Asymmetric Industrial Reorganisation and Adaptive Misallocation Post Disasters.

Maha Rehman*

Cornell University

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Abstract

This paper presents evidence on how firms adapted following the 2005 Pakistan earthquake, with a particular focus on the vulnerabilities that drove differential impact and the expectation of minimal government aid shaping firm behavior. Using a difference-in-difference methodology on a nationally representative panel of 390 firms, this paper explores: the immediate disruption, short-term adaptation, and long-term resilience. The seismic shock damaged stock and reduced sales asymmetrically. Fragile intermediaries, firms with moderate capital-labor ratios, experienced pronounced declines in sales, while labor-intensive firms, besides highly capital intensive firms demonstrated greater resilience. Firms prioritised skilled labor retention, reducing non-production roles, increasing operational hours, and diversifying across markets. There was no evidence of innovation. Building on these findings, this paper develops a theoretical model showcasing how adaptive misallocation, where firms over-invest in short-term adaptive measures such as increased reliance on backup infrastructure, driven by expectations of minimal government aid, diverts resources away from productivity, erodes public-private trust, and ultimately undermines resilience.

Keywords: earthquake, firms, adaptation, Pakistan, natural disasters, manufacturing.

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JEL Codes: H84, L25, O12, O14, O53, Q54, R11.

1 Introduction

Natural disasters rank as one of the most disruptive forces to an economy, imposing substantial costs on productivity, employment, and long-term development. For firms, these shocks necessitate immediate and often substantial adaptation to sustain operations and rebuild capacity. In developing economies, where public support mechanisms are often limited or inconsistent, the burden of adaptation and building long term resilience falls disproportionately on the private sector. This raises critical questions: How do firms adapt in the face of minimal government aid? Do these adaptive strategies optimise recovery and build resilience, or do they lead to resource misallocation that compromises long-term growth and productivity?

This paper reconciles perspectives from Neo-Classical Growth Theory and Schumpeterian creative destruction to explore the balance between disaster-induced destruction and firm-level adaptation. Neo-Classical Growth Theory emphasises how disasters impair production by damaging capital, whereas Schumpeter (1942) suggests that recovery periods can foster innovation, business formation, and technological advancements. By integrating these ideas, this paper investigates three key dimensions: the immediate disruption, short-term adaptation, and long-term resilience. It focuses specifically on the impact of Pakistan's 2005 earthquake on firm-level outcomes.

The 2005 Pakistan earthquake, one of the most devastating natural disasters in the country's history, caused economic losses equivalent to 2.6 percent of Pakistan's GDP, destroyed infrastructure, and disrupted supply chains. Firms near the epicenter experienced widespread capital destruction, operational disruption, and reduced demand, prompting asymmetric response and adaptation. The adaptive measures undertaken included extending production cycles and diversifying market reach. However, evidence from this paper reveals there was no innovation and negligible government support in aiding these recovery efforts.

The analysis in particular highlights the differential impact of the earthquake across firm types. Firms in the first quartile of capital-labor ratios (0% - 25%) , which I am defining and will refer to them as labor-intensive firms in this paper, demonstrated remarkable sales resilience. Despite substantial damage to machinery and buildings, these firms maintained their sales by relying heavily on their labor force. For instance, in the leather industry, there is no significant decline in sales. This is likely because the industry is labour intensive. It is also possible that increased demand for leather products during post-earthquake reconstruction efforts led to sustained sales. The industry also showed

significant increase in operational hours lending credibility to our proposed underlying mechanisms.

The second group I am defining as fragile intermediaries, or firms in the second quartile vis-a-vis capital-labor ratios (25% - 50%), were the most vulnerable to disruptions. Their dual dependency on both labor and capital made them particularly fragile. Damage to machinery or supply chain inputs significantly disrupted production processes, leading to sharp declines in sales. For example, garment industry faced halted operations due to machinery damage and supply chain interruptions, highlighting their heightened sensitivity to such shocks.

Conversely, capital-intensive firms in the third and fourth quartiles displayed minimal changes in sales. These firms often possess better financial buffers and deploy more shock-resilient machinery, enabling them to absorb disruptions effectively. Their operational stability reflects the robustness of their physical capital and the financial resources available to weather shocks.

In response to these pressures, firms adopted various strategic measures. Firms reduced their non-production labor force, particularly in capital-intensive sectors like chemicals, to streamline operations and minimise costs. We also see a decline in non-skilled production workforce. Firms prioritised skilled labour retention, especially in the leather industry, reflecting the growing importance of workforce adaptability in navigating disrupted supply chains and operational challenges. The emphasis on skilled labor highlights an adaptive action that is likely going to build a more resilient workforce. Firms also responded to infrastructure damage by increasing reliance on backup power solutions, such as generators, to mitigate disruptions caused by power outages.

Firms expanded their geographic and customer bases, diversifying from operating in a single or few markets to multiple markets. This expansion reduced reliance on localised demand, stabilising revenue streams and mitigating future risks. However, despite these proactive measures, the paper found no significant increase in innovation. The reliance on the same product menu, same or traditional practices and the lack of emphasis on innovation is indicative of a possible area for future intervention, as innovation may drive growth and competitiveness.

These results generate rich policy insights. Firstly, there is a need for governments to actively engage with the industrial sector in developing countries to reduce uncertainty and foster trust between the public and private sectors. As the paper highlights, unpredictability of government action and aid forces firms into over-adaptive behaviors that exacerbate inefficiencies and drain resources that could be directed toward innovation

and long-term resilience. Subsidised disaster insurance programs and predictable aid are approaches to reducing these uncertainties and ensuring timely support for vulnerable firms.

Second, targeted investments in infrastructure and industrial clusters, especially in areas with a higher proportion of fragile intermediaries, can significantly improve resilience. By improving transport networks, energy supplies, and communication infrastructure in regions with high concentrations of vulnerable firms, governments can reduce logistical challenges and support operational continuity during crises. Dynamic infrastructure assessments, which incorporate real-time data on firm outcomes and regional vulnerabilities, can further inform policy decisions and resource allocation, ensuring that interventions are efficient and impactful.

Building on these empirical findings, this paper introduces the concept of adaptive misallocation. Firms over-invested in short-term adaptive measures, such as increased reliance on backup infrastructure, driven by expectations of minimal government aid. This misallocation of resources created inefficiencies, reinforcing a feedback loop of firm self-reliance and government complacency. The theoretical model developed in this paper captures this dynamic, illustrating how these interactions may weaken the social contract between public and private sectors and undermine long term systemic resilience.

By combining empirical analysis with a theoretical framework, this paper contributes to the broader literature on disaster response and adaptation, offering rich insights for policymakers. It highlights the need for integrated public-private strategies that align firm-level adaptations with systemic support to optimise recovery and enhance resilience. The findings have profound implications for disaster-prone economies, highlighting the importance of balancing immediate recovery efforts with investments in long-term growth.

This paper makes several significant contributions to the literature on disaster resilience and firm dynamics.First, it contributes to the scarce literature on micro-level evidence regarding the immediate impact of exogenous shocks of this kind and the strategies firms in developing countries employ to adapt to such disruptions. More importantly, it highlights how asymmetric vulnerabilities, particularly those reflected in differential capital-labor ratios, drive heterogeneous outcomes across firms, alongside differences in sector and size. This approach provides a deeper understanding of firm-level dynamics in the wake of disasters. Second, it introduces the concept of fragile intermediaries—firms with moderate capital-labor ratios that are uniquely vulnerable to shocks due to their dual

dependency on both labor and capital. This characterisation offers a new lens to analyse firm vulnerabilities and tailor targeted interventions. Third, the paper advances the theoretical framework by proposing the concept of adaptive misallocation, demonstrating how firms' over-investment in short-term resilience strategies, driven by expectations of minimal government aid, creates systemic inefficiencies. This dynamic highlights the feedback loop between firm behavior and government complacency, weakening the social contract. Finally, the paper provides actionable policy insights, emphasising the importance of predictable government aid, investments in infrastructure, and incentives for innovation and diversification to aid recovery and enhance resilience. These contributions enrich the discourse on disaster management and firm adaptation.

The remainder of the paper is structured as follows: Section 2 reviews the relevant literature and frames the research questions. Section 3 presents the conceptual framework, while Section 4 outlines the context and data. Sections 5 through 8 detail the methodology, empirical findings, and robustness checks. Section 9 develops the theoretical model of adaptive misallocation, Section 10 provides policy recommendations and Section 11 concludes.

2 Related Literature

A review of the empirical literature reveals mixed results regarding the overall impact of disasters on firms. Tol and Yohe (2008) note that the impact of natural disasters on macroeconomic dynamics remains ambiguous, often varying by the context, timing and type of disaster. Meanwhile, papers suggest that firms with prepared disaster resilience strategies tend to sustain less damage in their asset prices during disasters. Similarly, Basker and Miranda (2018) demonstrate that larger firms with better access to financial and managerial resources recover more rapidly, a trend consistent with Schumpeter's notion of creative destruction. Further research by Balboni, Boehm, and Waseem (2023) and others highlights the importance of supply chain diversification and flexibility in building resilience against disruptions caused by disasters. Related literature on air pollution such as Khanna et al. (2022) carefully documents labour impacts of shocks and pollution. Recovery and resilience mechanisms are also critically analysed in the literature. Kunreuther and Michel-Kerjan (2009) and others discuss the role of public-private partnerships and government aid in supporting short-term recovery and fostering long-term resilience.

Despite the breadth of research, there remain gaps in understanding the specific impacts of disasters at the firm level, particularly in contexts like Pakistan, where geographic

and economic vulnerabilities present unique challenges. This paper tries to address these gaps by presenting evidence on the immediate impact on firms, their short-term adaptive strategies, and the strategic actions taken to potentially enhance resilience post-disaster. The interaction between firm adaptation and government response to natural disasters has been widely explored, particularly in the context of public good provision, mitigation strategies, and the role of government intervention. However, the model I build in this paper following my empirical results provides a new perspective by introducing a framework where firms increasingly adapt to disasters in response to expectations of minimal government aid, thereby creating a misallocation of resources and leading to suboptimal outcomes.

The literature on moral hazard in disaster response, such as Kahn (2005) and Hsiao (2024), has emphasised how government aid can distort behavior, leading to insufficient mitigation efforts. However, this view presupposes that governments provide consistent and reliable aid. My model breaks from this to model post disaster environment in developing countries where firms expect low government aid and in turn increase their independent adaptive measures leading to 'allocative misallocation'. In this context, government complacency emerges not as a response to over-reliance by firms but as a consequence of firms overcompensating for expected under-provision of aid. This feedback loop fundamentally alters the typical moral hazard narrative.

