the impact of the seismic shock on local demand are further addressed by estimating the treatment effects considering exclusively firms operating in trading activities, which should be unaffected by local demand dynamics.

Figure 4: Mari (2020) discontinuity in physical damages in 2012 earthquake

Figure 5: Identification set up for 2012 earthquake

The control pool is generated from firms located in municipalities not eligible for treatment within the provinces with at least one municipality unconditionally eligible for treatment (light blue shaded areas in **Figure 3**). **Figure 5** summarises the resulting identification set-up.

The existence of a geographical policy border not coinciding with NUTS 2 or NUTS 3 borders allows one to match treated firms with suitable control firms located within the same regions. This is particularly relevant in the case of Italy, being a country characterised by an elevated degree of decentralisation in which transport networks are integrated at NUTS 3 level (Mari, 2020), and NUTS 2 regional administrations are responsible for the implementation of national policies in a series of fields, including infrastructure investments, and business programmes and regulations.

The first step in the identification of treatment effects is ensuring an appropriate counterfactual to the treated firms considered. This is ensured in this paper through a matching procedure between treated firms and their associated control pools.

The matching algorithm is constrained to pair treated firms to the closest control firm operating within the same sector of economic activity, NUTS 3 region and size. This allows to estimate the policy effect at local level under the assumption of a constant risk-free rate (r) and relationship lending structure (b). Given the restrictions imposed on the selection of the treated sample (excluding firms located in municipalities having experienced seismic intensity above 7.25, associated with destruction of physical assets) we can also exclude any confounding effect of significant relocation/destruction of physical and human capital. This, together with the limited size of the programme, ensures the absence of general equilibrium effects affecting the estimates.

The constraints to the matching algorithm are not only identified on theoretical grounds but also empirically. As discussed in the previous section, eligibility for treatment occurs as a result of a random natural disaster shock, so is in itself spatially exogenous. But eligibility for treatment does not necessarily correspond with treatment, as it implies 1) an independent decision from the firm to ask for external financing for an investment project and 2) to obtain it from the banking sector. Therefore, within eligible municipalities, treatment is not fully random. Based on Company House Register's records, the treatment take-up rate is at 74% within the eligible pool.

The information available on the firms' size and sector of economic activity allows to estimate their impact on the likelihood of treatment through a propensity score measure. Within the eligible firms, being small in size and operating in the agricultural sector are two factors significantly decreasing the probability of receiving treatment (additional details contained in **Section B.2 of the Appendix**). These results are consistent with the lack of corporate financial data availability. This implies therefore first, that firms not getting treated within eligible municipalities are not a suitable control group for those which get treated, and second, that given its relevance in affecting the propensity of receiving treatment, treated firms should be matched with untreated ineligible firms characterized by the same size and operating in the same sector of economic activity and NUTS 3 region.

Subject to these three hard constraints, the match with the control pool is achieved by minimising the Mahalanobis distance for a series of firm's financial characteristics observed before the seismic shock[31]. Mahalanobis distance matching with replacement is favoured over the option without replacement in order to reduce bias; particularly given the large control pool, concerns of an associated trade-off with estimate precision are minimal. Robustness checks of the regression results between the matching option, with and without replacement, are nonetheless provided in the paper.

Instrumenting treatment status with eligibility would address any concern around the endogeneity of treatment take-up, but this is, however, not possible as there is not enough companies appearing as eligible for treatment but not treated which present corporate financial information pre-shock (needed to match them to the ineligible control pool) nor post-shock (needed to assess outcomes). This poses implications for the interpretation of the regression estimates presented.

[31] The constrained match is obtained by minimizing the Mahalanobis distance for the pre-shock 3 year average of capital level, operating revenue, estimated firm specific probability of default, number of employees, debt-to-asset ratio, debt-to-equity ratio, share of employment for the firm's sector in the firm's municipality, total assets, business density of the firm's sector in the firm's municipality, cost of employees (when available) and yearly capital growth rate (when available).

Records show that the firms eligible for treatment but non-treated are small firms, predominantly operating in the agricultural sector. The lack of treatment take-up for eligible firms could be a result of two possible scenarios: either i) the firm did not apply to a subsidized loan, suggesting that the eligible but non-treated firms are less investment-prone/growth-oriented than the treated firms, or ii) the firm applied but didn't obtain it from the bank, suggesting lower creditworthiness of eligible but non-treated firms than the treated ones as a result of potentially lower profitability, lower liquidity, higher leverage or a combination of these. The estimated impact of the investment subsidies is obtained from comparing their effectiveness on treated firms relative to matched firms from a control pool of ineligible and untreated firms. The estimated effect could be biased if the treated firm was matched to a control firm which, in case of eligibility would not have gotten treated. The Mahalanobis distance matching adopted appeases this concern. The variables[32] on which the Mahalanobis distance is minimized when optimizing the match aim to ensure the same degree of investment proneness and creditworthiness between the treated firm and the control matched firm. This thus significantly attenuates the potential for bias originating from the endogeneity associated with treatment take-up.

Furthermore, although the identification proposed makes progress in estimating the effect of investment subsidies on the average firm relative to previous contributions on the topic in literature which have been providing policy evaluation of capital investment subsidy programmes targeted to a narrow base of the corporate population (i.e. "local champions"/medium sized firms more productive than average), it falls short of estimating a global population Average Treatment Effect (ATE). This is because eligibility does not fully coincide with treatment (although the take-up rate is very high) and, as it cannot be controlled for, it allows to estimate only an Average Treatment Effect on the Treated (ATT) overall. Despite the lack of availability of outcome variables, we do know however that the entirety of the firms non-treated despite being eligible is of small size. This implies that the estimated treatment effects by firm size reported in Table 5 represent an ATE for medium and large firms, but an ATT for small firms. In the case of small firms, as pointed out above, it is not possible to know whether the ones eligible but non-treated have failed to satisfy the conditions for credit access by the banking sector or have simply not applied for financing. The inability to distinguish between these two does not allow any significant assumption on the relative size of the ATE for small firms relative to the estimated ATT.

Insights on the treatment effects are then captured through two econometric models. The first model is a simpler specification aimed at detecting heterogeneity of the investment subsidies' effect on the firm's outcomes by firm size and is specified as follows.

$$\Delta \boldsymbol{Y}_{\boldsymbol{f},\boldsymbol{t}} = \beta_0 + \beta_1 T_f + \beta_2 Small_f + \beta_3 Medium_f + \beta_4 \left(Small_f \times T_f\right) + \beta_5 \left(Medium_f \times T_f\right) + \boldsymbol{X}_{\boldsymbol{f},\boldsymbol{t}} + \varepsilon_{f,t}$$

Where $\Delta \boldsymbol{Y}_{f,t} \equiv \boldsymbol{Y}_{post-T} - \boldsymbol{Y}_{pre-T}$ is the logarithmic change in the outcome variables post-treatment, with capital, employment, output (proxied by operating revenue) and productivity (proxied by revenue per worker) being the outcomes of interest. T_f is a dummy for having received the investment subsidies. $Small_f$ and $Medium_f$ are dummies controlling for the firm size, whilst $\boldsymbol{X}_{f,t}$ is a vector of covariates including dummies controlling for the credit rating of the firm, the relative importance of the subsidised investment and the coverage ratio of the subsidy. In this model the coefficients β_4 and β_5 capture the heterogeneity of interest.

The second model, instead, aims to capture additional heterogeneity of the investment subsidies' effect by the parameters identified in the theoretical results. To do so, the treatment dummy is interacted with a series of empirical variables representing or proxying the theoretical model drivers presented in **Section III**. **Table 1** provides a summary of the mapping between the theoretical model variables and the empirical identification. These variables are also included as individual controls, like in the case of the treatment dummy.

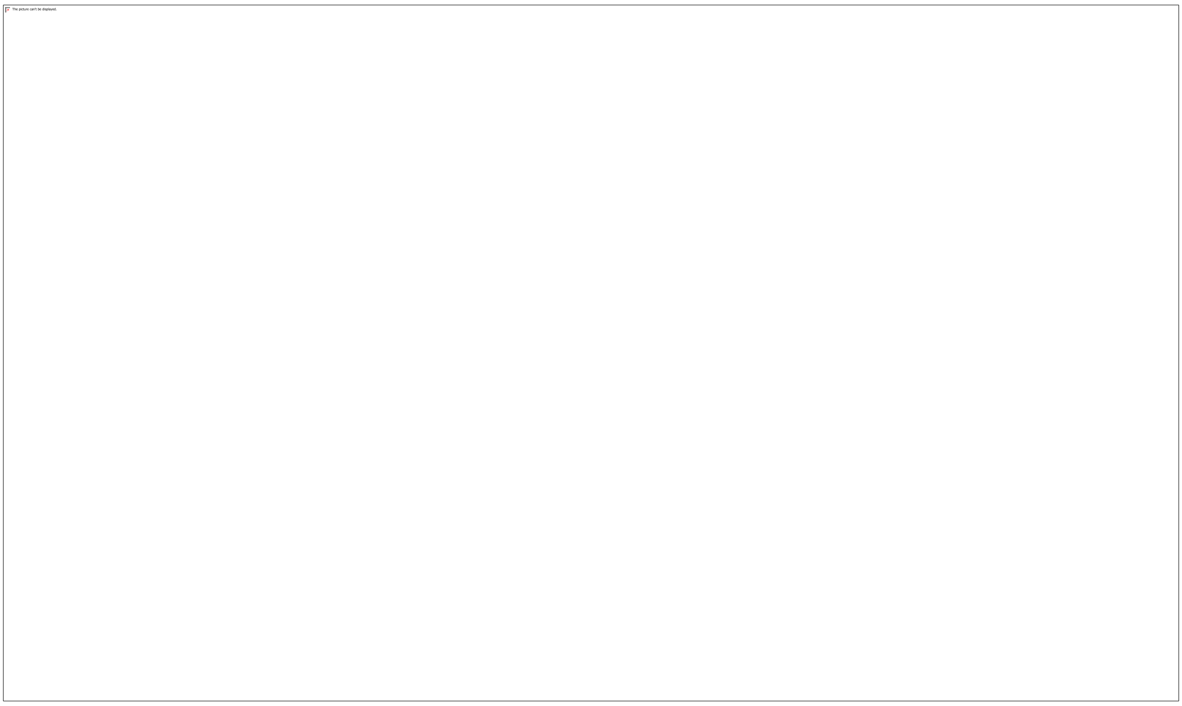
Whilst in some cases the empirical variables perfectly match the ones contained in the theoretical model, in other instances proxying or variable construction is needed, due to the lack of available data on the original model variables.

The interaction between the coverage ratio of the investment incentive and the treatment dummy aims to control for the relative intensity of treatment across the firms which received it. This is a proxy for the change in the interest rate.

The interaction between sector and size dummies aims to detect the heterogeneity of the policy impact by share of unmovable assets (1-α), which are assumed to be structurally determined by the sector and size of the firm (Chodorow-Reich et al., 2021). The interaction, instead, between sector dummies and business density aims to detect the heterogeneity of the policy impact by the location-specific recovery rate of unmovable assets (v_l). The rate of recovery of unmovable assets depends on the demand for industrial real estate with the same operational characteristics as the one that would go on sale upon default. It is assumed that the sectoral classification provides a sufficient representation of the operational characteristics of the industrial real estate a business operates from and of the associated segmentation of the industrial real estate market. The level of demand is proxied by the sectoral business density at NUTS 4 location, as it provides a good representation of agglomeration forces at local level and real estate market liquidity.

The firm-specific estimated credit rating before the treatment year is controlled through a series of dummy variables. This is obtained for the treated firms and their matched controls, by estimating a default probability from a survival model fit over the whole population of Italian firms on Historical Orbis (subject to data availability) from 1990 to 2019, and later converting it into a credit rating.

Table 1: Econometric model interactions



Additional details on the estimation of a firm's default probability and credit grade slotting are contained in **Section B.1 of the Appendix.**

V. Data

Data on the investment subsidies handed out by the Italian Government as part of the post-disaster policy package for seismic events are obtained from the OpenCup database, the official open data platform of the Italian government for public investments. A detailed discussion of the OpenCup database is provided in Mari (2022)[32]. Given the reduced coverage of the database for projects carried out in the early 2000s, we focus on investment subsidies legislated following the 2012, 2016 and 2017 earthquakes. The identification of records referring to the investment subsidies which are the object of this paper has been carried out through a text search within the database, for records covering the

[32] Mari, R. M. (2022). When Capital Falls to Pieces: Public Investment and the Role of Private Capital Stock. EMANES Working Papers, N. 64, 1-50, Appendix Section A.2.

provinces identified as eligible for the investment subsidies (**Table B1.A in Section B1 of the Appendix** contains the list of all the municipalities deemed eligible). A total of 2,416 records matched the search parameters, distributed across the regions of Abruzzo, Emilia-Romagna, Lazio, Lombardia, Marche, Toscana, Umbria and Veneto (**Table B1.B in Section B1 of the Appendix**), with details on the date of financing approval, the subsidy amount, the description and categorisation of the intervention and information on the receiving business (business name, address, sector of economic activity and tax code).

Financial data on the firms identified as receivers of the investment subsidies (2,367 unique firms) is obtained by matching OpenCup records with Orbis Historical records by tax code when available, and business name and municipality in the absence of that. Data is updated to end of 2020 balance sheets, when available. A match rate of 72% is achieved, slightly lower but comparable to the one of Bernini and Pellegrini (2011) for firms obtaining L.488 incentives. The lower match can be attributed to the fact that, whilst firms obtaining L.488 incentives are generally "local champions" given the competitive process, in this case funds were assigned exclusively on the location eligibility requirement, thus resulting in a higher share of "micro" firms obtaining them, which notably have a lower representation in Orbis Historical records.

Overall, in terms of business size[33], small firms account for 53% of the treated sample, followed by medium firms accounting for 37% (**Table 2**). Sector-wise, manufacturing is the most prevalent sector, with 47% of the sample firms engaged in that activity. Wholesale, retail trade and repair of motor vehicles and motorcycles is the second largest sector represented in the sample (19%), followed by construction activities (9%) – both sectors being characterised by prevalently small firms.

[33] The size classification adopted here closely follows the Orbis size classification. A firm is considered "very large" if it presents operating revenues above or equal to $130m, or total assets above or equal to $260m, or over 999 employees; "large" if operating revenues are above or equal to $13m, or total assets above or equal to $26m, or over 149 employees; "medium" if operating revenues are above or equal to $1.3m, or total assets above or equal to $2.6m, or over 14 employees; "small" otherwise.

Table 2: Economic Activity and Size distribution of Treated firms

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Financial data for the control pool of firms is also obtained from Orbis Historical. The control pool encompasses all the firms satisfying the following requirements: a) located within the provinces including the eligible municipalities but excluding those, b) active for at least 2 years, starting the business before 2016 and closing after 2012 (if inactive today), c) with detail on the sector of economic activity they operate in (to allow for sectoral matching with the treated sample). A result control pool of around 120,000 firms is obtained. In the control pool small firms account for 70%, a larger percentage than in the treated sample, with lower representation overall of both medium and large firms, suggesting somehow that, amongst the eligible firms, the probability of getting treated depends on size – consistent with the theoretical model on constraints to credit access. Additional details on the control pool characteristics are presented in **Tables D.1 - D.2 in the Appendix**.

Geographical coordinates data for municipalities' location is obtained from the Italian Statistical Office (ISTAT). Data on seismic intensity at municipality level for the 2012, 2016 and 2017 earthquakes is obtained through the application of Pasolini et al. (2008) seismic attenuation law over data from the Parametric Catalogue of Italian Earthquakes (CPTI15 v2.0), as detailed in Mari (2020).

The measure for business density by sector at NUTS 4 level and year is obtained from data from the Business Register of Local Units (ASIA LU) by dividing the number of local business units of a given sector *j* in municipality *i* at time *t* by the area of municipality *i*. This is then standardised at national level by subtracting the mean national business density of sector *j* at time *t* and dividing by the standard deviation observed at national level of such statistics.

$$bdens_{jit} = \frac{n.\,local\ units_{jit}}{area\ sqkm_{it}}$$

$$std.\,bdens_{jit} = \left(bdens_{jit} - mean\ bdens_{jt}\right)/st.\,dev.\,bdens_{jt}$$

The choice of the municipality surface area as denominator of the business density measure, instead of the municipality's population, aims to provide a measure of business density adequately proxying demand for commercial real estate in both rural sparsely populated municipalities and densely populated cities. This data is not available for the agricultural sector – hence, we exclude agricultural firms from the analysis, but all the remaining sectors are considered.

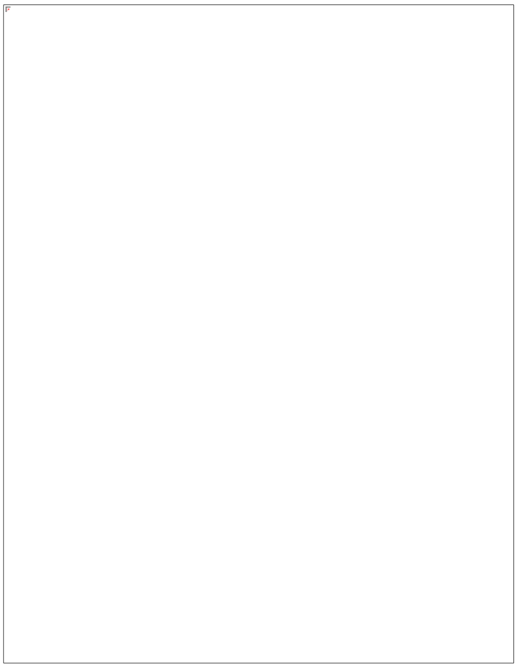
Annual estimates on firm-specific probabilities of default are the fitted values from a Cox-Proportional hazard model, stratified by firm size and calibrated over almost 30 years of historical balance sheet data on all the Italian firms with data available from Historical Orbis. These are then converted into credit ratings, as detailed in **Section B1 of the Appendix**.

Annual estimates on loan baseline probabilities of default by sector of economic activity, loan size and province (NUTS 3 region) from 2006 to 2019 are obtained using official data on default rates from Bank of Italy, territorial accounts data from the Italian Statistical Office (ISTAT) and data from the Business Register of Local Units (ASIA LU).

Data on the historical rate of annual conversions of performing loans into bad loans is commonly used as an indicator of historical probability of default (Grippa and Viviani, 2001). Bank of Italy publishes quarterly data on annual default rates by NUTS 1 region, loan size and borrower's economic activity and quarterly data on annual default rates by NUTS 3 region and loan size. Data on value added by branch of economic activity at NUTS 3 level is used to obtain a sectoral decomposition of probabilities of default at NUTS 3 level, under the assumption that province-specific risk factors, summarised by the average probability of default by loan size, are homogeneous across sector. Additional detail on the creation of probabilities of default estimates is discussed in **Section C3 of the Appendix**.

As **Figure 6** shows, the annual conversion rates to default are higher in more economically depressed areas, with an evident difference between the North and South of Italy. At sectoral level, construction activities appear to be characterised by the highest risk of default, followed by accommodation and food service activities and mining and quarrying (**Table 3**). This is in line with stylised facts of corporate risk.

Figure 6: Distribution of average loan's annual conversion rate to default by NUTS 3 region



VI. Empirical Results

Table 4 presents the mean differences for a series of firm and business location characteristics between the treated firms and the control firms (matched from the control pool) before the seismic shock. The Mahalanobis distance matching technique employed appears to be successful at eliminating most of the statistically significant differences observed from the unmatched sample (**Table D.2 in the Appendix**). No significant difference is detected between the matched treatment and control group for small sized firms. Instead, a few statistically significant differences remain between the groups in the medium and large sized categories. Those are, however, generally small and mostly associated with pre-treatment levels of outcome variables or covariates controlled for in the econometric model specification, thus they are of limited concern given the focus on changes in outcomes.

We start by estimating Model 1 (**Section IV**) to detect heterogeneity of the impact of investment incentives on the outcomes of interest by firms' size, with the results presented in **Table 5**.

The results show the effectiveness of investment incentives in stimulating investment (i.e., increasing capital) across all firm sizes. The impact is estimated to be largest for medium sized firms, followed by small and then large sized firms. Receiving the investment subsidies is associated with a 10.5% increase in capital for medium firms relative to the unsubsidised counterfactual- this comes from the sum of the impact associated with the *'Treated'* variable of 6.3% and the interaction term *'Medium x Treated'* of 4.2%. The impact is estimated to be 7.2% for small firms – and similarly derived from the *'Treated'* variable of 6.3% and the interaction term *'Small x Treated'* of 0.9 % - and 6.3% for large firms, which coincides with the impact associated with the *'Treated'* variable only.

Incentives are associated with a significantly positive impact on employment, operating revenue and productivity only for small and medium sized companies. In this instance, small firms register the highest impact, recording an increase in employment by 6.5% (coming from the impact associated with the *'Treated'* variable of -0.4% and the interaction term of 6.9%), operating revenue by 19.9% (coming from the impact associated with the *'Treated'* variable of -14.1% and the interaction term of

34%) and productivity per worker by 9.9% (coming from the impact associated with the *'Treated'* variable of -13.7% and the interaction term of 23.6%). The positive effect is, instead, substantially reduced in the case of medium firms, which register a 1.4% increase in employment (coming from the impact associated with the *'Treated'* variable of -0.4% and the interaction term of 1.8%), a 9.3% increase in revenues (coming from the impact associated with the *'Treated'* variable of -14.1% and the interaction term of 23.4%) and 7.9% increase in productivity (coming from the impact associated with the *'Treated'* variable of -13.7% and the interaction term of 21.6%). Large companies register a positive impact of incentives on capital but a negative impact on all the remaining outcomes. At the same time, the effect for large firms is insignificant on employment and, treated large firms experience revenues that, on average, are 14% lower than their untreated counterparts and show a 13.7% reduction in productivity per worker, as we can observe from the coefficient on the term *'Treated'*.

The inclusion of a control for the coverage ratio of the investment subsidy (i.e., the ratio between the subsidised part and the total investment financing cost) allows to ensure that the heterogeneity of these results is not the consequence of a differential in treatment intensity across firm size [term '*Coverage Ratio in Investment Subsidy x Treated'* in regressions 3, 6, 9, 12]. When the coverage ratio is controlled for, the estimated impact of investment subsidies on all outcomes – given by the coefficients on the term *'Treated'* and its interactions with firm size dummies - increases the most for small and large firms, somewhat suggesting a more generous investment subsidy to medium sized companies relative to small and large companies. The ranking of the effects by size remains unchanged across the outcomes of interest but, in the case of the impact of employment, only small firms register a statistically significant positive impact (regression 6). The negative impact of treatment on revenues and productivity per worker for large companies, instead becomes insignificant (regression 9).

Finally, a control is included to factor in the relative "importance" of the firm investment (i.e., as share of pre-investment capital) [term '*Subsidized Investment Size x Treated'* in regressions 2, 5, 8, 11]. A strongly significant positive coefficient is estimated for the impact on capital, consistent with the theoretical model. Furthermore, the results suggest that the subsidised investments were the largest in terms of capital increase for medium firms, followed by small and then large firms.

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The regression results are robust to the sampling specification of the matching technique, with the coefficients estimated by matching with the control pool without replacement being broadly unchanged (**Table D.3 in Appendix**). As a robustness check we also run the same regression on a sample including also firms located nearer to the epicentre (having experienced a seismic intensity above 7.25). These firms have received the investment subsidies but are likely to have experienced also structural damage and related capital destruction associated with the earthquake. The estimated effects of the investment subsidies dramatically decrease for SMEs, consistently with the negative impact on firm's outcomes associated with the post-earthquake effects (**Table D.4 in Appendix**). This provides further validation to the lack of endogeneity associated with the results presented here.

The marginal rate of substitution[34] is significantly higher amongst small firms relative to medium and large firms, even after controlling for the coverage ratio (**Table 6**). Furthermore, small firms are estimated to increase their employment by more than the increase in capital, differently from medium and large firms presenting a marginal rate of substitution below 1, although still positive. These results are particularly relevant given the absence of an employment conditionality associated with the investment subsidy programme analysed, in contrast to those previously considered in the literature. Whilst we cannot derive a definitive conclusion on it, these results provide evidence in support to the non-homotheticity hypothesis proposed in **Section II**.

[34] The marginal rate of substitution is computed as the ratio between the treatment effect on employment over the treatment effect on capital.

We then move on to test empirically the theoretical model on credit market frictions presented in **Section III** through Model 2 specification (**Section IV**). The results suggest that the local recovery rate for unmovable assets (controlled for by the business density of the sector within which the firm operates and in the municipality it is located, and proxying for the ease in liquidation/local demand) significantly affects the impact of treatment on capital growth at firm level. The relationship is estimated to be negative in the case of manufacturing and retail and hospitality, meaning that the higher the local recovery rate for manufacturing/retail/hospitality's unmovable assets at local level, the lower is the return on firm's capital growth from investment subsidies. The impact of treatment is, instead, positively associated with local demand for unmovable assets in the case of the construction sector and other services. The heterogeneity of impact across sector can be traced back to the relatively higher importance of unmovable assets, as share of total assets in the manufacturing and hospitality sectors relative to other sectors and, as consequence, the lower credit constraints firms from those sectors face when located in areas of relatively higher demand for their unmovable assets. In practice this means that upon being located in a "prime"/cluster area, firms in manufacturing, retail and hospitality sector are less credit constrained than construction or services firms (holding everything else constant) and therefore exhibit a lower return on capital growth from investment subsidies. But this equally means that firms operating in those sectors are likely to be more credit constrained than average when operating in an area characterised by low sectoral business density. This may suggest the presence of localization economies for the manufacturing, retail and hospitality sector, according to which an increase in their business density locally leads to an increase in the productivity of the businesses operating in those sectors locally, and therefore lower credit constraints.

This is consistent with the theoretical model presented in Section II, where, upon a negative differential between the local recovery rate for unmovable assets and the movable capital recovery rate, the higher the share of unmovable capital, the higher the probability of constraint to secured credit access. A higher impact from a relaxation of credit constraints, such as the one occurring from investment subsidies, should, therefore, be expected in the areas characterised by a lower expected recovery rate for sectors with high share of unmovable capital.

The regressions in **Table 7** also provide an insight into the heterogeneity by sector of the impact of treatment on small and medium enterprises. Noticeable is the higher impact of treatment, in terms of employment, output and productivity for the construction sector, relative to the other sectors. Partly, this could be due to the increase in local demand for construction services connected to seismic destruction, but only if we assume that treated construction services firms were more likely to capture the business demand in heavily damaged areas than control construction services firms. Stronger productivity gains are also experienced by the manufacturing sector and retail and hospitality services. For the latter, however, these are mostly driven by a lower impact of treatment on employment and capital accumulation, whilst output has remained unchanged.

Differences in credit rating and baseline probability of default of the sector and NUTS 3 region don't appear to have a significant impact on the treatment effect. Overall, a BB credit rating is associated with lower revenue growth relative to a firm rated as A. Lower productivity growth relative to A-rated firms is associated with both BBB and BB-rated firms. The lack of significance of credit rating on treatment effect could be attributed, in this setup, to the strong relationship between credit grade and firm size and the limited variation, observed as a consequence in the sample hereby analysed. The baseline sector-province default probability presents a positive (although insignificant) coefficient in its interaction with treatment, especially for SMEs in Table 7. This would suggest a larger impact of treatment on SMEs in particular when located in provinces characterised by higher probabilities of default associated with the sectors they are operating in. The coefficient remains positive across the board except for retail and hospitality services (negative but insignificant) in single sector regressions, acquiring significance for the utilities and construction sector (**Table D.5 in the Appendix**). Single sector regressions allow for the disentanglement of cross-sector effects from the coefficient, although these are subject to the trade-off of a smaller estimation sample.