Empirical studies, such as those by Cavallo and Noy (2011), have shown that government responses to disasters are often delayed and inconsistent, which can create an environment where firms must rely on self-help strategies. This aligns with my assumption that firms act with forward-looking expectations regarding government response, adapting their strategies accordingly. By including these expectations in my model, I expand on the idea that firms' anticipatory actions can perpetuate systemic inefficiencies.

Papers such as Hsiang and Jina (2014) demonstrates that firms and economies can suffer long-term productivity losses due to climatic shocks. My model, which incorporates expectation of minimal government aid, further contributes to this literature by highlighting the costs of over-adaptation, as firms divert resources from productive uses to defensive measures. This dynamic is similar to the findings of Dell, Jones, and Olken (2012), where firms in vulnerable regions demonstrate slower economic growth due to higher disaster-related costs.

The breakdown of the social contract between firms and governments is a central result of my theoretical modeling. Classic models of firm-government interaction, such as those by Olson (1996), have explored the role of government in providing public goods

that mitigate the risks faced by firms. However, in my framework, the failure of optimal cooperation between firms and the government results in firms internalising the cost of adaptation, while the government withdraws from its role. This shift creates an imbalance where firms take on excessive responsibility, further increasing their mitigation costs and reducing overall social welfare. This is particularly relevant to recent work on disaster recovery and firm dynamics, such as Cohen and Werker (2008), who argue that private sector responses often complement government efforts. However, in my paper, this complementarity breaks down, leading to a vicious cycle where firms increasingly adapt and the government becomes more complacent. This self-reinforcing loop results in higher adaptation costs for firms and a deterioration of public goods, providing a new angle on the relationship between firm adaptation and government aid.

3 Conceptual Framework

Earthquakes disrupt firm operations by damaging physical capital, reducing sales, and altering market dynamics. Using the Classical Growth framework, I demonstrate the effects of earthquakes on firm-level outcomes through the Cobb-Douglas production function:

$$Y = AK^{\alpha}L^{\beta} \tag{1}$$

where Y is the output, A is the total factor productivity (TFP), K is the capital, L is the labor, α and β are the output elasticities of capital and labor, respectively. An earthquake causes a destruction of capital stock. Let δ represent the fraction of capital destroyed. The post-earthquake capital stock, K', is given by:

$$K' = (1 - \delta)K \tag{2}$$

Additionally, productivity (A) may decline due to supply chain disruptions, infrastructure damage, and workforce inefficiencies. Let γ represent the proportional reduction in TFP. The post-earthquake TFP, A', is:

$$A' = (1 - \gamma)A \tag{3}$$

The adjusted production function after the earthquake becomes:

$$Y' = A'(K')^{\alpha}L^{\beta} \tag{4}$$

$$Y' = (1 - \gamma)A\left((1 - \delta)K\right)^{\alpha}L^{\beta} \tag{5}$$

Empirical results, that follow, corroborate these mechanisms, showing sharp declines in firm sales immediately after the shock. The results also highlight heterogeneity in the impact, response and adaptation, which is explored in subsequent hypotheses and results. I also revisit this model in section 9 as I build on the empirical results via a theoretical model.

Before delving into the hypotheses that guide the empirical analysis, I define two key concepts central to this paper: adaptation and resilience.

Adaptation is a process by which firms make strategic, financial and operational adjustments, such as reallocating resources, modifying production processes, or restructuring labour composition, to mitigate the impact of external shocks and reduce the productivity loss that would have occurred in the absence of any adjustments or actions.

Resilience refers to the capacity of firms to maintain or restore the expected (mean) levels of productivity, output, and sales through adaptive measures in the short, medium, and long term, reducing the expected losses should a similar shock of comparable magnitude were to reoccur.

Building on these concepts, I introduce in Section 9 the notion of over-adaptation, where firms—anticipating minimal government aid—over-invest in short-term measures to compensate for the lack of external support.

Firms engage in various forms of adaptation, including financial, operational, and strategic measures, to restore productivity and rebuild capital. However, my empirical findings and theoretical model indicate that these adaptations are not always efficient, often reflecting overcompensation for anticipated minimal government aid. This contributes to resource misallocation and higher adaptation costs. Firms' adaptation efforts can be categorised into three distinct groups, each representing a different aspect of their capacity to withstand and evolve in the face of disasters:

Operational Adaptation:
Actions aimed at maintaining or quickly restoring core business operations, such as changes in labour composition, changing hours of operations, increasing facilities' utilisation, or investments in disaster-resilient infrastructure.

Strategic Adaptation:
Actions undertaken including innovations in product lines, entry into new markets, or rethinking business models to incorporate disaster preparedness.

Financial Adaptation:
Actions undertaken to ensure financial stability through measures such as accessing

emergency funds, securing loans, or leveraging aid to rebuild operational capabilities.

This framework allows for a systemic evaluation of the ways in which the principles of creative destruction, adaptation and long term resilience shape firm behaviour following a disaster. By investigating how firms adapt and innovate in response to disruptions, the paper aims to lend evidence to not only the challenges faced but also the potential for positive interventions that may enhance long-term resilience and growth.

This conceptual framework yields hypothesis that are listed in the following subsection.

Resulting Hypothesis

Hypothesis 1:

An exogenous shock, such as an earthquake, destroys capital and hence lowers output, sales and profit. This follows directly from equations (1)-(5) in the conceptual framework. There are three direct testable mechanisms: Firstly, the destruction of capital directly lowers output. Secondly, the destruction of infrastructure lowers sales and hence profits. Thirdly, the shock changes market demand and hence changes the product mix demanded.

This hypothesis serves as a foundational premise for the analysis, setting the stage for understanding the immediate economic consequences of the earthquake on affected firms. By examining whether the earthquake acted primarily as a supply shock (through capital destruction) or a demand shock (through changes in market demand and product mix), the paper seeks to delineate the mechanisms through which firms' output, sales, and profits were impacted. This analysis is crucial for identifying the nature of the shock and its subsequent effects on the economy, thus forming the basis for subsequent hypotheses that explore industry-specific responses and long-term adaptations.

Hypothesis 2:

Capital intensive industries that deploy more capital are more resilient to shock. For shock resilient and capital intensive industries, reduction in sales is likely to be minimal.

This hypothesis builds on the first by introducing the concept of heterogeneity in response to shocks. By distinguishing between more capital-intensive and less capital-intensive industries, the paper explores how the structural characteristics of different firms influence their vulnerability to exogenous shocks. I further refine this categorisation to provide deeper insights. These distinctions are critical for understanding the differential impacts across industries, which in turn informs the broader analysis of adaptation and

resilience.

Hypothesis 3:

Short-term adaptation and rebuilding may change the composition of labour demanded.

This hypothesis introduces the dynamic nature of post-shock recovery, where the process of rebuilding itself becomes a significant economic force. By changing labour demand, rebuilding efforts may alter the labour composition across industries, potentially leading to shifts in productivity. The paper analyses these industry-specific changes to understand how initial shock and subsequent recovery efforts interact to influence overall productivity. This hypothesis is key to understanding the long-term economic consequences of the earthquake and the potential for recovery efforts to enhance or complicate productivity outcomes.

Hypothesis 4:

Short term adaptation and reconstruction activity changes the economic fiber potentially changing firm-level output and aggregate economic outputs.

This hypothesis extends the analysis to the broader implications of short-term adaptations and reconstruction efforts on economic resilience and growth. By positing that these activities can enhance the total factor productivity (A) in the Cobb-Douglas production function, the paper links microeconomic firm-level responses to macroeconomic outcomes. This connection is crucial for understanding how localised adaptation strategies can contribute to systemic resilience and economic recovery. The analysis under this hypothesis will help to demonstrate whether observed adaptations lead to sustained improvements in productivity and resilience, thus contributing to the overall narrative of recovery and growth. I define economic fiber as the structural and operational components of an economy, encompassing time-varying and responsive changes in market demand and supply, resource allocation efficiency, production technologies, labour force composition, and institutional coordination between public and private sectors. These adjustments collectively shape short-term adaptability and the long-term growth trajectory of the economy during reconstruction.

Hypothesis 5:

Firms may take strategic action diversifying markets or innovating that may build long term resilience by increasing total factor productivity.

This hypothesis addresses the strategic responses of firms in the aftermath of the earthquake, specifically through market diversification. By linking market diversification to

long-term resilience and increases in total factor productivity (A), my paper explores how proactive strategies can mitigate the impacts of future shocks. This hypothesis is crucial for understanding the forward-looking actions that firms can take to enhance their resilience, beyond immediate adaptive recovery efforts. The analysis will demonstrate whether such strategies contribute to improvements in productivity and long term resilience.

4 Context and Data

On 8th October, 2005, a 7.6 magnitude earthquake struck South Asia with its epicenter 19 km[1] (12 mi) northeast of Muzaffarabad, Azad Jammu and Kashmir, Pakistan and 100 km north of its capital in Islamabad. It proved to be the deadliest earthquake since 1935 surpassing the 1935 Quetta earthquake in fatalities and destruction. 780,000 buildings were either completely destroyed or sustained significant damage, 86,000 lives[2] were lost and 3.5 million people were rendered homeless. Overall it lead to economic losses equivalent to 2.6 percent of Pakistan's GDP.

The government setup the Earthquake Reconstruction and Rehabilitation Agency (ERRA) to distribute household grants and loans and rebuild public infrastructure. However, the allocation overlooked grants and loans to firms that were impacted, providing further rationale for evaluating the full impact and ascertaining the optimal government intervention for firms.

This paper, is using a panel survey of 390 firms, to evaluate the impact of this natural exogenous shock on firm output, productivity and adaptation strategies. The paper is using data from World Bank Enterprise Surveys from years 2002-2007. World Bank Enterprise Surveys are nationally representative firm level surveys conducted across 170 countries by surveying the owner/top manager of the firm collecting quantitative and qualitative data across various firm level dimensions. This paper uses two waves of the data collected in Pakistan in 2002 and 2007 i.e. two years before and approximately two years after the earthquake across 14 cities.

Using the data, this paper constructs a discrete variable of treatment intensity using distance measures of Latitude/Longitude of the firm location from the epicentre. Using this measure I draw causal inferences about the impact of natural disasters on key firm outcomes, such as sales, capital stock, and employment, and to explore how firms adapt and build resilience in the aftermath of such shocks.

[1] ReliefWeb (2005)
[2] ReliefWeb (2005)

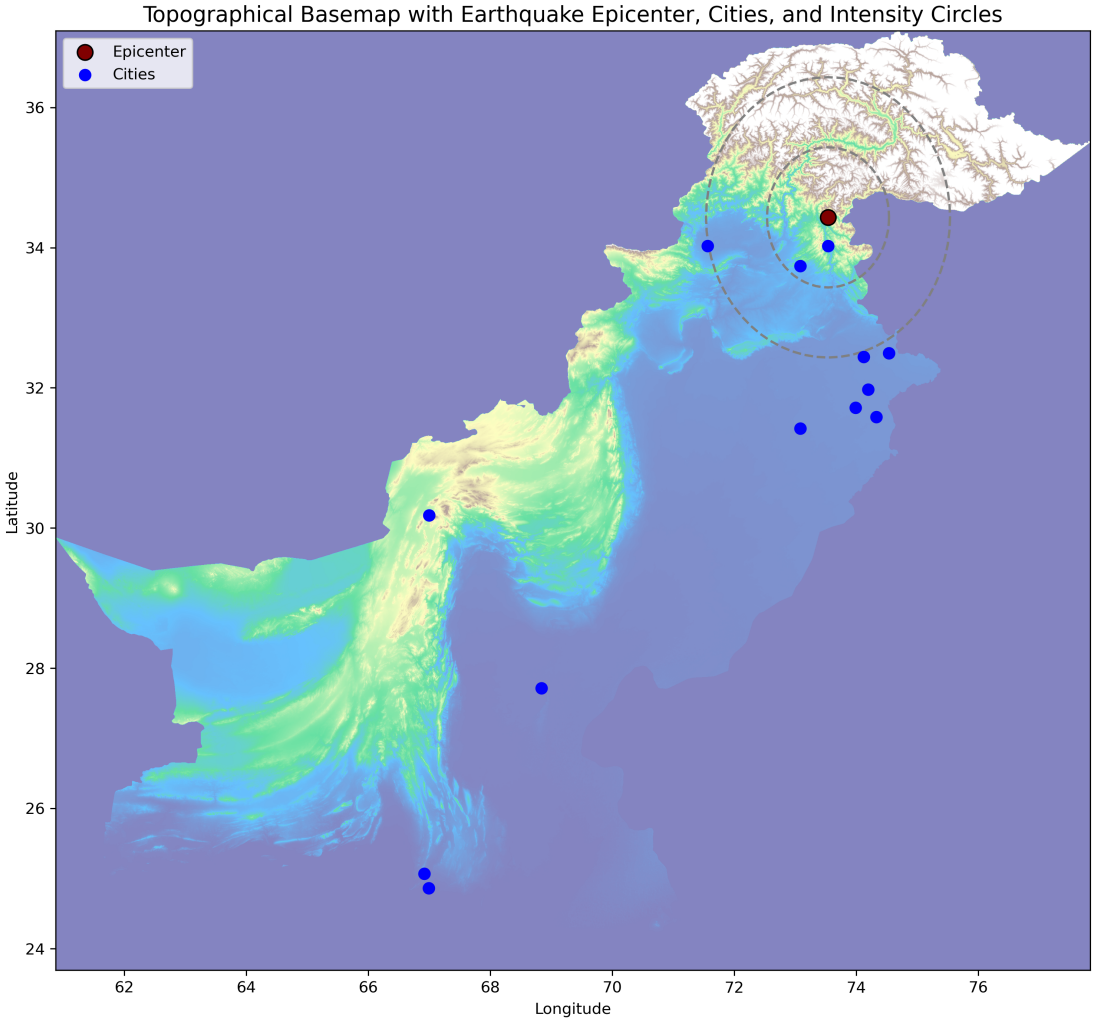


Figure 1: Epicenter and Firm City Locations.

5 Methodology

This paper is using difference-in-difference estimation to evaluate the impact of the 2005 earthquake on the immediate firm responses, short term firm adaptation and what forward looking actions does the firm take to build resilience. This paper will also presents some salient heterogeneous responses by firm characteristics.

In this paper, I employ a panel dataset, the World Bank Enterprise Survey Panel Dataset from 2002 to 2007 to analyse firm outcomes before and after disaster exposure. The sample comprises 390 firms in Pakistan. The methodological approach i.e. Difference-in-Differences analysis allows us to control for unobserved heterogeneity by comparing changes in outcomes over time between firms that were exposed to natural disasters and those that were not. This strategy helps isolate the causal impact of disasters from other concurrent economic fluctuations.To ensure robustness, I control for firm level variables such as labour costs, exporter status, number of employees, extent of automation and new products introduced along with industry fixed effects which are included in the regression models to draw causal estimates about the impact of natural disasters.

Furthermore, I am clustering the standard errors at the city level, which accounts for spatial correlations in disaster exposure and impact. This setup allows us to draw causal inferences about the impact of natural disasters on key firm outcomes, such as sales, capital stock, and employment, and to explore how firms adapt and build resilience in the aftermath of such shocks. The paper's findings aim to contribute valuable insights into disaster management strategies for businesses in highly vulnerable regions.

In this paper, the following regression specification will be estimated:

$$Y_{it} = B_0 + B_1(Exposure_i * \mathbf{1}(Year = 2007)) + \lambda_i + \epsilon_{it} \tag{6}$$

where Y_{it} are firm level outcomes. Exposure is defined as a discrete variable which takes on the value 1 for cities within 400 km of the epicentre. λ_i is a set of firm-level controls that include industry fixed effects. Standard errors are robust and clustered at the city level.

To establish the exogeneity of the shock, it is important to note that it cannot be predicted first. In spite of seismically active regions, the epicenter is completely randomly located and is not correlated with the local infrastructure. This is also established in earlier seminal work, for example, in Andrabi, Daniels, and Das (2023) and Frankenberg et al. (2011).

6 Descriptive Analysis and Summary Statistics

Table 1 provides a summary of key variables that describe the characteristics of firms included in the sample. These variables include annual sales, labour costs, exporter status, level of computerisation, number of employees, days of inventory, new product introduction and hours of operation. The table shows there is considerable variation in sales and labour costs and the firms in the sample are fairly heterogeneous. 35 percent of the firms export, number of employees ranges from 0 to 2,000, with an average of 39 employees, hours of operations range from 0 to 168 hours, with an average of 31.3 hours per week and firms store an inventory of upto 32 days of the primary input.

Table 1: Summary Statistics

Variables	Count	Mean	Std. Dev	Min	Max
Annual Sales	759	2.3e+08	1.1e+09	0.00	1.8e+10
Labour Costs	780	1.1e+07	5.0e+07	0	7.2e+08
No. of Employees	780	40.24	103.43	0	2000
Hours of Operations	780	32.22	40.22	0	168
Exporter	780	0.36	0.48	0	1
Days of Inventory	780	33.236	43.671	0	365
New Product Introd.	780	3.63	16.54	0	100

Note: This table summarises the key variables in the dataset. Annual Sales and Labour Costs record large variations, exporter is a categorical variable that takes on the value 1 for an exporting firm, computerisation is also a categorical variable that takes on the value 1 if a firm uses computers, days of inventory is the number of days for which a primary input's stock is kept in the store, new product introduced is a categorical variable that takes on the value 1 if the firm introduced a new product in the last fiscal year.

Table 10 shows the summary statistics by exposure to the earthquake. Statistically significant differences, especially, in the exporter status and extent of automation justify the use of Difference-in-Difference methodology to evaluate the impact of the earthquake on firm level outcomes. There is heterogeneity by firm size and industry, as expected, in the firm level outcomes, as visualised by Figures 4 and 5. Leather industry is an outlier and the result section that follows will attempt to explain this heterogeneity empirically.

7 Empirical Results and Underlying Mechanisms

Impact on Capital Stock, Buildings and Sales

The first set of results correspond directly to hypothesis 1-3. The remaining hypothesis are investigated via both the empirical results and the theoretical model that follows the results.

The results show that the Kashmir earthquake significantly altered the economic landscape for Pakistani firms. As shown in Table 2, there were considerable declines in sales and capital stock alongside shifts in employment patterns and operational strategies, which were indicative of the broader economic impact of the earthquake and the adaptive responses by firms. The impact of employment is captured by Table 3.

Post-earthquake, machinery and buildings declined significantly at 1 percent level indicating tangible asset damage and sales subsequently registered a substantial decline statistically significant at the 1 percent.

Table 2: Impact on Sales,Capital Stock, Buildings

	(1)	(2)	(3)
	Log Sales	Log Stock	Log Buildings
Treatment=1 × Post=1	-.794***	-5.117***	-5.117***
	(.231)	(1.350)	(1.471)
Exporter	1.275***	1.665***	2.267***
	(.154)	(.360)	(.493)
Observations	759	707	692
Firm Level Controls	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes

Note: This table reports the impact of the earthquake on Log Sales, Log Capital Stock i.e. Machinery and Vehicles and Log Buildings. The treatment dummy is interacted with the post dummy. Firms within 400 km of the epicenter are exposed and ones outside are not. The regression is controlling for firm level variables and industry fixed effects. Standard errors in parentheses:$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. The dataset used is the World Bank Enterprise Survey.

What is driving the results in these key variables? I look at the heterogeneity driven by differential Capital-Labour Ratios and also in turn by sectors and firm sizes.

Firms in the first quartile dissected by Capital-Labour ratios i.e **labour intensive firms** demonstrate sales resilience. Despite experiencing substantial damage to machinery

and buildings, these firms maintain their sales. Labour-intensive firms rely more heavily on workers than on physical capital. This reliance means they can continue operations even if machinery or infrastructure is damaged, as long as workers remain available. For example, in industries like leather production, firms can often resume work quickly by deploying their labour force without needing extensive repairs or replacements to machinery. The supply of labour is fairly elastic in developing countries like Pakistan, owing to its abundant availability. The results for Leather Industry are also likely driven by increase in market demand as leather products are in greater demand as reconstruction and rebuilding activities pick up post the earthquake. As a result, when industries adapt by increasing the operational hours, the increase is significantly large for Leather industry.

Firms in the second quartile dissected by Capital-Labour ratio which I will refer to as **fragile intermediaries** from hereon are highly vulnerable to disruptions. The dual dependency on both labour and capital makes them more fragile. Damage to capital significantly disrupts their production processes. As a result, firms in this quartile experienced a sharp decline in sales. For example, in the garment industry, which often falls into this category, disruptions to machinery or supply chain input can quickly halt operations, reducing sales.