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Section VII - Conclusions

This paper studies the impact of investment subsidies in a quasi-experimental setting exploiting a productive investment subsidies programme rolled out in response to three major earthquakes in Italy to derive causal estimates of their impact on firm outcomes. In contrast to most contributions in the policy evaluation literature, this design allows to investigate the average treatment effect and its heterogeneity across a large set of firm characteristics. The extent of collateral constraint the firm is subject to provides the key heterogeneity of interest in this paper, which is approached both theoretically and empirically. From a theoretical standpoint, this paper contributes by developing a theoretical model incorporating secured credit constraints in the framework for assessing the impact of subsidies on firm-level capital and employment decisions. Empirically, this is first approached exploring the heterogeneity of subsidies by firm size; and later by considering the other drivers of the collateral constraint brought out in the theoretical model.

The empirical evidence presents a positive impact of productive investment subsidies on capital growth for all the treated firms, with medium firms being the most strongly affected, followed by small and large firms, when not considering the relative size of the investment, but controlling for the coverage ratio of the subsidy. When controlling for the relative size of the investment, instead, large firms appear to be the ones with the highest return on capital growth from the subsidy. Other factors amplifying the impact of treatment on capital growth include the relative importance of the subsidised investment, the firm specific probability of default and, with less strong evidence, the baseline probability of default of the sector in the province (NUTS 3 region) in which the firm operates.

The location specific recovery rate for unmovable assets, proxying for their ease in liquidation/local demand, is found to significantly affect the impact of treatment on capital growth at firm level. The relationship is estimated to be negative in the case of manufacturing and retail and hospitality, meaning that the higher the recovery rate for unmovable assets in manufacturing/retail/hospitality at local level, the lower is the return on firms' capital growth from investment subsidies. The impact of treatment is instead positively associated with recovery rate for unmovable assets in the case of the construction sector and other services. The heterogeneity of impacts across sectors can be traced back to the relatively higher importance of unmovable assets as share of total assets in the manufacturing and hospitality sectors relative to other sectors and, as consequence, the lower credit constraints firms from those sectors face when located in areas of relatively higher demand for their unmovable assets. This means that firms operating in manufacturing, retail or hospitality are likely to be more credit constrained than average when operating in an area characterised by low sectoral business density.

Overall, the impact of productive investment subsidies on firm-level capital growth appears to be particularly high for SMEs; for firms operating in manufacturing, retail hospitality when operating in areas characterised by a low sectoral business density; and for firms that are generally not targeted by traditional investment subsidies programmes.

The results estimating the impact of investment subsidies on employment paint a similar picture. The incentives, to which no employment conditionality was associated, are estimated to have a strongly significant positive impact on employment only for small sized companies, with a positive impact on medium sized companies' employment becoming insignificant when controlling for differences in the coverage ratio of the subsidies. The estimated marginal rate of substitution between capital and labour of small firms is above 1 and significantly higher than those of medium and large firms, suggesting stronger impacts on employment from the intervention when targeting small firms.

Smaller firms, therefore, not only appear to be amongst those realising the largest marginal increases in investment following the receipt of investment subsidies, but they also seem to be the ones recording the largest marginal expansion of their work force. This appears to be a result of larger scale effects (driven by the larger gains in terms of capital) and lower substitution effects.

This paper innovatively contributes to the literature studying investment subsidies by adopting an identification strategy which allows to test the policy impact over a local population of firms, absent any productivity, size or employment-based targeting and conditionality characterising the majority of existing policy-evaluation contributions in the literature. The sample of firms object of this analysis ranges across different sizes and sectors and on a broader set of dimensions than what has been explored in previous literature contributions. This also allows to delve deeper on the optimal targeting of public investment subsidies studying the policy effect in the context of credit market frictions, particularly those arising from secured access to credit.

The quasi-experimental nature of the estimation however comes with its caveats in terms of external validity of the estimates hereby presented. The treatment effects presented are derived within the credit market and business environment of Central Italy between 2012 and 2019 from firms located adjacent to an area affected by large scale destruction. Directionally, this is likely to imply that the estimated treatment effects could be a lower bound. The identification strategy hereby adopted could, in fact, bring in slightly underestimated impacts on output and employment if treated firms (located in the outmost border of the "disaster area") were more integrated with heavily damaged firms located nearby the epicentre than control firms were (located just outside the "disaster area"). This is except for firms operating in the construction sector for which instead the results could be suffering for a positive bias due to an increase in local demand for construction services, but only if we assume that treated construction services firms were more likely to capture the business demand in heavily damaged areas than control construction services firms. The inability to accurately observe the firms eligible but not treated, due to the lack of data, means the estimates obtained in this paper do not fully represent an average treatment effect, but an average treatment effect on treated, although with a very large treatment base, much wider than the one generally observed in research papers studying the impact of public investment subsidies programmes. Overall, the identification adopted makes progress on the ability of identifying an unbiased causal effect of investment subsidies relative to previous literature contribution but it comes somewhat at a cost in generality. The specific post-disaster context in which results are derived however is likely to become more and more relevant in the future as natural disasters increase in frequency as a result of climate change.

Overall, the findings suggest that there could be benefits in adopting productive investment subsidies more widely as a policy tool than what they are generally targeted to. The results show that SMEs located in depressed areas characterised by low sector-specific business density realise some of the highest returns from productive investment subsidies in terms of capital, employment, revenue and productivity growth. The often observed strict targeting of capital subsidies to large/medium sized firms characterised by high productivity appears therefore not to grant the best value for money in terms of local employment and capital creation and would benefit from being loosened or having its focus entirely pivoted towards SMEs. We appreciate that screening SMEs for capital subsidies may pose higher challenges than large-medium firms, but if anything, this paper shows that even universal, unscreened allocation could grant higher returns overall, although probably at the cost of higher rates of default post-subsidy.

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Appendix

Section A – Theoretical Model

A1. Mathematical proofs for supply of capital curves and impact of subsidies on capital formation

Given, a standard downward sloping demand for capital,

$$MRPK \quad \rho^D = q - xK$$

A) For <u>unconstrained firms internally financing</u>,

$$\rho^S = \rho$$

In equilibrium, $\rho^S = \rho^D$

$$\rho = q - xK$$

$$xK = q - \rho$$

$$K = \frac{q - \rho}{x}$$

Given a change $\Delta\rho$,

$$\rho^S = \rho \rightarrow \rho + \Delta\rho$$

$$\rho + \Delta\rho = q - xK$$

$$xK = q - \rho - \Delta\rho$$

$$K = \frac{q - \rho - \Delta\rho}{x}$$

Hence,

$$\Delta K = \frac{q - (\rho + \Delta\rho)}{x} - \frac{q - \rho}{x} = -\frac{\Delta\rho}{x}$$

B) For Pecking Order constrained firms (see Box A for proof to obtain the supply of funds curve for constrained firms),

$$\rho^S = \rho - \eta m + \gamma K$$

$$\rho - \eta m + \gamma K = q - xK$$

$$(m + x)K = q - \rho + \eta m$$

$$K = \frac{q - \rho + \eta m}{\gamma + x}$$

Given a change $\Delta\rho$,

$$\rho^S = \rho - \eta m + \gamma K \rightarrow \ \rho + \Delta\rho - \eta m + \gamma K$$

$$\rho + \Delta\rho - \eta m + \gamma K = q - xK$$

$$(\gamma + x)K = q - \rho - \Delta\rho + \eta m$$

$$K = \frac{q - \rho - \Delta\rho + \eta m}{\gamma + x}$$

Hence,

$$\Delta K = \frac{q - (\rho + \Delta\rho) + \eta m}{\gamma + x} - \frac{q - \rho + \eta m}{\gamma + x} = -\frac{\Delta\rho}{\gamma + x}$$

C) For <u>Pecking Order constrained firms and Endogenous Internal Financing Limits</u> (see Box A for proof to obtain the supply of funds curve for constrained firms),

Given a change $\Delta\rho$,

$$\rho^S = \rho - \eta m + \gamma K \rightarrow \rho + \Delta\rho - \eta m - m\Delta\eta + \gamma K$$

$$\rho + \Delta\rho - (\eta + \Delta\eta)m + \gamma K = q - xK$$

$$(\gamma + x)K = q - \rho - \Delta\rho + (\eta + \Delta\eta)m$$

$$K = \frac{q - \rho - \Delta\rho + (\eta + \Delta\eta)m}{\gamma + x}$$

Hence,

$$\Delta K = \frac{q - (\rho + \Delta\rho) + (\eta + \Delta\eta)m}{\gamma + x} - \frac{q - \rho + \eta m}{\gamma + x} = -\frac{\Delta\rho - m\Delta\eta}{\gamma + x}$$

Comparing the relative size of ΔK(C) and ΔK(A),

$$\Delta K(C) - \Delta K(A) = -\frac{\Delta\rho - m\Delta\eta}{\gamma + x} - \left(-\frac{\Delta\rho}{x}\right) = \frac{-x\Delta\rho + xm\Delta\eta + \Delta\rho(\gamma + x)}{(\gamma + x)x} = \frac{\gamma\Delta\rho + xm\Delta\eta}{(\gamma + x)x}$$

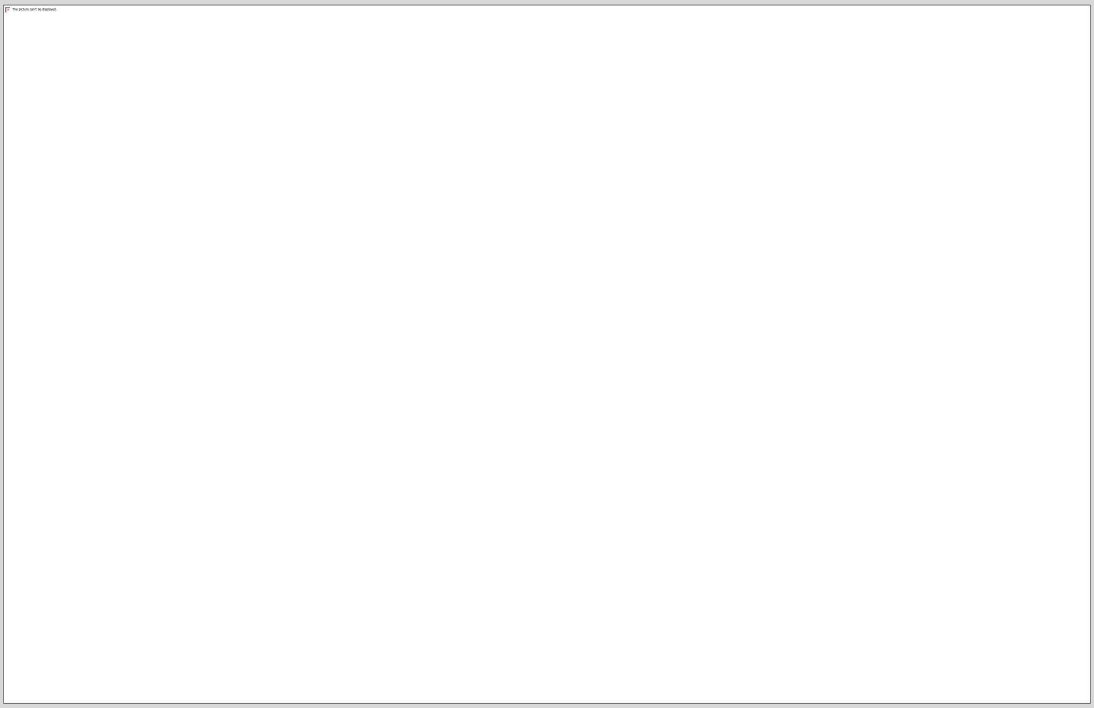
$$As\ \gamma + x > 0\ and\ x > 0,$$

$$\Delta K(C) - \Delta K(A) > 0 \quad if \quad \Delta\rho\frac{\gamma}{x} > -m\Delta\eta$$

$$\Delta K(C) - \Delta K(A) < 0 \quad if \quad \Delta\rho\frac{\gamma}{x} < -m\Delta\eta$$

Box A: Derivation of supply of funds curve for Pecking order constrained firms with endogenous internal financing limits

Figure A: Trigonometric solution



- The endogenous financing limit does not affect the extent of pecking order constraint → the slope of the external financing segments remains at γ
- Given $b = \Delta\eta(\rho) = \Delta\eta$ and angle $\hat{1} = \arctan(\gamma)$, $\hat{1} = \hat{3}$ as adjacent and $\hat{2} = \hat{3}$ as opposite, hence $\hat{1} = \hat{2} = \hat{3} = \arctan(\gamma)$
- It follows that $a = -b \times \tan(\arctan(\gamma)) = -\Delta\eta \times m$ as we set $\tan(\arctan(\gamma)) = m$

Same logic applies to the derivation of the supply of funds for pecking order constrained firms without endogenous internal financing limits, in which the downward shift in the intercept of the supply of capital relative to the unconstrained one is $-\eta m = -\eta \times \tan(\arctan(\gamma))$

A2. Non-Homothetic CES Production Functions (Sato, 1977)

Under homogeneity, competitive markets and Hicksian neutral technological progress, a CES production function's marginal rate of substitution between labour and capital (ω) is related to factor allocation as follows:

$$\log(k) = \log(a) + \sigma \log(\omega)$$

Where *k* is the capital-to-labour ratio (K/L) and σ is the CES between labour and capital.

Sato (1977) shows that there exists a class of non-homothetic production functions still characterized by CES, of which standard homothetic CES functions are a special case.

NH-CES production functions are characterized by a variable marginal rate of substitution even at constant factor prices, translating into a non-linear expansion path of preferences (Panel B, Figure A2), as opposed to the linear expansion path of H-CES traditional production functions (Panel A, Figure A2).