Firms in the quartiles in the third and the fourth quartile i.e. **capital intensive firms**, which rely heavily on machinery and physical infrastructure, showed no significant changes in sales. These capital-intensive firms often have better financial buffers which allow them to absorb shocks more effectively. Additionally, their reliance on shock-resilient capital may provide operational stability, as the machinery and technology they deploy is robust to shocks that are otherwise hugely disruptive. This lends empirical support to our second hypothesis.

The industry-level results align with the quartile-wise analysis and provide additional context. Labour-Intensive Industries such as leather, which are highly dependent on labour, exhibited resilience and even saw an increase in sales. The ability of these industries to resume production quickly, relying on their workforce, makes them more adaptable to shocks. For example, leather production often involves manual processes that can continue even when infrastructure is damaged. Fragile Intermediary Industries such as Garments, which typically fall into the second quartile, experienced significant declines in sales. These industries are more susceptible to disruptions because they depend on intermediate inputs and machinery, making them less flexible in responding to shocks. For instance, if a key piece of equipment or supply is unavailable, production halts entirely, leading to immediate sales declines.

Firm size further reinforces the patterns we earlier saw and demonstrate how shocks impact sales and operations. Small and Medium-Sized Firms were the most affected, with both sales and stock levels declining significantly. Small and medium-sized firms often lack financial reserves, insurance, or access to credit, which makes it difficult for them to recover from damages. Additionally, their operations are often concentrated in a single location, making them more vulnerable to localised disruptions. Large firms demonstrated a mixed response. While their sales remained stable, their stock levels declined, reflecting challenges in maintaining inventory or managing supply chain disruptions. Large firms may have the resources to sustain sales during a shock but still face difficulties in fully mitigating the impact on operations.

Is this primarily a supply shock?

As I dissect the results of this exogenous shock by exporter status, I do not see a significant impact on sales, allowing us to conclude that this disruption was largely driven by supply-side interruptions.

Impact on Labour

The results illustrate nuanced and significant shifts in employment patterns as firms adapted to the challenges posed by declining sales and reduced productive capacity.

In response to these pressures, firms strategically opted to reduce their non-production labor force. We also witness decline in in the non-skilled workforce as there is insignificant impact on skilled production employees. This decision to cut back on non-production and unskilled roles was likely driven by the need to streamline operations and minimise costs during a period of economic strain. By focusing on core production activities and in turn skilled labour force, firms aimed to maintain operational efficiency while grappling with the constraints imposed by the economic downturn.

Table 3: Impact on Salesforce

	(1) Production	(2) Non-Production	(3) Skilled	(4) Unskilled
Treatment=1 × Post=1	.01	-.59***	.07	-.46***
	(.14)	(.12)	(.13)	(.17)
Observations	692	777	778	761
Firm Level Controls	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes

Note: This table reports the impact of the earthquake on Labour Employed. The Treatment dummy is interacted with the Post dummy. Firms within 400 km of the epicenter are exposed and ones outside are not. The regression is controlling for firm level variables and industry fixed effects. Standard errors in parentheses:$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. The dataset used is the World Bank Enterprise Survey.

At the same time, there was a noticeable strategic shift toward prioritising the employment of a skilled workforce especially in the leather industry. It laid off unskilled labour in favour of employing more skilled workers. As firms encountered new operational challenges, particularly in maintaining production levels and navigating disrupted supply chains, the value of a highly skilled labor force became increasingly apparent. Skilled workers, with their ability to adapt to changing circumstances and manage more sophisticated tasks, were seen as essential to sustaining business continuity and driving recovery efforts. This emphasis on skilled labor reflects a broader strategy to not only survive the immediate crisis but also to build a more adaptable workforce capable of supporting long-term growth.

The decline in non-production labor was most pronounced in the Chemicals industry which is highly capital intensive. The significant reduction in non-production labor within these sectors highlights the difficult choices firms had to make in order to preserve their core production capabilities.

Moreover, the analysis indicates that these employment shifts did not differentially impact labor outcomes based on gender. Despite the reductions in non-production roles and the strategic emphasis on skilled labor, the data suggest that male and female workers were affected similarly. This finding is significant as it suggests that, at least in terms of employment outcomes, gender did not play a defining role in how labor adjustments were made during this period. The uniformity of impact across gender lines may reflect broader industry-wide trends rather than gender-specific vulnerabilities, indicating that the challenges faced were more universally felt across the workforce.

Firms reduced non-production labor to cut costs and maintain operational efficiency, while simultaneously prioritising skilled labor to address new challenges. The differential impact across industries highlights the asymmetric vulnerability faced by different types of firms. However, the absence of a differential gender impact suggests a uniform approach to labor adjustments during this period of economic restructuring.

Table 4: How did Firms Adapt?

	(1)	(2)
	Hours of Operations	Level of utilisation of facilities
Treatment=1 × Post=1	58.297***	56.659***
	(4.603)	(5.197)
Observations	780	780
Firm Level Controls	Yes	Yes
Industry FE	Yes	Yes

Note: This table reports the impact of the earthquake on Firm Level Adaptation. The Treatment dummy is interacted with the Post dummy. Firms within 400 km of the epicenter are exposed and ones outside are not. Hours of Operations are weekly and the Facilities Utilisation is a percentage utilised of the total available space. The regression is controlling for firm level variables and industry fixed effects. Standard errors in parentheses: $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. The data used is from the World Bank Enterprise Survey.

Operational Adaptation

Operational strategies also demonstrate significant adaptations. Notably, there was an observed increase in weekly operational hours, with a coefficient of 58.3 indicating that firms extended their weekly working hours significantly to compensate for production time lost due to the earthquake driven by Leather, Garments, Textiles and Food. This was a direct attempt to sustain business continuity amidst ongoing disruptions. Moreover, facilities' utilisation saw a marked increase, reflecting a strategic shift in resource allocation—firms likely repurposed their facilities to streamline operations and reduce dependencies on disrupted supply chains. This short term adaptation and reconstruction activity changes the economic fiber potentially leading to more resilience and lending empirical evidence to the fourth hypothesis.

Financial Adaptation

These operational adaptive measures were accompanied by a greater likelihood amongst the firms to borrow from a private bank indicative of the firms' readiness to expedite

recovery and build resilience. This increased likelihood of borrowing suggests that firms were not only focused on short-term survival but were also strategically positioning themselves to rebuild and enhance resilience against future shocks.

Table 5: Infrastructure Impact and Adaptation

	(1)	(2)
	Electricity	Percent electricity from generators
Treatment=1 × Post=1	1.421***	11.753***
	(.164)	(2.143)
Observations	779	534
Firm Level Controls	Yes	Yes
Industry FE	Yes	Yes

Note: This table reports the impact of the earthquake on Infrastructure Adaptation. The Treatment dummy is interacted with the Post dummy. Firms within 400 km of the epicenter are exposed and ones outside are not. The LHS variable in the first regression is a categorical variable asking respondents how much of an impediment is electricity in their operations. The LHS variable in the second regression is the percentage of utilised electricity that is produced by generators. The regression is controlling for firm level variables and industry fixed effects. Standard errors in parentheses:$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. The data used has been sourced from World Bank Enterprise Surveys.

Strategic Adaptation

To cope with frequent power outages and other infrastructure disruptions, firms increasingly invested in backup power solutions, such as generators, to maintain short-term operational continuity. This behaviour motivates the theoretical model in Section 9 that firms, anticipating minimal government support, take self-reliant measures to mitigate immediate shocks. However, these strategic investments in short-term adaptation may come at a significant cost to both long-term productivity and resilience. Resources diverted towards short-term adaptative measures, like generators, are resources not invested in productivity-enhancing activities such as technological upgrades, innovation, or workforce development. Furthermore, while these measures address immediate disruptions, they may fail to build the kind of structural resilience that could better prepare firms for future shocks, leaving them locked in a cycle of reactive adaptation rather than sustainable growth.

The theoretical framework that follows captures this trade-off between short-term adaptation and long-term productivity and resilience, emphasising how resource misallocation can undermine firms' ability to achieve sustained improvements. Section 9 develops

these ideas further, incorporating empirical insights to illustrate the broader implications for firm dynamics and economic development.

Building Resilience

Market diversification is another dimension in which the firms adapted post 2005 quake. It likely highlights the strategic decisions made by affected firms to broaden their market reach. These firms, recognising the risks inherent in relying on a limited local market, may have sought to expand their presence. This entailed an adaptive response with some firms moving from operating in just one market to as many as five, or from five markets to twenty and so on. Such diversification could have mitigated the vulnerabilities associated with a concentrated market presence, allowing firms to spread risk across a broader geographic or customer base. By entering new markets, these firms may have aimed to stabilise their revenue streams and reduce the impact of any future disruptions in their local markets. This could also be a response to disrupted operations and an attempt to diversify across markets with fewer disruptions.

Table 6: Do Firms Diversify Across Markets?

	Diversify Markets?
Treatment=1 × Post=1	.106*
	(.059)
Observations	647
Firm Level Controls	Yes
Industry FE	Yes

Note: This table reports the impact of the earthquake on Firm's Market Diversification. The treatment dummy is interacted with the post dummy. Firms within 400 km of the epicenter are exposed and ones outside are not. The LHS variable is a categorical variable reporting whether firms diversified from 1 market to 5 and from 5 to 10 and so on. The regression is controlling for firm level variables and industry fixed effects. Standard errors in parentheses:$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. The dataset used is the World Bank Enterprise Survey.

Despite market diversification, there was no significant increase in innovation i.e. introduction of new products or processes among the affected firms following the disaster. The data suggests that while firms were keen on reducing their market risk through expansion, they did not similarly prioritise innovation as a means of adapting their business models. This also indicates a reliance on same product menu, same or traditional business practices and a reluctance or inability to explore new ways of operating in

the changed environment with new products and processes. This also indicates that market diversification was not a result of tapping newer markets with new products but expanding reach with the same product menu.

Table 7: Do Firms Innovate?

	Innovate
Treatment=1	-.204***
	(.060)
Observations	401
Firm Level Controls	Yes
Industry FE	Yes

Note: This table reports the impact of the earthquake on Firm's Innovation. The treatment dummy is interacted with the post dummy. Firms within 400 km of the epicenter are exposed and ones outside are not. The LHS variable is a dummy defined as 1 or 0, 1 indicating whether firms introduced a new product or process. The regression is controlling for firm level variables and industry fixed effects. Standard errors in parentheses:$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. The dataset used is the World Bank Enterprise Survey.

It is important to understand the likely underlying mechanisms that impede innovation, which may not always require heavy capital investment. Firms may struggle to innovate due to knowledge bottlenecks, which could possibly arise from a lack of local and global connectivity. Limited access to national and international networks of knowledge, expertise, and technology may prevent firms from identifying opportunities or adopting innovative practices. Without being part of global value chains or learning networks, their exposure to cutting-edge ideas is constrained. Additionally, the lack of precedents could discourage innovation. In many cases, firms might not have local examples of successful innovation to emulate, which could limit their willingness to take risks or experiment with new approaches. While financial constraints are often cited as a barrier, it is worth noting that innovation is not always capital-intensive. Many forms of innovation, such as process improvements or incremental changes to products, can be achieved with minimal capital. Therefore, the real barriers may lie in gaps in knowledge and skills rather than financial limitations. To address these challenges, it may be necessary to incentivise connectivity and learning. Efforts to foster collaborations between local and international firms, create spaces for knowledge-sharing, and invest in skills development could potentially encourage firms to innovate. By bridging these knowledge gaps, firms could be better equipped to engage in innovation, improving their competitiveness and contributing to economic growth.

While market diversification was a clear and strategic response to the disaster, the lack of innovation highlights an area of intervention. This presents an opportunity for government to intervene and incentivise innovation and, in turn, likely enhance the long-term resilience of these firms to future shocks.

Grants

The impact on sales is the largest for smallest and medium firms. This means it is critical for grants to be well-allocated to small and medium enterprises as well as fragile intermediaries. However, grants analysis reveals contrary results. The overall effectiveness of financial aid and grants was mixed, with some sources like Export Promotion Bureau and Board of Investment showing almost no grant delivery,

Does the overall market concentration change?

Economic theory traditionally suggests that an exogenous shock, such as the 2005 earthquake, would lead to the exit of of a subset of firms. However, in the analysis of this panel dataset, there is no evidence to support this theoretical outcome. The data does not indicate any significant exit of firms in the aftermath of the earthquake. There are no direct records of firm closures. This lack of observed exits suggests that firms managed to survive the immediate effects of the earthquake. This maybe so since earthquakes of this magnitude are rare and considered a one off event with their epicentre being exogenously located. As a result, the expected shift in market dynamics, wherein firms exit the market and market concentration increases, did not materialise. The market concentration, therefore, remains stable, with no significant changes in the composition of firms in the market.

This finding challenges the conventional expectations derived from economic theory. It suggests that in certain contexts, firms may the survive shocks that are typically one off without leading to the anticipated market restructuring in this case.

8 Robustness Checks

To establish the robustness of the results, I run the following tests:

8.1 Continuous Treatment

I now define the exposure as continuous distance variable measuring the distance of the firms from the epicentre. I do this using the Longitude and Latitude of the epicenter

and each of the firms in the sample. The results are displayed in Table 12. The closer the firm to the epicenter, the larger is the increase in reduction in capital stock and hence sales. This new definition yields similar results establishing beyond doubt that the exposure variable is robust to any changes in definitions. I also use alternate definitions of discrete treatment Variables and the results are robust beyond 400 km.

Table 8: Robustness Check: Impact on Sales and Capital Stock

	(1)	(2)
	Log Sales	Log Stock
Post=1 × Distance	.001***	-.000
	(.000)	(.001)
Observations	760	708
Firm Level Controls	Yes	Yes
Industry FE	Yes	Yes

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: This table reports the impact of the earthquake on sales and capital stock using continuous treatment measure. The treatment dummy is interacted with the post dummy. The regression is controlling for firm level variables and industry fixed effects. Standard errors in parentheses:$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. The dataset used is the World Bank Enterprise Survey.

9 Adaptive Misallocation

In this section, I develop a theoretical model that is motivated by empirical results presented earlier in the paper. Specifically, the model seeks to capture the trade-offs firms face when engaging in short-term adaptive strategies, while mitigating immediate operational disruptions, that may undermine long-term productivity and resilience when firms 'over-adapt.'.

The core principle of the model is that firms operate under the expectation of minimal government support during crises. This expectation drives them to invest in self-reliant measures and self-provide quasi-public goods, such as backup power solutions and other forms of operational mitigation, to ensure continuity. However, these investments often divert resources from more productive uses, such as technological upgrades, capacity expansion, and innovation. The result is a misallocation of resources that can impede long-term growth while locking firms into a cycle of reactive over-adaptation leading to misallocation.

The model builds on this empirical foundation by formalising the mechanisms through which short-term adaptation impacts firm-level outcomes over time. It incorporates key features such as firm expectations, and the feedback loop between government complacency and firm mitigation efforts. By examining these interactions, the model provides a framework for understanding how resource misallocation in response to shocks can lead to structural inefficiencies and hinder economic recovery.

This framework not only deepens our understanding of firm behaviour under constrained environments but also has broader implications for policy. It highlights the need for targeted interventions that reduce the reliance on costly short-term adaptations, promote long-term productivity, and strengthen structural resilience, ensuring a more balanced response to shocks. The following sections develop this model in detail, integrating both theoretical constructs and empirical evidence to provide a comprehensive analysis of firm adaptation dynamics.

We earlier saw that firms extended their operational hours, with an average increase of 58.3 weekly working hours, to offset production disruptions. Firms increased reliance on power generators to cope with frequent power outages, demonstrating a shift toward costly, immediate survival measures. This is likely driven by expectations of minimal government aid. Additionally, firms laid off non-production managerial staff—focusing on cost-cutting and operational efficiency—while prioritising the retention of skilled workers, indicating a preference for short-term survival over long-term resilience. To further shield themselves from future risks, firms engaged in market diversification, moving into new markets to reduce dependency on local demand. This strategic adaptation allowed firms to build resilience, but likely at the cost of diverting resources away from innovation, which remained stagnant. The over-adaptation, along with short-term overdrive and market diversification, reinforced a cycle where the government provided even less support, pushing firms further into self-reliance while exacerbating government complacency. This feedback loop of adaptive misallocation resulted in inefficiencies that weakened long-term resilience and productivity, as firms focused on immediate survival rather than growth.

As a result of these empirical findings, I develop a theoretical model that extends current theories on firm adaptation and government response to disasters. By incorporating expectations of minimal government aid and the resulting over-adaptation by firms, my model introduces the concept of adaptive misallocation, where firms over-invest in short-term adaptive measures at the expense of innovation and long-term growth. This model highlights the feedback loop of firm self-reliance pushing the government further into complacency, leading to inefficiencies and a reduction in the social contract.

This model explores the behavior of firms that anticipate minimal future government aid in the face of natural disasters and, as a result amplify the adaptative measures. However, this leads to a form of adaptive misallocation, where firms over-invest in self-protection at the expense of productive investment. The production function incorporates expected government aid and the inefficiencies caused by misallocation.

Post disaster, the firm's production function depends on several factors: expected future government aid $E_t[G_{t+1}]$, firm adaptation A_t, post-earthquake capital K_t, and labor L_t. In this model, the production function incorporates a misallocation term τ_A, representing the inefficiencies arising from firms diverting too many resources into adaptation. I define over-adaptation as firms investing in quasi-public goods in expectation of minimal expected government aid. This misallocation of resources leads to inefficiencies.

The model considers firm behavior over a finite time horizon with two key periods:

- **Period t (Post-Disaster):** Firms initiate adaptation efforts (A_{it}) and allocate resources based on expected government aid ($E_t[G_{t+1}]$).
- **Period $t+1$:** Firms observe outcomes, update expectations about government aid, and revise their strategies.

The production function for firm i in period t is:

$$Y_{it} = F(A_{it}, E_t[G_{t+1}])K_{it}^{\alpha}L_{it}^{\beta} \cdot (1 - \tau_A), \tag{7}$$

where:

$$F(A_{it}, E_t[G_{t+1}]) = A_0 \cdot (1 + \theta A_{it}^{\gamma}) \cdot (1 - \lambda E_t[G_{t+1}]^{\delta}).$$

The term $F(A_{it}, E_t[G_{t+1}])$ captures the direct impact of adaptation effort (A_{it}) and expected government aid ($E_t[G_{t+1}]$) on output.

- The first component, $1 + \theta A_{it}^{\gamma}$, reflects diminishing marginal returns to adaptation. For $\gamma < 1$, as A_{it} increases, its additional contribution to productivity decreases. This property ensures concavity in the production function with respect to adaptation efforts.
- The second component, $1 - \lambda E_t[G_{t+1}]^{\delta}$, captures the substitution effect between firm adaptation and expected government aid. When $E_t[G_{t+1}]$ is high, firms anticipate sufficient public support, reducing their need for private adaptation efforts.

The misallocation term $\tau_A = \eta A_{it}^{\zeta}$ introduces inefficiency. As firms over-adapt, τ_A rises,

reducing total factor productivity (TFP). This reflects resource misallocation when private efforts substitute public goods provision. The marginal product of adaptation, $\frac{\partial F}{\partial A_{it}}$, diminishes as A_{it} increases, consistent with the concavity imposed by $\gamma < 1$.

Firms maximise profits, accounting for adaptation and labor costs:

$$\Pi_{it} = F(A_{it}, E_t[G_{t+1}])K_{it}^{\alpha}L_{it}^{\beta} \cdot (1 - \tau_A) - \psi A_{it}^2 - wL_{it}. \tag{8}$$

- The first term, $F(A_{it}, E_t[G_{t+1}])K_{it}^{\alpha}L_{it}^{\beta} \cdot (1 - \tau_A)$, represents total output net of misallocation inefficiencies.
- The second term, ψA_{it}^2, reflects the convex cost of adaptation. As A_{it} rises, marginal adaptation costs increase, discouraging excessive efforts.
- The third term, wL_{it}, represents labor costs, proportional to the wage rate and the quantity of labor employed.

Government aid in period $t + 1$ is modeled linearly as:

$$G_{t+1} = G_0 - \kappa A_t + \varepsilon_t, \tag{9}$$

where $\kappa > 0$ captures the negative relationship between adaptation and aid. A higher adaptation effort by firms reduces the perceived need for government intervention. The stochastic term $\varepsilon_t \sim N(0, \sigma^2)$ accounts for uncertainty in disaster severity and government response.