Figure A2: Expansion paths for Production Functions with Constant Elasticity of Substitution

Panel A: CES Homothetic Preferences

Panel B: CES Non-Homothetic Preferences

Sato (1977) provides an in-depth discussion of the properties and different classifications of the class of NH-CES production functions. For the purposes of this paper, it is assumed that firms operate according to a production function characterized by a constant non-homotheticity parameter, CES between factors of production and asymptotical behaviour in L (as in **Panel B of Figure 3**). This corresponds to the following functional form[35]:

$$Y^{\zeta} = \frac{b - L^{-\psi}}{s_K K^{-\psi} - a}$$

$$\psi = \frac{(1-\sigma)}{\sigma}$$

Such functional specification retains positive but decreasing marginal products of capital and labour like in the case of a standard H-CES/Cobb-Douglas functions commonly adopted in the literature. It differs however, as discussed, in the marginal rate of substitution (ω) between capital and labour, which is equal to,

$$\omega = \frac{\partial Y/\partial L}{\partial Y/\partial K} = \frac{Y^{-\zeta}}{s_K}\left(\frac{K}{L}\right)^{1/\sigma}$$

and is log-linearizable as follows,

$$\log(k) = \sigma\log(s_K) + \sigma\log(\omega) + \sigma\zeta\log(Y)$$

Where *k* is K/L as before, *Y* is the output level, s_K is the share of capital in total costs, σ is the CES between labour and capital, and *a* and *b* are constants. Y^{ζ}provides a constant homotheticity parameter for the variation of the Marginal Rate of Substitution with output.

[35] To be valid (i.e., $Y \geq 0$) over the domain $K, L \in [0, +\infty)$, the following condition of existence applies: either $b \leq 0 \ \vee a \geq 0$, or $b \geq 0 \ \vee a \leq 0$.

Section B – Econometric Modelling Strategy

B1. Survival Model

A Cox-Proportional hazard model, stratified by size of the firm, $h(t, \boldsymbol{X}(t), \boldsymbol{\beta}) = h_0(t)\ exp(\boldsymbol{\beta} \cdot \boldsymbol{X}(t))$, is used to estimate firm-specific probabilities of default for the firms in the treated and control group. In order to do so, the hazard model is calibrated on the whole sample of firms in Italy, with records on Orbis from 1990 to 2019. This is consistent with other literature applications (Ferragina et al, 2014 in the context of Italy) and there is evidence pointing to the higher performance of Cox-Proportional hazard models over alternative techniques in credit scoring for retail credit (Dirick, 2017).

In this application, the hazard is represented by default. For ease, the model is estimated in terms of survival probabilities (**Table B1.C**) and then converted into default probabilities. The annual survival probability at time *t* for firm *f* ($s_{f,t}$), corresponding to the complement of the probability of default, is a function of s_0 representing the baseline probability of survival, and $X_{f,t}$ is a vector of covariates affecting firm survival.

$$s_{f,t}|age_{f,t} = s_{0,t}|age_{f,t} \cdot exp\left(\boldsymbol{\beta}'\boldsymbol{X}_{f,t}\right) + \epsilon_{f,t}$$

$$s_{f,t} = 1 - \pi_{f,t}$$

$age_{f,t}$ is defined as the difference between the year of observation and the year of entry, with the latter obtained in practice from the first year for which balance sheets records are available.

Stratification occurs at size level, with four size categories, "Very Large", "Large", "Medium" and "Small". The classification of firms in each of these age categories is based on Orbis classification detailed in footnote 5. **Table B1.A** and **table B1.B** show how larger firms tend to be around for longer on average and are characterised by lower credit risk indicators.

The vector $\boldsymbol{X}_{f,t}$ contains splines of indicators of leverage and liquidity of the firm (**Table B1.D**) plus time effects, constructed as follows.

- Leverage: proxied by a 3 nodes spline for the ratio of debt to total assets based on percentiles
- Liquidity: proxied by a 3 nodes spline for the ratio of debt to equity based on percentiles
- Time effects: controlled through year dummies

A spline function applied to variable *x* with 3 nodes at x_1, x_2, x_3, generates four segmentations of variable *x* as follows:

$$splineX1 = \begin{cases} x_1 \; if \; x \geq x_1 \\ x \; if \; x < x_1 \end{cases}$$

$$splineX2 = \begin{cases} x_2 - x_1 \; if \; x \geq x_2 \\ x - x_1 \; if \; x_1 < x < x_2 \\ 0 \; if \; x \leq x_1 \end{cases}$$

$$splineX3 = \begin{cases} x_3 - x_2 \; if \; x \geq x_3 \\ x - x_2 \; if \; x_2 < x < x_3 \\ 0 \; if \; x \leq x_2 \end{cases}$$

$$splineX4 = \begin{cases} x - x_3 \; if \; x > x_3 \\ 0 \; if \; x \leq x_3 \end{cases}$$

A default event is recorded at the year of exit. Although this approach directly links firms' default to exit, with that in reality not being necessarily coincidental, this is common practice in credit risk models.

The continuous measure of probability for default obtained from the fitted model is then "slotted" into a credit rating (**Table B1.E**) in order to appropriately account for non-linearities and threshold effects in the credit risk associated with the firm by the banking sector.

Figure B1: Survival functions by size

B2. Propensity Score for Treatment

As in most cases, in this empirical set-up, eligibility for treatment does not correspond necessarily to treatment, given that it implies an independent decision from the firm to ask for external financing for an investment project and to obtain it from the banking sector.

As a result, within eligible municipalities, treatment is not perfectly random.

It is necessary, therefore, to identify the factors affecting propensity of treatment, in order to match treated observations to the control pool characterised by the same propensity – had they been eligible for treatment.

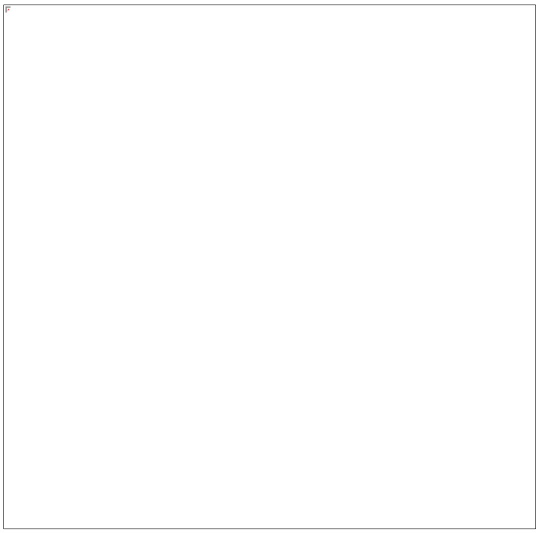
This is done by estimating a probit model predicting the probability of receiving treatment conditional on eligibility ($P(T_{it}|E = 1)$) over a dummy for being a small sized firm in the year prior to the shock, as well as a series of sector dummies controlling for operating in agriculture (NACE 2 code A), industrials (NACE 2 codes B, C, D, E), construction (NACE2 code F) and consumer services (NACE 2 codes G, H, I), omitting other services to avoid multicollinearity.

$$P(T_{it}|E = 1) = \beta_1 small_{i,t-1} + \beta_2 agri_i + \beta_2 industrial_i + \beta_2 construction_i + \beta_2 consumer\_services_i + \varepsilon_i$$

The results suggest that being a small firm significantly negatively affects the probability of getting treated, despite being eligible. Given the structure of the incentives programme, this is not surprising. Given the higher riskiness, small firms are more likely to be denied credit from the banking sector, which remains an entry barrier to the treatment (although lowered, given the interest rate subsidy, than in the case of a standard loan). Furthermore, small firms might also have a lower propensity to invest.

At sectoral level, operating in the agriculture sector is associated with a significantly lower probability of receiving treatment.

These results suggest the need to ensure size and sector pairing when matching treated firms to the control pool. They cannot, however, be applied directly in a propensity score matching set-up, given the limitation of the control group underlying this probit specification. The eligible but untreated firms' sample is, in fact, obtained from Orbis database, as the firms located in the eligible municipalities do not correspond to a match with those receiving the subsidies registered on the public procurement database. This approach inevitably underestimates the size of the control group, particularly for small firms, given the non-mandatory filing of information on Orbis relating to the city the firm operates from. Furthermore, the lack of a sufficiently sized control sample, paired with the scarcity of financial information for small firms, make it impossible to account for a broad range of financial characteristics in the calibration of the propensity to get treated, which are likely to be relevant.



Section C – Data

C1. Investment incentives data

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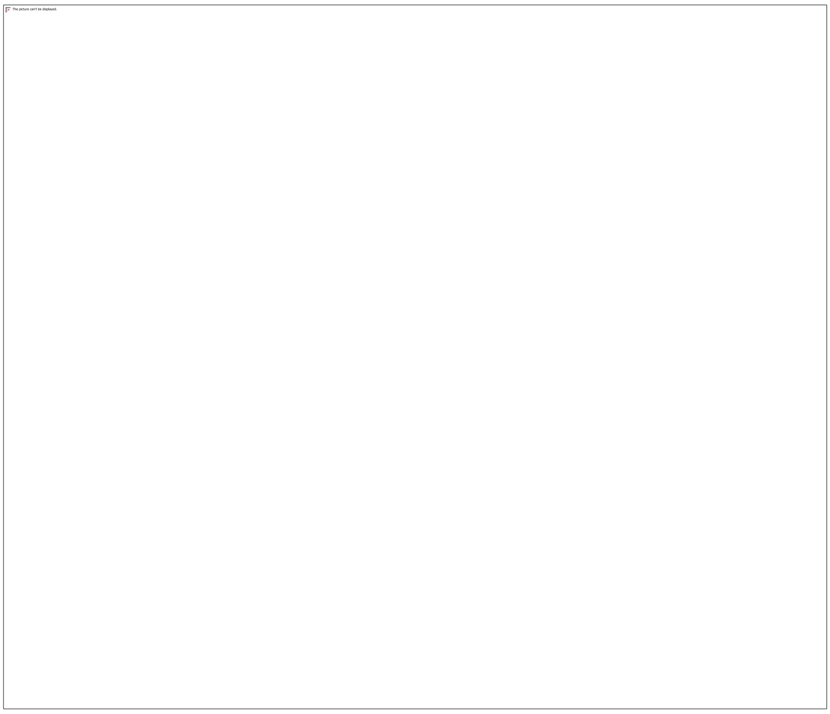
C2. Business density data

Figure C2: Top NACE 2 business density by percentile rank at NUTS 4



C3. Probabilities of default data

Annual estimates on loan probabilities of default by sector of economic activity, loan size and province (NUTS3 region) from 2006 to 2019 are obtained using official data on default rates from Bank of Italy, territorial accounts data from the Italian Statistical Office (ISTAT) and data from the Business Register of Local Units (ASIA LU).

Data on the historical rate of annual conversions of performing loans into bad loans is commonly used as an indicator of historical probability of default, π (Grippa and Viviani, 2001).

$$\pi_{it} = \left(\frac{n.of\ loans\ defaulted\ in\ year\ t, which\ were\ performing\ in\ year\ t-1}{n.of\ loans\ performing\ in\ year\ t-1}\right)_{it}$$

Bank of Italy publishes quarterly data on annual default rates by NUTS1 region, loan size and borrower's economic activity and quarterly data on annual default rates by NUTS3 region and loan size. The NACE 2 sectoral decomposition of probabilities of default at NUTS 3 level used in this paper is obtained using data on value added by branch of economic activity at NUTS3 level[36] under the assumption that province-specific risk factors, summarised by the average probability of default by loan size, are homogeneous across sector.

For any given territorial unit *i*, the average probability of default in year *t* can be considered as the weighted average of probabilities of default by NACE 2 sector of economic activity *s* in year *t*, with the weights (w_{sit}) being the share of borrowing represented by sector *s* in year *t*.

$$\bar{\pi}_{it} = \sum_{s=1}^{n} w_{sit}\pi_{sit}$$

Given the absence of granular data on the share of borrowing by sector and province (NUTS 3 region) over time, we approximate w_{sit} by the contribution to total value added at regional level *i* by sector *s*.

$$w_{sit} \cong s_{sit}$$

$$s_{sit} = \frac{VA_{sit}}{VA_{it}}$$

Therefore,

$$\forall\ NUTS\ 1\ region, i = m \qquad \bar{\pi}_{mt} \cong \sum_{s=1}^{n} s_{smt}\pi_{smt}$$

[36] An additional complication is created by the imperfect match between the NACE 2 sectoral decomposition of probabilities of default by microregion (NUTS 1) and the decomposition of value added by branch of economic activity and province (NUTS 3). Whilst the former has details for every NACE 2 individual primary code except U (ie. A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T), the contributions of value added are aggregated for some codes at NUTS 3 level (BDE, GHI, MN, OPQ, RS). In those cases, except for sector O (public employment), the relative shares of each sector contributing to the aggregated sectoral detail for value added data is proxied by the relative share of employment (employees and employed) in that sector at province level obtained from municipality level data from the Business Register of Local Units (ASIA LU). In the case of sector O (public employment), the share of O within OPQ at NUTS3 is assumed to be the same as that observed at NUTS1 level.

A difference between the average observed PD and the sectoral PD for every sector and year at macro-region would deliver consistent sectoral spreads consistent at macro-region level (calibrated on the average) but would ignore the differences in sectoral composition between each individual province and the macro-region they belong to. This can lead to substantial estimation error for provinces with a heavier prevalence of high risk or low risk activities within the macro-region. To solve this problem a decomposition approach akin to Oaxaca is applied which aims to control for sectoral composition differences when generating sectoral spreads calibrated on the average PD.

Through data on the probability of default by sector *s* and macro-region (NUTS 1) *m* for every year *t* and the shares of value added by sector s at provincial level (NUTS 3) *p*, it is possible to obtain an indicator by province of the average probability of default calibrated on macro-region sectoral PDs adjusted to reflect the province's sectoral decomposition ($\widehat{\bar{\pi}_{m(p)t}}$). This indicator is used to obtain provincial sectoral composition-adjusted default spreads by sector (ds_{pst}), which are then used to decompose the average probability of default by province p and year t obtained from Bank of Italy data.

$$i = p \; for \; NUTS \; 3 \; regions, m \; for \; NUTS 1 \; regions$$

$$\bar{\pi}_{mt} \cong \sum_{s=1}^{n} s_{smt} \pi_{smt}$$

$$\widehat{\bar{\pi}_{m(p)t}} = \sum_{s=1}^{n} s_{spt} \pi_{smt}$$

This indicator is then used to obtain provincial sectoral composition-adjusted default spreads by sector (ds_{pst}), which are then used to decompose the average probability of default by province *p* and year *t* ($\bar{\pi}_{pt}$) obtained from Bank of Italy data.

$$\forall s,t \quad ds_{pst} = \frac{\left(\pi_{mst} - \widehat{\bar{\pi}_{m(p)t}}\right)}{\widehat{\bar{\pi}_{m(p)t}}}$$

$$\pi_{pst} = \bar{\pi}_{pt}(1 + ds_{mst})$$

The estimates of probability of default sector and time at provincial level thus obtained encompass information on the relative sector riskiness observed at macro-region controlling for differences in relative sector composition. Through this approach, positive (/negative) differences in the average provincial PD relative to the macro-region they belong to, which are not explainable by differences in sectoral composition, are attributed to a higher (/lower) probability of default across every sector, holding spreads to the average constant.

Section D – Additional Tables

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SMEs under Water

The Impact of Households' Capital Shocks on SMEs

I. Introduction

This paper contributes to the literature studying the relationship between households and the corporate sector and the transmission of risks from the housing market to the broader economy. In particular, this paper explores the impact of a negative shock to SME entrepreneurs' private real estate capital on their SMEs and its sensitivity to indicators of regional resilience.

Whilst literature is rich in contributions studying the impact of a positive shock on housing valuation on entrepreneurship, scarcer is empirical evidence documenting the impact of a negative shock. The study of negative shocks is particularly important given the higher risk associated with those in terms of consequences they can have on the economy as a whole, but empirically it poses a few additional challenges. First, negative shocks tends to be highly correlated to local demand effects, which are hard to disentangle from macro-regional price data. Second, whilst a positive shock is associated with investment and start-up of new business ventures (Bahaj et al., 2020; Jensen et al., 2022; Berggren et al., 2018; Chaney et al., 2012; Adelino et al., 2015), both of which are observable also at aggregate level, a negative shock is not going to translate directly in business destruction, but it is much more likely to result in liquidity and credit rationing issues at firm level (Adelino et al., 2015). This paper therefore aims to fill this gap in literature by adopting a granular approach. Through the use of firm-level high-frequency data, we can, not only convincingly exploit exogenous shocks, but also observe the transmission of the shock over time and have an insight on both short-term and medium-term dynamics, which is not possible in the case of annual observations most literature contributions are based on.

Empirical evidence is obtained in the context of the United Kingdom, exploiting floods as exogenous shocks to entrepreneurs' residential real estate private capital. Monthly data on SMEs' business current and borrowing accounts at UK major banks is used to assess the impact of the shock on the firms' business continuity, access to credit and medium-term investment behaviour.

The results suggest a significant impact of a flooding shock to the entrepreneur's home onto the SME's business activities. Immediately after the shock we observe a temporary reduction in the firms' current account balances, and a temporary increase in firms' borrowing accounts' balances, particularly in the case of collateral backed ones. Over time the firm's revenues revert to counterfactual trends, potentially suggesting a temporary disruption caused by the flood to the entrepreneur's ability to conduct their business. Secured borrowing however, following the pick-up in the quarter after the shock, significantly decreases, and deteriorates further over the horizon.

Existing literature suggests different channels through which the transmission of the shock can occur, among which changes in risk aversion, wealth effects and the use of personal assets as collateral in business' credit access. The identification design adopted does not fully allow to attribute the shock transmission to one channel over the other, but such findings are consistent with an increase in risk aversion motivating precautionary borrowing and/or anticipation effects immediately after the shock, followed by a credit contraction from the banking sector, as a result of collateral revaluation around six months after the treatment. Indicators of local resilience and financial constraint for the local authority in which the firm operates are found to significantly affect the estimated treatment effect. Higher local unemployment pre-shock is associated with a lower credit limit for unsecured borrowing and lower firm's revenues for treated firms, still persisting two years after the shock. Operating in a rural area is instead associated with a lower current account balance for treated firms two years after the shock and a higher increase in unsecured borrowing straight after the shock which does not appear to get offset over time.

The paper is structured as follows: Section II provides an overview of the existing literature of reference, Section III introduces the paper's methodology where the econometric identification strategy, and Section IV details the sources of data employed in this paper. Results are discussed in Section V, followed by conclusions presented in Section VI. This paper includes an Appendix where additional technical details on the dataset underlying the analysis are provided.

II. Literature Review

This paper contributes to the literature studying the development of entrepreneurship at local level and particularly the link between entrepreneurship and housing markets.

Literature has conceptualised the relationship between entrepreneurship and housing markets through three main channels: the 'collateral' channel, the 'equity' channel and the 'wealth' channel.

The 'collateral' channel arises as a result of financial frictions to which the business is exposed and, as a result, is particularly relevant in the case of SMEs. In the presence of financial frictions, collateral pledging enhances a firm's financing capacity (Barro, 1976; Stiglitz and Weiss, 1981; Hart and Moore, 1994), especially with regards to its ability to access credit through the banking sector. Financial frictions in bank lending are particularly acute for small firms, due to the lower reliability of their balance sheet information (Kashyap et al., 1993; Gertler and Gilchrist, 1994).

Furthermore, whilst larger firms can often draw on their sizeable fixed assets, including corporate real estate property and machineries, in addition to inventory and, at times, accounts receivables, smaller firms are more likely to be collateral constrained lacking insufficient amounts of assets pledgeable as collateral (Chodorow-Reich, 2022).

When faced with collateral constraints, literature documents the widespread use of the entrepreneur's home equity as collateral to obtain credit from the banking sector (Chaney et al., 2012).

This is particularly common in the case of SMEs, not just because of their higher likelihood to face collateral constraints, but also because of the higher financial frictions they face with respect to the banking sector as a result of information asymmetry (Chodorow-Reich, 2022). This, therefore, generates a relationship between the housing market and the development and conduction of entrepreneurial activities, in particular of smaller size (i.e., SMEs).

Home-ownership enables the use of the entrepreneur's real estate residential assets as collateral for the financing of his firm's business activities. The collateral channel plays a meaningful role in the financing of both start-up costs and business investment when faced by a shortfall of internal collateral needed to access credit externally.

Bahaj et al. (2020) are the first to investigate the household real estate-firm collateral channel at firm-level in the UK and find a significant relationship between variation in the valuation of directors' homes and firms' investment behaviour, with this relationship being stronger in the case of SMEs. They estimate that a 1% increase in value of residential real estate of SMEs directors is associated with a 0.21% increase in UK aggregate investment demand. They also find that high loan-to-value mortgage ratios are associated with a higher sensitivity of entrepreneurship activities to changes in house valuation relative to low loan-to-value ratios.

At times, however, entrepreneurs don't limit themselves to pledging their homes as a guarantee/collateral for their business' credit lines, but re-mortgage the house, 'extracting equity' to start a business or expand it – the 'equity' channel. Differently from the 'collateral' channel described above, a re-mortgage does not involve a judgement on the expected returns of the business activity from the banking sector, but predominantly lies on the revaluation of the residential property on which the re-mortgage occurs (and the future prospects of that). This means that this option can be

entered into if a commercial loan is refused or, at times, can be cheaper than applying for a commercial loan (Reuschke and Maclennan, 2014). Jensen et al. (2022) present evidence of re-mortgaging supporting business generation in Denmark by studying the impact of a reform allowing outright home-owners to take out a mortgage and use the proceeds for any purpose, not just for buying a house. They find that those benefiting from the reform experienced an increase in entry into entrepreneurship by 14% relative to those who did not benefit from unlocked collateral. In the US context, Kerr et al. (2015) show that equity withdrawal overall appears to be a negligible channel when it comes to business creation and expansion, contrary to the collateral channel. Similar to Kerr et al.'s findings, mortgage refinancing appears to be mostly used to finance durables consumption or house alterations/improvements in the UK rather than supporting business creation (Maclennan and Tu, 1998; Parkinson et al, 2009; Benito, 2009; Smith and Searle, 2008). This is particularly the case since the Global Financial crisis as regulation in the UK has significantly restricted the usage of residential mortgages and housing equity for business funding (Reuschke and Maclennan, 2014).
Reuschke and Maclennan (2014) find that in the UK in 2010/2011 only 3.1% of remortgager households did so for business purposes and the rate decreased from 3.5% observed in 2005/2006. This therefore appears as a negligible channel for shock transmission between housing markets and the corporate sector in the UK context.

Finally, as housing constitutes an important part of an individual's wealth, housing markets influence entrepreneurial decisions through their impact on the entrepreneur's wealth – the 'wealth' channel. The positive linkage between individual wealth and entrepreneurship is widely documented in literature. Two distinct channels, at least, appear to be contributing to this. First, there exist non-pecuniary benefits associated to entrepreneurship, such as flexibility around working hours, lack of a boss and personal ownership of ones' work achievements (Hurst and Pugsley, 2011; Benz, 2009; Astebro et al., 2014). Hurst and Pugsley (2015) show how entrepreneurship can be considered a normal good, thus "consumed" in larger quantities from wealthier individuals. Second, wealth decreases risk aversion (Kihlstrom et al., 1981; Evans and Jovanovic, 1989). This is a result of the higher income uncertainty and probability of facing liquidity constraints at lower levels of wealth (Guiso and Paiella, 2008; Ashcroft et al., 1991, 2007). Paravisini et al. (2016) indeed find that a negative housing wealth shock increases investors' risk aversion. Bracke et al. (2018) find that the presence of a mortgage loan still outstanding over a property diminishes the likelihood of entrepreneurship by amplifying risk aversion. This, they argue, can also occur with an increase in house prices under no change in household wealth, which inevitably becomes associated with a higher mortgage burden. They find also that the negative relation between mortgage debt and entrepreneurship increases with income volatility or higher correlation of the income with house prices.

Whilst literature is rich in contributions studying the impact of an increase in housing valuation, scarcer is empirical evidence documenting the impact of a negative housing valuation shock on entrepreneurship. This paper aims to fill this gap adopting a granular approach. Such an approach is warranted by the type of question itself, as if an increase in the property value can be associated with investment and start-up of new business ventures, both of which are observable also at aggregate level, a decrease in property value is not going to translate directly in business destruction, but it is much more likely to result in liquidity and credit rationing issues at firm level.

This paper aims to provide a contribution also to economic geography literature by investigating how the transmission of a negative capital shock changes on the basis of regional/local characteristics. The field has already studied extensively the role of housing markets in shaping differences in regional performance, both from differences in initial conditions (i.e., shares of home-ownership) and responsiveness to shocks (i.e., changes in house prices) and it has delved into the determinants of regional economic resilience. The contribution of this paper positions itself in between these two streams of work whose main arguments are hereby presented.

At regional level, there is a significant body of literature finding that higher home-ownership rates are associated with higher rates of self-employment and entrepreneurship (Laamanen, 2018; Reuschke, 2016) and higher rates of business survival (Robson, 1996). This is predominantly attributed to the collateral channel and the wealth channel operating at individual-level just discussed.

But economic geography literature discusses also how labour markets represent an additional potential channel shaping this relationship at regional level. Higher regional home-ownership has been estimated to cause worse labour market outcomes through significant negative externalities (Oswald, 1996; Blanchflower and Oswald, 2013). Blanchflower and Oswald (2013) observe how in US states higher homeownership rates lead gradually to higher unemployment levels as a result of i) lower labour mobility, ii) longer commuting times and iii) lower rates of business formation. Individual home-owners are less willing to relocate both within and across state than their peers renting out, and this leads to higher congestion associated with higher costs for employers and employees. Zoning restrictions and Not In My Back Yard (NIMBY) effects, characteristics of home-owners (Fischel, 2004), may be instead behind the negative impact of home-ownership detected on business formation.

Higher local unemployment in turn acts as a push and pull force towards entrepreneurship at regional level (Svaleryd, 2015). On one hand entrepreneurship is embraced upon lack of other job opportunities, so-called "necessity entrepreneurship", above all by home-owners, unwilling to relocate elsewhere. The push factor towards necessity entrepreneurship is mitigated under the presence of a mortgage, as it is shown to intensify job search pressures (Flatau et al., 2003; Munch et al., 2006; Laamanen, 2017). On the other hand, "opportunity entrepreneurship" is lower under adverse labour market conditions, as fewer business opportunities arise during economic downturns. The net effect of labour market conditions on entrepreneurship at regional level depends on which of the two forces dominates. For people with lower levels of human capital, push factors appear to dominate, with pull factors dominating instead for those holding high levels of human and financial capital.

Figure 1: Regional level relationship between home ownership and entrepreneurship

At individual level, home-ownership is more strongly associated with a higher likelihood of undertaking entrepreneurial activities. This comes from the ability of using the home as a collateral or to extract equity from it for business activities, and as a response to the unwillingness to relocate when facing unfavourable labour market conditions. When still repaying a mortgage however, home-owners are more constrained in their ability of collateral-backed financing and more risk-averse, thus are less likely to be pushed into "necessity entrepreneurship" from unemployment. At regional level, the relationship becomes however less clear as, in addition to the individual-effects, home-ownership causes a gradual deterioration in labour market conditions, which on their turn can lead to an ambiguous effect on entrepreneurship.

Economic geography literature has investigated the consequences of the linkages between housing markets and entrepreneurship, not only to study regional entrepreneurship differentials, but also the impact of regional changes in home valuations on local business performance and development, although literature on this is much scarcer.

The literature mostly focuses on the impact of positive price shocks to housing markets to study the intensive margin of home-ownership on entrepreneurship decisions through the three main channels previously discussed.

Increases in house prices lead to an increase in their value as collateral against which the entrepreneur can borrow to finance firm’s additional investment or further business generation (Mian and Sufi, 2011; Bahaj et al., 2020; DeFusco, 2018). Bahaj et al. (2020) provide evidence of this mechanism occurring at household level and estimate a positive impact of entrepreneur’s house prices on its firm’s investment.