The interaction between firm adaptation and government aid expectations creates a feedback loop:

- Firms anticipate minimal aid ($E_t[G_{t+1}]$ decreases), prompting over adaptation efforts (A_{it}) by investing in quasi-public goods.
- Over-adaptation increases τ_A, reducing productivity.
- Higher adaptation reduces G_{t+1}, reinforcing firms' reliance on self-protection and perpetuating inefficiencies.

This loop highlights the dynamic interplay between private and public responses to disasters.

Firms update their expectations about government aid using Bayesian updating. The

belief dynamics are governed by the transition matrix:

$$T = \begin{bmatrix} P(G_{t+1}|G_t) & P(B_{t+1}|G_t) \\ P(G_{t+1}|B_t) & P(B_{t+1}|B_t) \end{bmatrix}. \tag{10}$$

The updated probability of aid failure is:

$$P_t(b|\text{history}) = \frac{P(b_t) \cdot P(b_{t+1}|b_t)}{P(G_t) \cdot P(b_{t+1}|G_t) + P(b_t) \cdot P(b_{t+1}|b_t)}. \tag{11}$$

- Firms use historical data to revise beliefs about government aid provision.
- Successful aid increases $P(G_{t+1}|\text{history})$, reducing the need for private adaptation.
- Repeated failures increase $P(b_{t+1}|\text{history})$, reinforcing self-reliance and over-adaptation.

The eigenvalues of T determine the steady-state probabilities, representing long-term trust dynamics.

The first-order condition for A_{it} is:

$$\frac{\partial \Pi_{it}}{\partial A_{it}} = \frac{\partial F}{\partial A_{it}} K_{it}^{\alpha} L_{it}^{\beta} \cdot (1 - \tau_A) - \frac{\partial \tau_A}{\partial A_{it}} F K_{it}^{\alpha} L_{it}^{\beta} - 2\psi A_{it} = 0. \tag{12}$$

Solving this yields the optimal adaptation effort:

$$A_{it}^{*} = \frac{\frac{\partial F}{\partial A_{it}} K_{it}^{\alpha} L_{it}^{\beta} - \frac{\partial \tau_A}{\partial A_{it}} F K_{it}^{\alpha} L_{it}^{\beta}}{2\psi}. \tag{13}$$

The more firms engage in adaptive behavior, the lower the government's perceived need to provide aid or infrastructure, thereby reinforcing a feedback loop of declining public intervention and increasing private adaptation. These countervailing incentives result in a breakdown of the social compact, where firms bear a disproportionate share of the disaster risk mitigation efforts, while the government retreats from its role in providing public goods, leading to inefficiencies in disaster resilience and an erosion of cooperative behavior between the public and private sectors. By modeling the government's behavior as a Markov process, the analysis highlights the feedback loop where firms over-adapt, leading to reduced government aid and persistent inefficiencies. Policy interventions that address the transition dynamics and encourage cooperative behavior between firms and governments are critical to restoring the social contract and ensuring efficient disaster recovery.

I will now introduce heterogeneity in misallocation (τ_A) across firms segmented by capital-labour quartiles. This addition captures the diverse adaptive responses and vulnerabilities observed in the data, particularly reflecting how misallocation and productivity vary systematically across the quartiles

Misallocation (τ_A) varies across quartiles of capital-labour ratios, with the highest misallocation observed in fragile intermediaries (Quartile 2) and the lowest in capital-intensive firms (Quartiles 3 and 4):

- **Quartile 1 (Labour-Intensive Firms):** Misallocation cost is *moderate* for these firms, as their reliance on abundant and flexible labour allows them to adapt efficiently in the short term. However, their focus on operational hours and workforce reallocation diverts resources from productivity-enhancing investments such as innovation.

$$\tau_A^{(1)} = \eta \cdot A^{\zeta_1}, \quad \text{where } \zeta_1 > \zeta_3, \zeta_4 \text{ but } \zeta_1 < \zeta_2.$$

- **Quartile 2 (Fragile Intermediaries):** Misallocation is *highest* among these firms due to their dual dependency on both capital and labour. This heightened vulnerability leads to over-investment in costly adaptive measures, such as backup infrastructure, which fail to translate into sustained productivity gains.

$$\tau_A^{(2)} = \eta \cdot A^{\zeta_2}, \quad \text{where } \zeta_2 > \zeta_1, \zeta_3, \zeta_4.$$

- **Quartiles 3 and 4 (Capital-Intensive Firms):** Misallocation is *lowest* in these quartiles as firms rely on durable, shock-resilient capital and possess financial buffers to absorb disruptions. These firms exhibit greater stability and require minimal resource diversion into adaptation.

$$\tau_A^{(3)} = \eta \cdot A^{\zeta_3}, \quad \tau_A^{(4)} = \eta \cdot A^{\zeta_4}, \quad \text{where } \zeta_3, \zeta_4 < \zeta_1, \zeta_2.$$

The impact of heterogeneous misallocation on productivity (Y_i) can be expressed as:

$$Y_i = F(A_i, E_t[G_{t+1}])K_i^{\alpha} L_i^{\beta} \cdot (1 - \tau_A^{(q)})$$

where q denotes the capital-labour quartile of the firm. The differences across quartiles are:

- **Labour-Intensive Firms (Quartile 1):** Productivity remains stable in the short

term due to effective utilisation of labour but shows limited growth potential due to moderate misallocation.

- **Fragile Intermediaries (Quartile 2):** High misallocation results in substantial productivity losses as resources are inefficiently allocated to short-term measures.
- **Capital-Intensive Firms (Quartiles 3 and 4):** These firms maintain higher productivity levels due to minimal misallocation and efficient capital utilisation.

The heterogeneity in misallocation and productivity across quartiles highlights the need for targeted interventions.

10 Policy Implications

In addressing the vulnerabilities of firms categorised as *fragile intermediates*—those with capital-labour ratios in the second quartile that leave them particularly exposed to shocks—policy interventions must strike a balance between immediate support during crises and proactive measures to foster long term resilience. This section outlines actionable policy recommendations aimed at supporting these firms, boosting productivity, and enhancing disaster response, all while recognising fiscal constraints and systemic challenges.

Establishing consistent and transparent engagement between the public sector and industrial firms, especially fragile intermediates, fosters trust in government support systems. This ensures better cooperation when shocks occur, leading to optimal responses from both firms and government agencies. Collaboration on resilience strategies through public-private partnerships enhances preparedness, ensuring firms are better positioned to withstand shocks while reducing dependence on ad hoc government aid.

Prioritising infrastructure development in areas with high concentrations of fragile intermediates is essential. Improved transport, energy, and communication networks reduce logistical challenges and enhance firms' ability to adapt during crises. Incorporating real-time data on firm outcomes, infrastructure functionality, and supply chain networks helps identify gaps and iteratively adjust policies.

Incentivising firms to adopt more capital-intensive technologies where feasible can shift them toward greater productivity and reduced vulnerability. Tax credits or subsidies for acquiring advanced machinery can facilitate this transition. Developing workforce training programs enables labour to transition toward more productive roles in increasingly capitalised environments, mitigating the risk of displacement while enhancing

competitiveness. Providing tailored support for workers during readjustments, including wage subsidies or redeployment programs, minimises disruptions in employment during crises.

Designing transparent and predictable aid schemes reduces uncertainty about government response and enhances trust in public support mechanisms. According to the transition matrix developed in this paper, which models the probability of transitioning between states of good and bad government, predictable aid can stabilise firm expectations by increasing the likelihood of remaining in the ”good government” state. This stability prevents firms from over-adapting due to uncertainty and reinforces the social contract, creating a positive feedback loop. When firms perceive a higher probability of good government responses, they reduce over-investment in self-reliance, leading to a more efficient allocation of resources and optimal disaster recovery outcomes. Additionally, subsidised disaster insurance programs can spread risks across firms and industries, ensuring individual firms are not disproportionately burdened by rare, high-impact shocks such as earthquakes.

Addressing knowledge bottlenecks, driven by limited global connectivity and a lack of precedents, is crucial for fostering innovation in fragile intermediates. Providing platforms for international and national collaboration, participation in global value chains, and access to cutting-edge technologies can encourage learning and innovation. Incentives should be created for firms to engage in global networks, including export promotion programs, technology sharing agreements, and industry-specific knowledge exchanges. It is also important to emphasise that innovation does not always require heavy capital investment. Policies supporting process improvements, managerial innovations, and incremental technological adoption can lead to significant gains for resource-constrained firms.

Regularly evaluating the outcomes of industrial interventions helps identify successes and areas for improvement. Data-driven evaluations should inform future policy designs, creating a virtuous cycle of learning and iteration. Establishing centralised databases to track firm-level outcomes, infrastructure conditions, and regional vulnerabilities can guide resource allocation and policy decisions more effectively.

Given Pakistan’s limited fiscal space, policy solutions should focus on systemic improvements rather than reliance on recurring financial assistance. Prioritising investments in shared infrastructure and services that benefit multiple firms and industries reduces the need for firms to over-invest in private capital. Ensuring policies are predictable and transparent minimises uncertainty and reduces inefficient adaptations by firms. Sub-

sidised disaster insurance can help distribute risk across industries and reduce the direct financial burden on the government during crises.

The recommendations outlined above provide a multi-faceted approach to addressing vulnerabilities, especially those of fragile intermediates, enhancing their resilience to shocks, and fostering a more robust industrial sector. By combining proactive engagement, targeted investments, innovation support, and fiscal pragmatism, policymakers can build a foundation for sustainable growth and resilience, even in the face of recurring crises.

11 Conclusion

This paper presents evidence on how firms adapt to natural disasters in environments characterised by minimal government aid, focusing on the 2005 Pakistan earthquake. Using a difference-in-difference methodology on a nationally representative panel of 390 firms, the paper presents evidence of how firms respond differentially to the disaster and undertake adaptive strategies to reduce disruption. These strategies include extending operational hours, increasing reliance on backup power solutions, prioritising skilled labour retention, and diversifying market reach. However, these measures, while effective for short-term survival, often come at the expense of long-term productivity and resilience.

The findings highlight heterogeneity in firm outcomes based on capital-labour ratios. Labour-intensive firms demonstrated remarkable resilience by leveraging their workforce, while capital-intensive firms showed operational stability due to their financial buffers. In contrast, fragile intermediaries—firms with moderate capital-labour ratios—suffered the most severe declines, reflecting their heightened vulnerability due to dual dependencies on labour and capital. Despite these adaptive responses, the paper found no evidence of innovation.