It also leads to an increase in the value of equity which can be extracted through re-mortgaging, but literature evidence suggests this channel is negligible in the UK after the Global Financial Crisis.

Furthermore, as house prices increase, so does wealth, thus increasing i) the ‘consumption’ of entrepreneurship (Hurst and Pugsley, 2011; Benz, 2009) and ii) the propensity for undertaking risk – a characteristic feature of an entrepreneurial occupation and driver of entrepreneurial undertaking (Van Praag and Cramer, 2003).

The positive association between house prices and business investment and new business generation persists at regional level (Berggren et al., 2018; Chaney et al., 2012; Adelino et al., 2015). The associated increase in investment at firm level has been shown to translate in an increase in demand for labour in the case of SMEs, with the effect monotonically decreasing for larger firms (Adelino et al., 2015; Mari, 2022). The impact it has on employment at regional level in the long-run remains however an open question. If on one hand labour demand is higher from SMEs, on the other hand increases in house prices are associated with an increase in household leverage, such as the one fuelling the Global Financial Crisis, and responsible for the increase in unemployment in non-tradable industries, which followed at local level as a response to deleveraging and lower demand for consumption (Mian and Sufi, 2011).

The focus of literature on positive rather than negative price shocks on housing is mostly motivated by the higher difficulty faced for negative price shocks in isolating the empirical estimates from local demand effects, when using macro/regional price data. Another reason for this is, however, also due to the close link between literature contributions examining the intensive and extensive margin on entrepreneurship associated with the collateral lending and wealth channel. Business destruction is not generally associated with negative shocks in the same way as business generation is to the positive shocks (Adelino et al., 2015). Although one may argue that a negative impact on investment can lead to business depletion over the medium-long term and consequent default/liquidation, surely the time lag through which the shock operates is longer. Likewise if a positive shock to wealth is associated to an increased 'consumption' of entrepreneurship and an increased likelihood of becoming an entrepreneur, a negative wealth shock is unlikely to have a symmetrical effect due the stronger stickiness to the status quo associated with higher utility.

The stream of economic geography literature on regional economic resilience provides a suitable framework to better interpret the differences in responsiveness to negative shocks at regional level.
Regional economic resilience is conceptualised in literature through four different dimensions: resistance, recovery, re-orientation and renewal (Martin, 2012). Resistance is the vulnerability of a regional economy to disturbances and disruptions (Hopkins, 2008), such as recessions, and we will focus on this dimension of regional resilience, given the focus on the paper on the reaction to a negative shock. Literature has identified a set of regional characteristics affecting regional resistance in the face of a negative shock, which include the region's prior economic growth performance, economic structure, competitiveness, innovation system, skill base, entrepreneurial culture, institutions and economic governance. A stronger underlying growth dynamic prior to the shock has been found to make a region more resistant to a recessionary downturn. A varied, more diversified, economic structure is associated with stronger regional resistance than a more specialized structure

(Conroy, 1975; Siegel et al., 1994, 1995a-b; Dissart, 2003; Ormerod, 2008), but the interrelatedness and the cyclicality of the regional sectoral activities matter too (Conroy, 1975).

Most literature contributions to this stream of literature have studied macro shocks observed through regional lenses in order to derive the conceptual framework just discussed. The macro shocks studied are often large recessions characterised by significant contractions in output, major job losses and meaningful disruption to liquidity and credit supply (Crescenzi et al., 2016). Such a macro approach has allowed to identify the set of macro characteristics associated with regional resilience and how they interact with its different stages/dimensions, but it has not really enabled an understanding of the relative importance of each these characteristics in the face of a specific circumscribed negative shock. This is an exercise which cannot be approached through a macro perspective due to the general equilibrium effects any large negative shock to labour demand/supply or credit, for instance, would have on the regional economy. A study of individual micro shocks, such as the one presented in this paper, can contribute towards such "bottom-up" understanding and ultimately shed more light on regional vulnerabilities to specific shock transmission channels.

III. Methodology

A. Empirical Identification Strategy

This paper looks to investigate the impact of a negative shock to households' capital on their associated small-medium sized businesses, with an interest in particular on the impact on their business continuity, access to credit and medium-term investment. It does so by exploiting flooding as an exogenous negative shock to household capital. Existing literature suggests different channels through which the transmission of the shock can occur, among which changes in risk aversion, wealth effects and the use of personal assets as collateral in business' credit access, as discussed in **Section II**.

Literature presents evidence that real estate properties are subject to a temporary (medium-term) reduction in value when affected by unexpected natural disasters (e.g., flooding, wildfires etc). Yeo et al. (2015) provide an in-depth review of literature contributions on the impact of flooding specifically on real estate valuation. Flooding risk is associated with a discount in property valuation, but the realization of actual flooding – even when consistent with the estimated flood risk - appears to trigger an additional decrease in valuation, with estimates ranging from 4% to 19% (Lamond and Proverbs, 2006; Lamond et al., 2010; Beltran et al., 2014; Dobes et al., 2013; Doupe' et al., 2019; Eves and Wilkinson, 2014). Beltran et al. (2014) estimate an additional 3.8% discounting upon the occurrence of a flood for properties located within an area with Average Recurrence Interval (ARI) of 100 (i.e., flood risk of 1 in 100 years), and a 6.2% discounting for properties located in an ARI 500 area. The discounting is found to attenuate over time (Doupe' et al., 2019), with the behaviour of property prices in response to floods being consistent with a cycle of amnesia – forgetting past floods – and myopia – disregarding future risks (Pryce et al., 2011). The length of period estimated to induce amnesia and fully unwind the discount associated with the past flood is around 5 years on average (3 years in Lamond and Proverbs (2006) and Lamond et al. (2010); 5 years in Yeo (2004), between 4 and 9 years in Atreya et al., (2013)). Part of the negative impact of flooding events on properties' valuation is associated to the increase in the cost of flood insurance. The existence of a subsidized flooding re-insurance scheme in the market is associated with a significant mitigation of the negative price shock on real estate following the flood. Garbarino et al. (2022) show that in England, a market characterised by a 95% take-up rate of home insurance, which entails, the introduction of FloodRe - a subsidised reinsurance scheme for floor risk - has mitigated the negative impact of floods on properties valuation.

It is on the back of this evidence that this paper looks to derive insights on the shock transmission from the household to the corporate sector by observing flooding affecting SMEs company directors' residential capital.

Results are obtained in the context of the United Kingdom, a country historically affected by flooding on a regular basis due to its geographical location, which makes it prone to floods from both storm surge and sea level rise. Over the last 40 years the amount of water precipitations in the UK has increased by 7% and the sea level has risen by 1.6cm, leading to an observed rise in the incidence of flooding, which is expected to increase further due to climate change over the next few years. The adoption of floods in this paper as an exogenous shock to private capital in the UK provides therefore not just a technical solution for an endogeneity problem, offering a strong case for the exogeneity of the shock to capital, but also direct evidence on the impact of floods on the local economy, contributing to a growing literature estimating the economic consequences associated with climate change (Jia and Xie, 2022).

Figure 2 presents a stylised representation of the identification set up adopted in this paper. The treatment group is constituted by SMEs for which at least one of the directors' homes has been flooded but not the business premise. The control group includes firms with business premises located nearby the treated firms, operating in the same sector and of a similar size, but with no experience of flooding, neither in the business premise, nor in the directors' homes. Both treated and control firms' business premises are not affected by flooding and are located within the same outward code perimeter.[37] The outward code part of a UK postcode identifies the town or a district of the town depending on the town's size. Treated firms are matched to those in the control group subject to these three hard conditions (location, sector and size) plus minimising differences in other firm's characteristics later discussed in detail in **Section III.B**.

[37] They are not necessarily located in a municipality completely unaffected by flooding.

Figure 2: Stylised representation of the empirical identification strategy

This setup allows to compare firms as similar as possible in terms of business circumstances, with the only difference being a decrease in the value of the directors' personal capital in the case of the treatment group. The fact that both control and treated firms are co-located and operate in the same sector ensures that, even if there were customer demand side effects from flooding, both treated and control firms would be equally affected. This approach reduces the need for large distances between the director's house and the firm's premises.

In order to ensure a significant impact of the flooding event on the property valuation, flooded directors' homes are considered part of the treatment group only if, prior to the treatment flood, they had not been flooded for 5 years, consistently with literature findings (Lamond and Proverbs, 2006; Lamond et al., 2010; Yeo, 2004; Atreya et al., 2013). They are otherwise excluded from both the treatment and control group. Their inclusion would be in fact expected to lead to a decrease in the impact from treatment, consistent with a lower impact of flooding on their valuation, as it was already priced in from previous flooding events. This source of downward bias could be affecting the lack of evidence found by Garbarino and Guin (2021) of the impact of a substantial flooding event on the affected properties' bank valuations. As the properties affected were for the majority located in coastal postcode districts, the flooding associated with the major event considered by the authors might not have represented such an exogenous shock for the majority of them. Recent evidence of the banking sector's responsiveness to changes in natural disaster's risk has been provided by Xu and Xu (2023). They show that the occurrence of noticeable non-damaging earthquakes (NNDEs) is associated with an increase in loan denial and securitization rate by the banking sector with the effect lasting for up to three years. They find the impact of NNDEs to be however limited in terms of collateral revaluation, as a result of the moderate and short-lasting (9 months) drop in house prices following the event.

The solution adopted in this paper aims to control for sources of bias to the estimate attributable to anticipation and previous treatment effects by strengthening the conditions for the exogeneity of treatment, but it aims to also minimize concerns on the occurrence of sorting into treatment. Literature in fact suggests that wealthier people tend to live in properties more prone to flooding. Although this may sound counterintuitive, assuming market information efficiency and higher flood risk being reflected into a property's price, the finding is motivated by the amenity associated with living next to a water source (Earnhart, 2001; Bin et al., 2008 a-b, Bin and Kruse, 2006), which in its turn pushes up prices, offsetting the negative impact of higher flood risk, and, overall, generally resulting in a valuation premium (Beltran et al., 2014; Bin and Kruse, 2006).

Therefore, estimates obtained from flooding shocks mostly affecting "front-row" properties, not only suffer from potential downward bias associated with anticipation and previous treatment effects, but also from the confounding impact of wealth-based sorting, with a large share of the treated group being composed by wealthier than average households. In this specific set up such sorting can lead to further downward bias in the estimated property revaluation effect from the banking sector, if the overall borrower's creditworthiness history and other unobservable characteristics are considered. This could further explain the lack of significant impact detected by Garbarino and Guin (2021).

Additionally, this identification strategy relies on the assumption that SMEs directors own the property in which they live. Although it is not possible to test this assumption directly, results from the latest

English Housing Survey[38] suggest that 68% of small employers and own account workers are owner occupiers, of which 54% own outright and 46% are mortgagors. This is higher than the national average at 65%. As this paper excludes self-traders, who largely conduct their business activities alongside a regular employment, it is fair to assume that the rate of home ownership for SMEs directors is even higher than 68%. Bahaj et al. (2020) estimate that around 90% of company directors are homeowners using two main arguments: 1) the 2011 UK census shows that 88% of individuals with occupation “managers, directors, and senior officials”, and located in the same age group as the median director in their sample, own the property they live in, 2) they obtained empirical evidence of the ownership rate among directors to be 83% in the population of directors based in Scotland and 90% in a sample of those based in England and Wales.

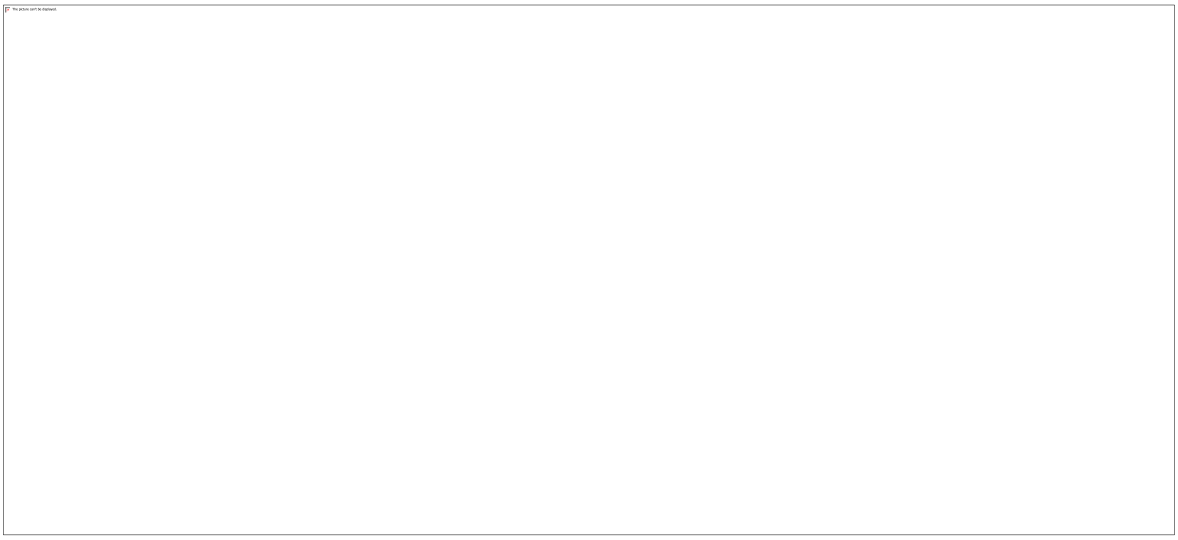
Overall, the identification setup adopted in this paper therefore allows to observe the impact of a household capital shock on treated SME directors being as close as possible to the average, isolating differences in local demand effects between the treated and control group.

B. Econometric Model

The treatment effect is estimated through a Staggered Difference-in-Difference design with matching. The treated firms are matched to their counterfactuals minimising the Mahalanobis distance in a selection of pre-treatment outcome variables[39], subject to three hard conditions: same business size, same NACE 2 sector of activity and same UK outcode (first part of postcode). The variation in treatment date across treated firms calls for a staggered approach to the estimation and matching procedure (**Figure 3**), which is carried out with replacement in one-to-one matches[40]. No treated firm is treated more than once over the observed time window.