Building on these empirical results, this paper introduces the concept of adaptive misallocation, where firms, anticipating minimal government aid, over-invest in short-term protective measures such as backup infrastructure. This behaviour, while providing immediate relief, diverts resources from productivity-enhancing investments like innovation. The theoretical model formalises this dynamic, illustrating how the feedback loop between firm over-adaptation and government complacency erodes the social contract and perpetuates systemic inefficiencies. This cycle not only undermines long-term resilience but also constrains broader economic growth in disaster-prone regions.

From a policy perspective, these findings emphasise the need for coordinated public-private strategies to align firm adaptation with systemic support. Predictable and timely government aid can reduce uncertainty, preventing over-adaptive behaviour and enabling firms to focus on sustainable recovery. Investments in infrastructure and targeted support for vulnerable firms, particularly fragile intermediaries, are critical to fostering resilience. Policies incentivising innovation, market diversification, and workforce development are also essential to address the long-term challenges posed by disasters.

This paper contributes to the literature by providing micro-level evidence of firm responses to disasters, presenting evidence on how asymmetric vulnerabilities drive asymmetric firms' response. It introduces the concept of fragile intermediaries, and the framework of adaptive misallocation. It highlights the need for proactive relationship building with industries so that firms' do not expect the aid to be minimal and can in turn build on the existing relationships to recover and adapt in wake of such a disastrous shock.

12 Appendix A

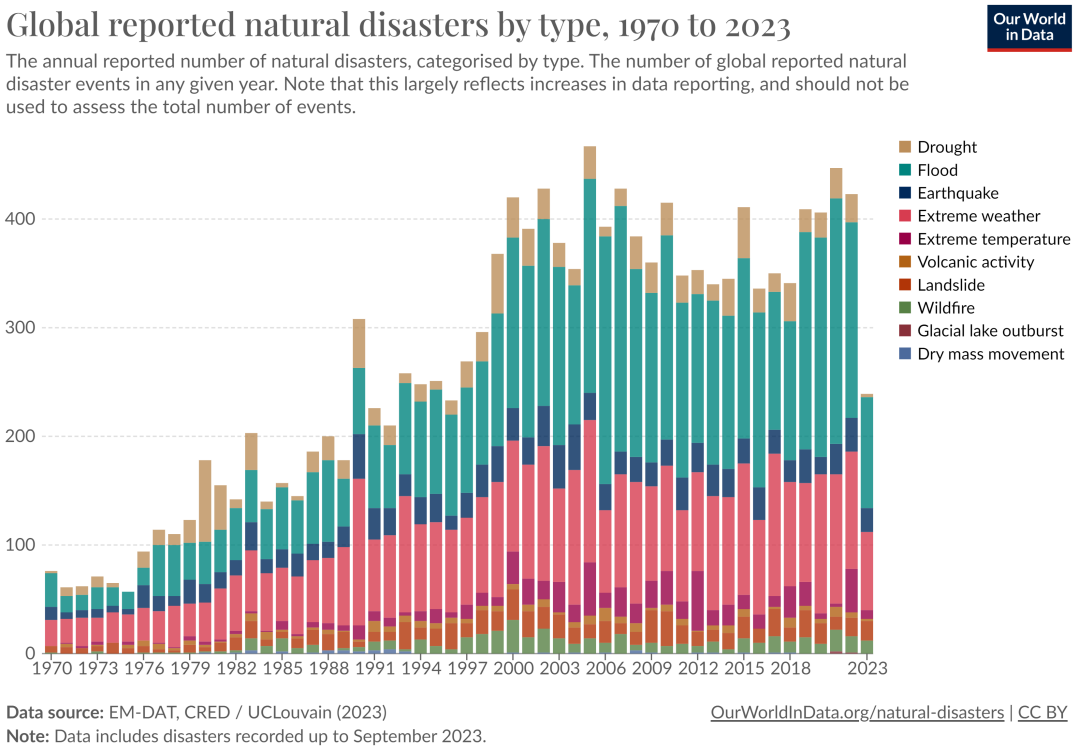


Figure 2: Increase in Frequency of Natural Disasters globally. Source: Our World in Data 2024

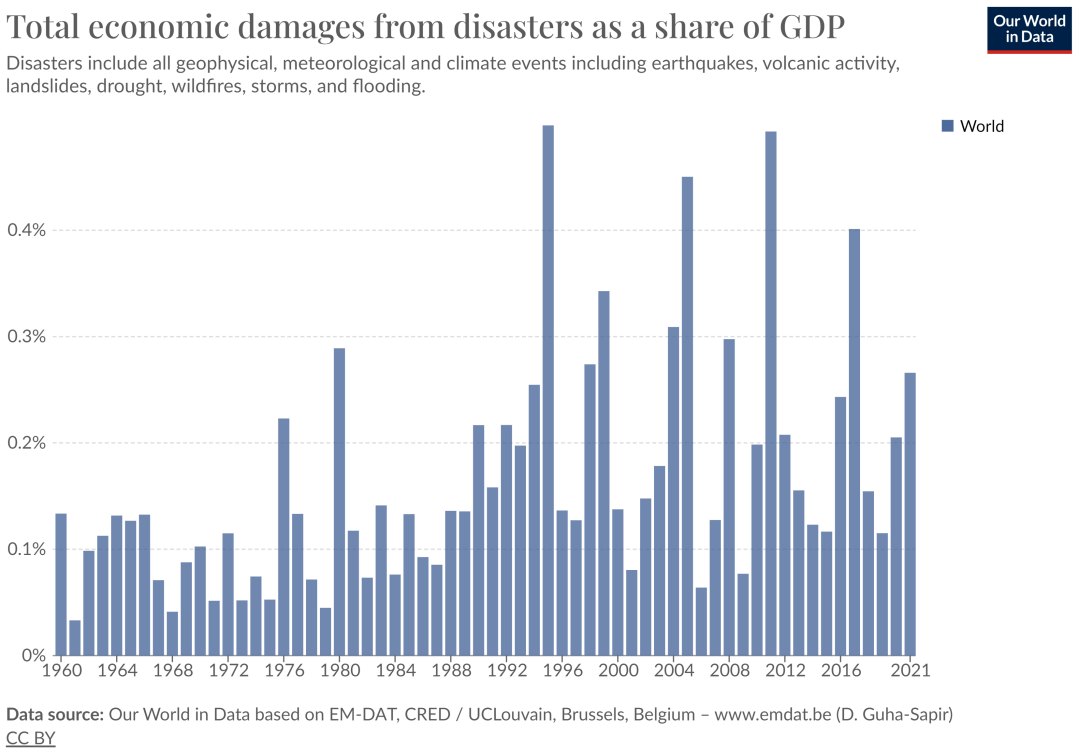
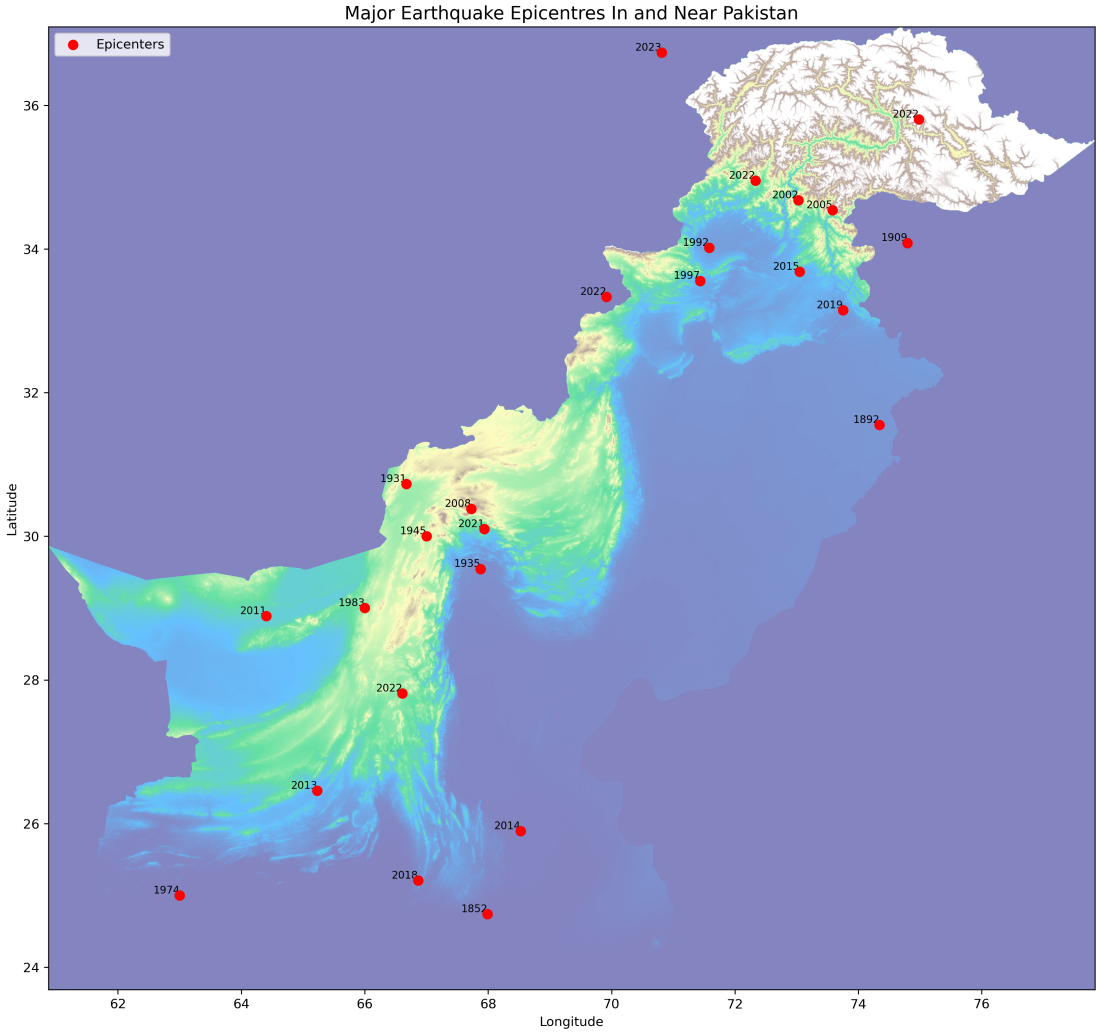


Figure 3: How the economic damages from natural disasters as a percentage of GDP are increasing globally. Source: Our World in Data 2024



Data source: https://en.m.wikipedia.org/wiki/List_of_earthquakes_in_Pakistan

Figure 4: Epicentres of Main Earthquakes in and near Pakistan.