[38] English Housing Survey, 2019 to 2020: home ownership
[39] The value and growth rate of current account balance, credit and debit turnover, and credit limit and of borrowing account balance and credit limit in the three months prior to treatment.
[40] There are 30 different treatment dates which lead to 30 different matching rounds in which every control firm participates.

Figure 3: Staggered Treatment Matching



The following econometric model is adopted to estimate the treatment effect:

$$y_{it} = \alpha + \beta T_i + \sum_{t=0}^{n} \gamma_t (q_t T_i) + \sum_{t=0}^{n} \delta_t q_t + \varepsilon_{it}$$

Where T_i is a dummy equal to 1 for firms where one of the directors' homes has been flooded, 0 otherwise, and q_t are a series of time dummies for the quarters post-treatment. This specification allows to observe the dynamics of pass-through onto the outcome variables of interest on a quarterly basis, with the coefficients γ_t describing those. y_{it} is the set of outcome variables. The outcome variables considered include changes in the firm's current account balance, current account credit turnover, current account debit turnover, current account credit limit, borrowing account balance, borrowing account credit limit, and borrowing account monthly payment. **Section IV** provides additional detail on the exact definition of each of these variables. These variables provide an insight on the firms' business continuity and access to investment opportunities. Insight on the business continuity is provided by the variables associated with firms' liquidity positions: changes in the current account balance, the current account credit turnover and the current account credit limit, with this latter being less directly related to the firm's cash position but still associated with the firm's ability to cope with liquidity shocks. Insight on the firms' ability to access investment opportunities is instead provided by changes in the borrowing account balance and credit limit. Finally, changes in the borrowing account balance can provide also an insight on the rate of increase in firm's debt. When read together, these outcomes allow to draw a view on the impact of a household capital shock not just on the SME's short-term business continuity but also on its medium-term access to credit and investment decisions.

The impact of treatment is monitored onto the outcome variables dynamically overtime through quarterly windows. This is possible because of the monthly frequency of outcome variables and it represents a significant innovation relative to the contribution of Bahaj et al. (2021), which looks at treatment impact on an annual basis. This also crucially allows to draw insights on firms' short-term responsiveness to negative shocks, and the evolution of their response over time. Whilst the re-evaluation of collateral from the banking sector is expected to operate with a lag, the potential impact of flooding on the entrepreneur's ability to conduct their business is likely to be immediate. Evidence on the impact of bereavement on cognitive ability (Abdelnoor and Hollins, 2007; Liu. et al, 2022) suggests that this could affect firm's performance in the short-run. Liu et al. (2022) estimate that mutual funds managers experiencing parental losses register a 3% decline in returns for up to one year. The impact of the flood-related stress on the entrepreneur's ability to conduct their business effectively is expected to be less than the one associated with bereavement and it is, therefore, unlikely to interfere with the recognition of the impact of collateral re-evaluation, as the cycle of credit records updates is generally assumed to occur every six months (Bogin et al., 2019). One would also expect a longer lag for the change in the entrepreneur's wealth to pass through into changes in risk perceptions affecting the business profitability.

After investigating the results at UK aggregate level, the paper aims to derive insights on the influence of indicators of regional resilience on the size of the estimated treatment effect. The treated firms operate in 73 different local authorities, distributed across 55 different districts. To effectively identify the impact of different factors associated with regional resistance to shocks, we introduce in the regression model previously discussed, not just the measure of regional resistance, but control also for the heterogeneity in treatment intensity across local authorities. The regression model specification thus is expanded as below

$$y_{it} = \alpha + \beta T\_int_i + \gamma \boldsymbol{Regio}_i + \delta(T\_int_i \times \boldsymbol{Regio}_i) + \theta Post_t + \mu(Post_t T\_int_i) + \pi(Post_t \boldsymbol{Regio_i}) + \rho(Post_t T\_int_i \times \boldsymbol{Regio}_i) + \varepsilon_{it}$$

Where T_int_i is the interaction between the treatment dummy T_i and the firm-specific measure of treatment intensity and it is, therefore, positive for firms where one of the directors' homes has been flooded, 0 otherwise. $\boldsymbol{Regio_i}$ represents an indicator of regional resilience. In this paper, economic growth dynamics, labour market dynamics, and structure of the economy are tested.

When looking at economic growth dynamics, $Regio_i$ is a dummy equal to 1 if the average economic growth in the 3 years before the shock of the district in which the firm operates is higher than average, 0 otherwise. When looking at labour market dynamics, $Regio_i$ is a dummy indicating high local unemployment and equal to 1 when the unemployment rate of the local authority in which the firm operates pre-shock is above 4.9%, 0 otherwise. When looking at the structure of the economy, $Regio_i$ is a dummy equal to 1 if the local authority in which the firm operates is classified as rural, 0 otherwise. $Post_t$ is a dummy equal to 1 after the shock, 0 otherwise, and y_{it} is the set of outcome variables. The coefficient ρ represents the marginal impact of the indicator of regional resilience on the treatment effect (controlled for treatment intensity).

IV. Data

This section provides detail on the datasets used in this paper.

Records of historical flooding in the UK are obtained individually for each nation from the relevant authority. Recorded flood outlines for England have been sourced from the Department of Environment, Food and Rural Affairs, and recorded flood extents for Wales from Natural Resources

Wales. For all the three nations the data collected for each flooding event includes the outline map of the maximum flooding extent, the start date and the end date of the flooding outline and the source. For the purpose of this analysis we concentrate on the flooding events occurring in 2017 and 2018. This choice is motivated by the start of Experian records in 2015-2016 and the onset of the pandemic in early 2020.

The flooding records are mapped to postcodes in the UK through the use of the CodePoint with Polygons dataset providing outline maps for every postcode unit under the Public Sector Geospatial Agreement. This allows to identify which individual postcodes units have been flooded and to which extent (**Figure 4**). This determines the treatment status and allows to derive a measure of treatment intensity obtained as the percentage of the postcode unit appearing as flooded.

Figure 4: Representative overlay of flooding records over postcode units

Overall, 165 flooding extents are used for the purposes of the identification strategy previously discussed in **Section III** in this paper. **Table 1** below shows the distribution of the flooding records across UK NUTS 1 regions and the number of postcodes affected by flooding. The most common source of flooding in the sample is the sea, accounting for 29% of the floods, followed by the main river (27%) and drainage (11%).

Company financials' information for SMEs is obtained on a monthly basis from Experian. According to the Small Business Enterprise & Employment Act, enacted in 2015 in the UK, the nine major banking groups are required to send regular data on all of their SME[41] business customers to a list of designated credit reference agencies. On their turn credit reference agencies have to share the data they collect with the Bank of England, and with all finance providers to promote competition in the SME lending market, as per the Credit Information Regulations. Self-employed individuals referred to as "self-traders" in the UK tax system are also considered SMEs and, therefore, covered by the Small Business Enterprise & Employment Act disclosure requirement. In practice, however, self-traders rarely open business accounts to conduct their business, and the reported data is, as a result, excluding most self-traders, with the probability of inclusion likely to be positively correlated to the size of their conducted activities. Overall, Experian data is estimated to cover around half of the population of SMEs operating under a limited liability legal form. Additional information on Experian data is provided by Hurley et al. (2021). The data considered for the analysis contained in this paper spans from 2015 to end of 2019. Experian data provides information over that timespan for 5,122,039 individual SMEs with

[41] SMEs are defined as UK businesses meeting three criteria: i) having an address in the United Kingdom, ii) carrying out commercial activities as its principal trading activity and iii) being not part of a group having an annual turnover above or equal to £25 million as a whole.

business activities starting before 2018, with a total of 14,936,337 business accounts in the banking sector (which include current accounts, credit card accounts and loan accounts). For each account type the balance, credit turnover and debit turnover are reported at the monthly account reporting date. The process for cleaning Experian data follows Hurley et al. (2021) (more detail in the **Appendix**) and leads to the generation of firm-level current account balance, credit turnover, debit turnover and credit limit, and borrowing account balance, credit limit and monthly payment. In addition to Hurley at al. (2021)'s set of variables we use Experian data to obtain additional outcome variables: balances, credit limits and monthly payments for secured and unsecured borrowing accounts. **Table 2** below summarises the definition and interpretation of each of these variables.

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Information on the SMEs business premises' address and the company directors' identities, status (current or previous), appointment and resignation date and registered addresses are obtained from FAME/Orbis Bureau van Dijk. These records are matched by the Company House registration number to Experian records. The publicly available filings of the Companies House register constitute the raw source of FAME records for the UK. By UK law all limited liability companies are required to disclose on the public Companies House register the company's official address and the directors' name, nationality, occupation and month and year of birth. Directors' residential address is also publicly available for directorships until at least 2009 (Bahaj et al. 2020 – Online Appendix). Since then directors have had the chance to remove their residential address from the public domain. That possibility has become a default option since 2018; from that time onwards only the directors' correspondence address is within the public domain for current directors whilst the residential address continues to be disclosed to credit rating agencies, financial institutions and law and order.

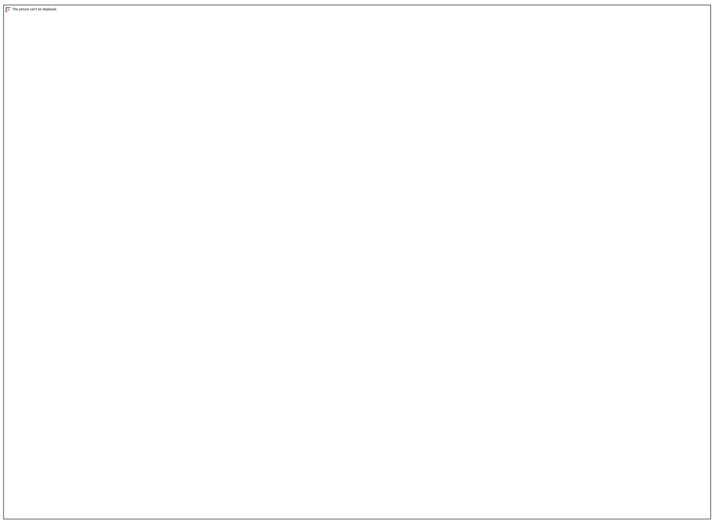
Access to historical records on directors' appointments, resignations and addresses allows to identify cases in which observed changes in individual directors' addresses simply correspond to an update of the address from residential to correspondence in the years following the guidance update. Under those circumstances we make the assumption that the residential address of the director remains unchanged relative to the last one observed before the address update on the public register.

Additional information on the cleaning procedure and assumptions made in the process are contained in the **Appendix.**

Economic growth rates at district level are obtained from the UK Office of National Statistics. Annual growth rates of GDP in chain-volumes are used to compute the 3 year average before the shock. Districts with pre-shock average growth rates below 2.5% are considered "low growth".

Unemployment rates at local authority level are obtained from the UK Office of National Statistics. The rates are available monthly and are modelled on a 12-months window basis. Local authorities with pre-shock unemployment rate over 4.9% in the sample are considered as "high unemployment" (**Figure 5**).

Figure 5: Sample Local Unemployment Rates



The classification of local authorities into rural and urban is based on the Rural Urban Classification (2011) of Local Authorities in England and Wales from the Department of Environment, Food and Rural Affairs. Overall, 44% of the local authorities in which the firms operate are rural.

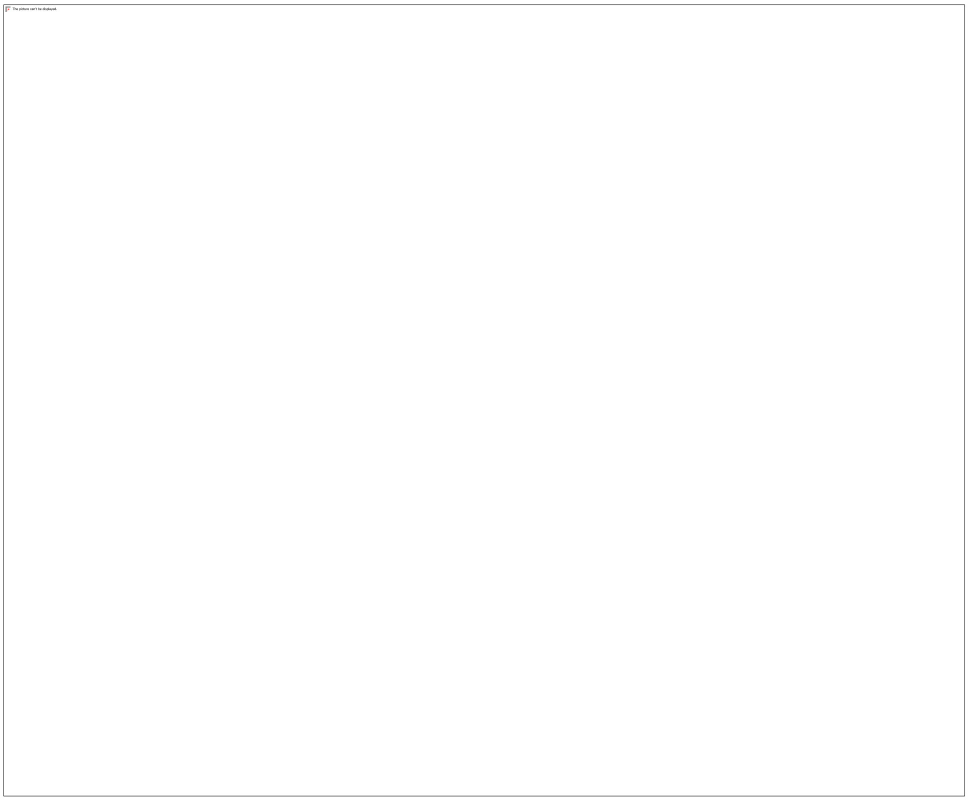
V. Results

In this section results based on the empirical identification outlined in **Section III** are presented.

The treated sample considered in this paper includes 320 individual UK small-medium enterprises. Of those, 81% are of small size. The treated firms span over all the NACE 2 sectors of economic activity, with medium firms predominantly concentrated in utilities, manufacturing, agriculture and transportation and storage (**Table 3**).

The distribution of firms' business premises by area (**Table 4**) mirrors broadly the prevalence of floods by region over 2017-2018 (**Table 1**). Based on the identification set up this does not necessarily need to be the case, however, as floods affect directors' homes and not business premises, but in practice in most cases the two end up falling within the same macro region. Overall, North and South West are the regions with the highest concentration of treated firms.

As detailed in **Section III**, counterfactuals for the treated firms are obtained through a matching process aimed at minimising pre-treatment differences in outcome variables subject to the firm operating in the same sector of economic activity, in the same geographical area and being of similar size. The differences in pre-treatment outcomes between the treated firms and their chosen control matches are presented in **Table 5**. No significant differences are detected between pre-treatment growth rates for both current account and borrowing account variables, whilst treated firms appear to show higher current account balances and credit limits and lower current account maximum excesses (i.e., the number of days during the period that the facility has gone in to excess of the approved limit) prior to treatment than their control counterparts. There is a 1:3 incidence of secured versus unsecured borrowing in the firms of our sample. This is attributable to the widespread usage of credit cards across SMEs, which are classified as an unsecured credit line, and do not necessarily entail carrying balances which are interest-charged.



The results present a significant impact of the flooding shock to the entrepreneur's home onto the SME's current accounts (**Table 6**). The shock is associated with a decrease in the firm's current account balance, which is estimated to return to its counterfactual level only one year later. The short-term reduction in the current account balance appears to be driven by a reduction in inflows into the current account larger than the contemporaneously observed reduction in outflows. The weakness in the current account balance detected here immediately after the shock is small and could be explained with the potential impact of the shock on the entrepreneur's ability to conduct their business (Abdelnoor and Hollins, 2007; Liu et al., 2022). The entrepreneur might in fact be too busy to chase payments from clients or to execute the orders received at the usual pace. Such a backlog effect could help explain also the strength in treated firms' current account balances seven quarters since the shock. No statistically significant change is instead observed in the current account credit limit (i.e., overdraft), but the estimates suggest a reduction of up to 20% in the second year after the shock for the treated firms. The occurrence of the effect on the current account straight after the shock rules out its attribution to any possible change to the value of collateral, which is instead expected to come through with a lag as the banking sector updates collateral valuations on a yearly basis. Similarly, one would expect a longer lag for the change in the entrepreneur's wealth to pass through into changes in risk perceptions affecting the business profitability.

When investigating the impact of the shock on the SME's borrowing accounts, secured and unsecured ones are considered separately. Secured borrowing accounts are backed by a collateral and they are generally not associated with an open-ended credit line. Unsecured borrowing accounts instead are not backed by collateral and they can be associated with an open-ended credit line with a credit limit, such as a credit card. A more detailed explanation of the facilities included in each of these two classifications is provided in **Table 2**.

A significant impact of the shock is also observed both in the secured and unsecured borrowing accounts of treated SMEs (**Table 7**). In the first quarter after the shock, secured borrowing balances experience a significant 2% increase. This is then followed by a persistent contraction in secured borrowing balances starting in the second quarter after the shock and weakening further towards the end of the observation horizon (**Figure 6**). A pick up in borrowing balances following the shock with a decrease thereafter is observed also for unsecured borrowing facilities, although not as sharp as in the case of secured facilities.

Figure 6: Dynamic Treatment Impact

a. Balance

b. Credit limit

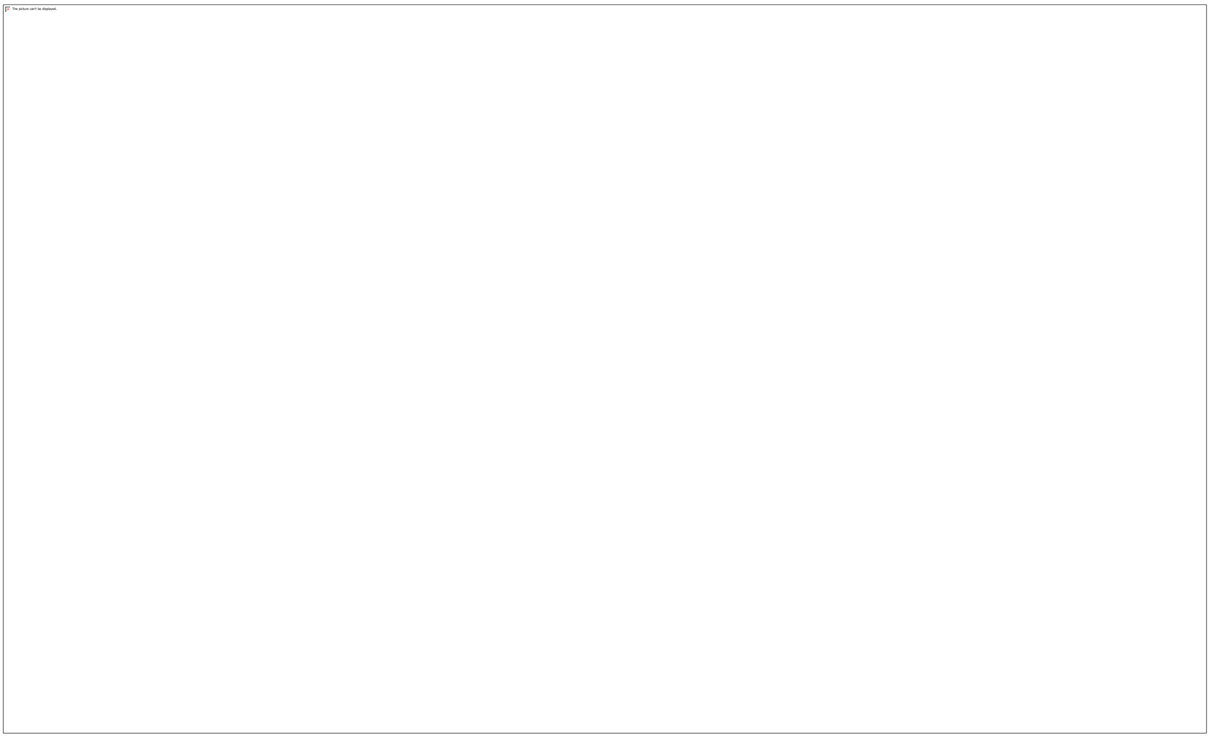
The identification design adopted does not fully allow to attribute the shock transmission to one channel over the other, but the results obtained on the impact of a negative personal capital shock on secured borrowing are possibly evidence of precautionary behaviour and anticipation effects in borrowing in the short run, and a credit rationing through the collateral channel in the medium run. Precautionary borrowing is consistent with the increase in risk aversion documented in literature following from a negative wealth shock (Guiso and Paiella, 2008; Paravisini et al., 2016). As entrepreneurs face a negative wealth shock, their risk aversion is expected to increase and precautionary borrowing acts as a form of insurance against the future potential inability of the entrepreneur in providing collateral from his personal wealth to the company's credit lines, or the likelihood of a larger salary pay-out to face unexpected personal expenses. Examples of precautionary behaviour in borrowing are often found in literature (Druedahl and Jorgensen, 2018; Bosshart and Kakhbod, 2021), and appear to be much more likely among financially constrained firms than financially unconstrained ones (Han and Qiu, 2007). UK SMEs' response to the UK government pandemic policy provides a relevant example. During the COVID-19 pandemic the UK government offered access to government-guaranteed loans to SMEs under the Bounce-Back Loan Scheme, with official estimates suggesting that around 1.5 million businesses had borrowed a total of around £45 billion. Results from Bank of England analysis[42] suggest that much of that borrowing was likely to be precautionary in nature and was repaid before the associated interest rate costs started being borne by the borrower. Hence, under historically low costs of debt as the ones observed in 2017-2019, an increase in the SME's borrowing following a negative shock to its director's home can well be a result of precautionary behaviour. In fact, even if the director's property should be insured against such events, slow pay-outs from the insurance company or the fear of, together with constraints on personal liquidity on the side of the entrepreneur, are likely to motivate a similar precautionary measure.

In the case of secured borrowing for SMEs however, an additional dynamic could also be at play. The widespread use by SMEs of the entrepreneur's home equity as guarantee to obtain secured credit from the banking sector suggests that a negative shock to the home's value is expected to reduce the amount of secured credit available to the SME. We find suggestive evidence of that as we observe the persistent reduction in the secured credit balance for treated firms relative to their control counterfactuals. In this setup however, at least initially, there is an information mismatch between the entrepreneur and the banking sector, with the former being aware of the damage and the likely impact on the home valuation and the latter expected to become aware of it in a few months' time during the next cycle of credit records' update. This generates the opportunity for an entrepreneur with perfect foresight to act on anticipation effects, and still obtain credit at the pre-shock terms

[42] Financial Stability Report, Bank of England, December 2022.

during that window, more advantageous than the ones offered following the update to the collateral valuation. Similar anticipation effects guiding borrowing behaviour have been observed in drawdown of credit lines from corporates during times of distress before they become evident (Bosshart and Kakhbod, 2021; Shin and White, 2020).

The estimated treatment effect shows significant sensitivity to the local characteristics of the local authority in which the firm operates. Local characteristics of the area in which the firm operates are expected to affect the impact of a collateral shock due to the conditioning impact they have on the financial constraints at firm-level, and therefore the extent of the reliance of the firm on the entrepreneur's collateral. As Mari (2022) shows, a higher local average probability of default for the sector in which the firm operates is associated with a higher probability at firm level of experiencing financial constraints in accessing secured credit, and therefore a higher marginal impact of changes in their collateral's valuation. But local characteristics also determine the resilience of a local economy from a shock and its recovery speed and path. **Table 8** presents the marginal impact of a series of regional indicators over a short (one quarter) and medium term (2 years) horizon after the shock. Low growth, high unemployment and rural location, the regional indicators tested here, are all correlated with lower regional resilience and higher local probabilities of default for corporates.



The results suggest that higher local unemployment pre-shock is associated with a lower credit limit for unsecured borrowing and lower firm's revenues for treated firms, still persisting two years after the shock. Operating in a rural area is instead associated with a lower current account balance for treated firms two years after the shock and a higher increase in unsecured borrowing straight after the shock, which does not appear to get offset over time. The impact of local unemployment rates and rural location on the credit response to the shock (i.e., larger contraction in credit limit and higher short-term increase in secured borrowing) is a significant indicator of their role in determining financial constraints at local level for SMEs. Their amplifying impact on the revenue contraction after the shock is, instead, evidence in support of their role in determining the resilience and recovery of a local economy.

VI. Conclusion

This paper provides an insight on the transmission of housing shocks to small-medium enterprises in the UK. The use of floods as an exogenous shock to housing valuation not only allows to derive strongly causal estimates but it also allows to study the direct consequences that increased flooding, as a result of climate change, can have on the UK productive capacity. This paper contributes to broader macro-regional literature on the relationship between housing markets and enterpreneurship by exploiting a quasi-natural experiment through micro-level data. The chosen identification design allows to develop a more causal insight on the transmission of risks from the household to the corporate sector, with the related macro-regional literature providing support to the external validity of the estimates hereby presented.

The results present evidence of a reduction in the treated firm's revenue capacity for the first year, potentially pointing to a temporary decrease in the entrepreneur's ability to conduct their business as a result of flood-related stress. Evidence is also obtained consistent with an increase in the entrepreneur's risk aversion motivating precautionary borrowing immediately after the shock, as treated firms' borrowing balances increase. But as this particularly affects collateral backed (secured) borrowing accounts, it could be an indication also of anticipation effects of credit rationing. Such an increase in borrowing is, however, short-lived and precedes a significant decrease in secured borrowing starting in the second quarter after the flooding shock, and deteriorating further over the course of two years. This can be consistent with a decrease in credit terms and/or supply from the banking sector, as a result of the backing collateral revaluation. Evidence suggests that the impact of the shock is sensitive to drivers of regional resilience and financial constraint. Higher local unemployment and a rural setting for the area in which the firm operates appear to be respectively associated with a stronger and persistent contraction in credit limits and a larger and persistent hit to the firm's liquidity.

Overall, this suggests that a reduction in house prices, potentially due to natural disasters, is associated with an increase in risk aversion and a significant reduction in the borrowing undertaken by SMEs, and, as a consequence, in investment undertaken. Although there is suggestive evidence of precautionary behaviour and/or anticipation effects from the firm's, that is unlikely to sufficiently counteract the longer-term reduction in access to credit. This is also going to going to disproportionately affect regions characterised by lower shock resilience, thus potentially widening regional disparities. Furthermore, when the reduction in housing valuation is a consequence of a sudden and unexpected event, that appears to be also associated with a temporary reduction in the entrepreneur's ability to conduct their business which can lead to lower productivity.

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Appendix

Matching Experian to BvD

Experian data is first matched to BvD records by the Companies House Registration number, when available. For the unmatched BvD records a match by company name and business postcode is applied. The first step in identifying the firms whose director's home has been flooded is matching flooding records to postcode units and identifying the UK directors living /having lived in those postcodes. The matches where the company was not operating at the time of the flooding event are then removed, and also those where the company director living in the affected postcode had not been appointed yet, or had already resigned at the time of the flood. In the absence of a director's resignation date we assume the director continued its appointment until the business ceased its operations or it is still ongoing over the 2017-2020 timespan. We also treat as a continuous appointment the situations in which directors resign in 2018 and then get reappointed with another registered address in the same year, as that reflects rather an update of address from residential address to correspondence address, coinciding with the rule change allowing to do that. For the purposes of the identification design the last address pre-2018 is considered as the relevant director's residential address in those instances.

In the analysis we remove also those matched records in which the directors' residence coincides with business premises. We identify broadly two reasons for which directors' residential and business addresses coincide before 2018. The first one is because effectively the entrepreneur works from home, i.e., works in their residential address. This is much more likely in the case of sole traders or very small companies, with the former being excluded from the sample of firms analysed in this paper due to the lack of data on them in BvD. The second one being the case of accommodation/hospitality businesses like hotels and B&B, in which case the entrepreneur lives in their business premise.