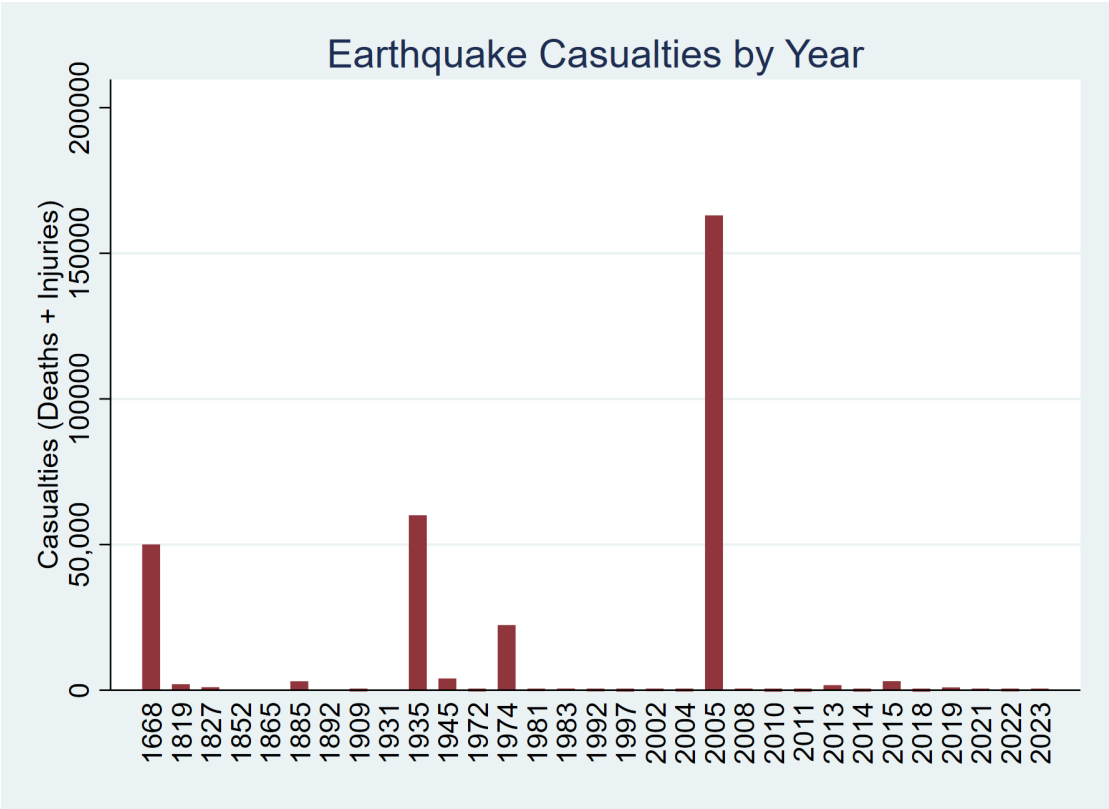


Figure 5: Loss of Lives Over Years Due to Earthquakes in Pakistan

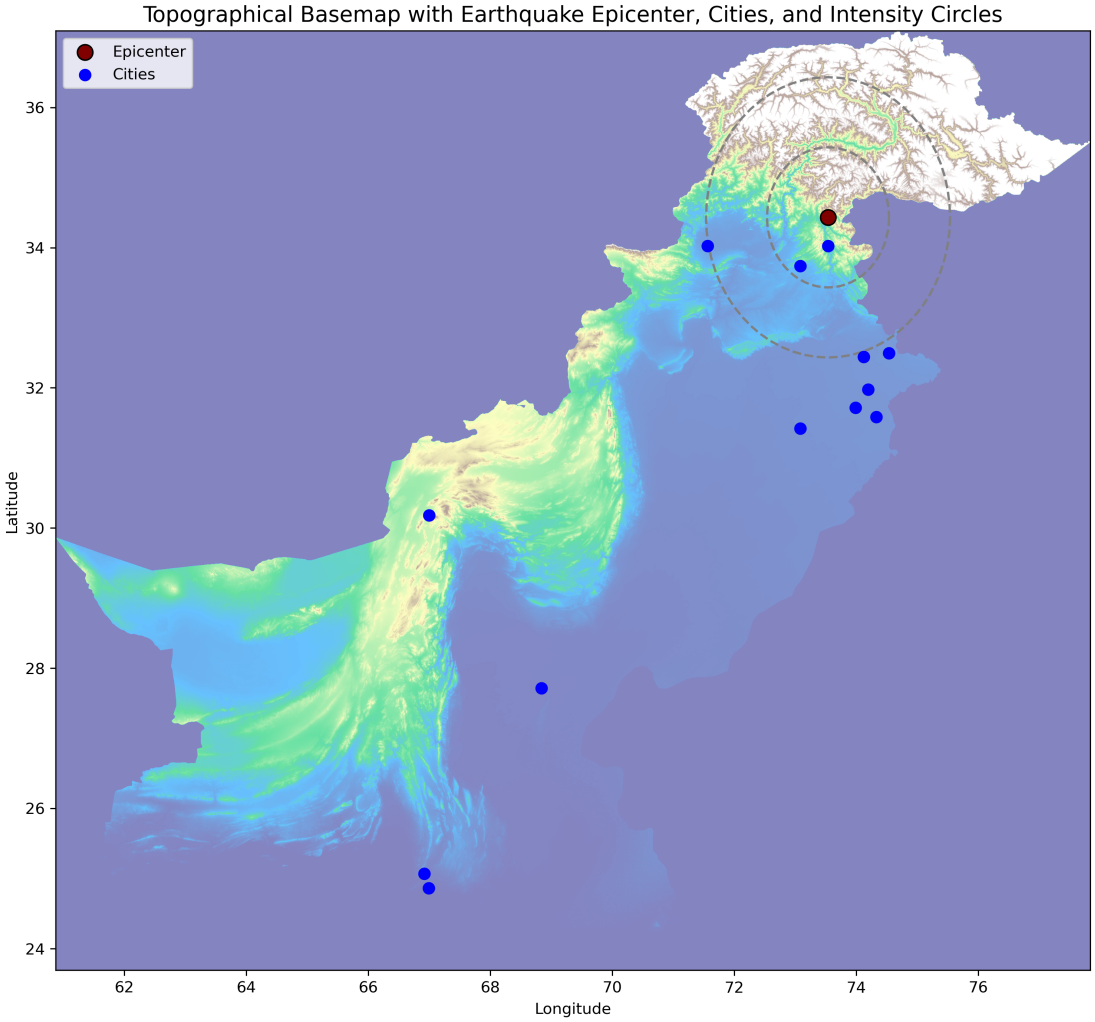


Figure 6: Earthquake Epicentre and Firm Locations

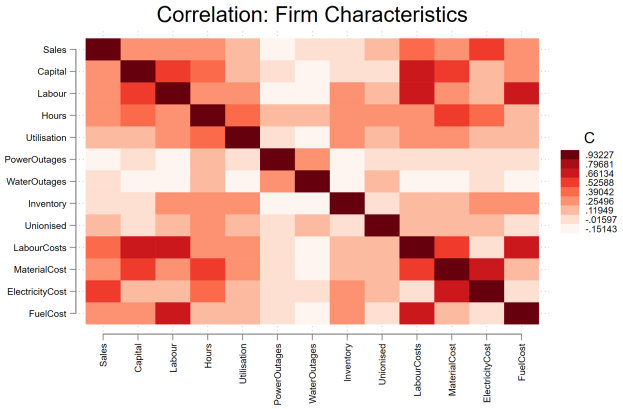


Figure 7: Correlates of Firms Operations

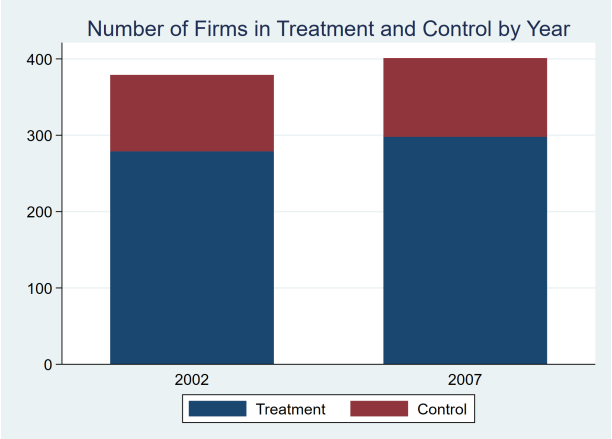


Figure 8: Firms by Exposure

Table 9: Summary Statistics

Variables	Count	Mean	Std. Dev	Min	Max
Annual Sales	759	2.3e+08	1.1e+09	0	1.8e+10
Labour Costs	780	1.1e+07	5.0e+07	0	7.2e+08
No. of Employees	780	40.24	103.43	0	2000
Hours of Operations	780	32.22	40.22	0	168
Exporter	780	0.36	0.48	0	1
Days of Inventory	780	33.236	43.671	0	365
New Product Introd.	780	3.63	16.54	0	100

Note: This table summarises the key variables in the dataset. Annual Sales and Labour Costs record large variations, exporter is a categorical variable that takes on the value 1 for an exporting firm, computerisation is also a categorical variable that takes on the value 1 if a firm uses computers, days of inventory is the number of days for which a primary input's stock is kept in the store, new product introduced is a categorical variable that takes on the value 1 if the firm introduced a new product in the last fiscal year.

Table 10: Summary Statistics By Treatment

Variables	Control	Treatment	P-Value
Annual Sales	1.9e+08	1.1e+08	0.25
	(5.7e+08)	(5.4e+08)	
Labour Costs	9.6e+06	3.8e+06	0.03
	(3.4e+07)	(1.9e+07)	
No. of Employees	41	29	0.08
	(59.45)	(61.34)	
Days of Inventory	30.34	25.54	0.12
	(27.50)	(26.43)	
Exporter	0.170	0.301	0.01
	(0.38)	(0.46)	

Note: This table summarises the key variables in the dataset by Treatment Status. Annual Sales and Labour Costs record large variations, exporter is a categorical variable that takes on the value 1 for an exporting firm, computerisation is also a categorical variable that takes on the value 1 if a firm uses computers, days of inventory is the number of days for which a primary input's stock is kept in the store, new product introduced is a categorical variable that takes on the value 1 if the firm introduced a new product in the last fiscal year.

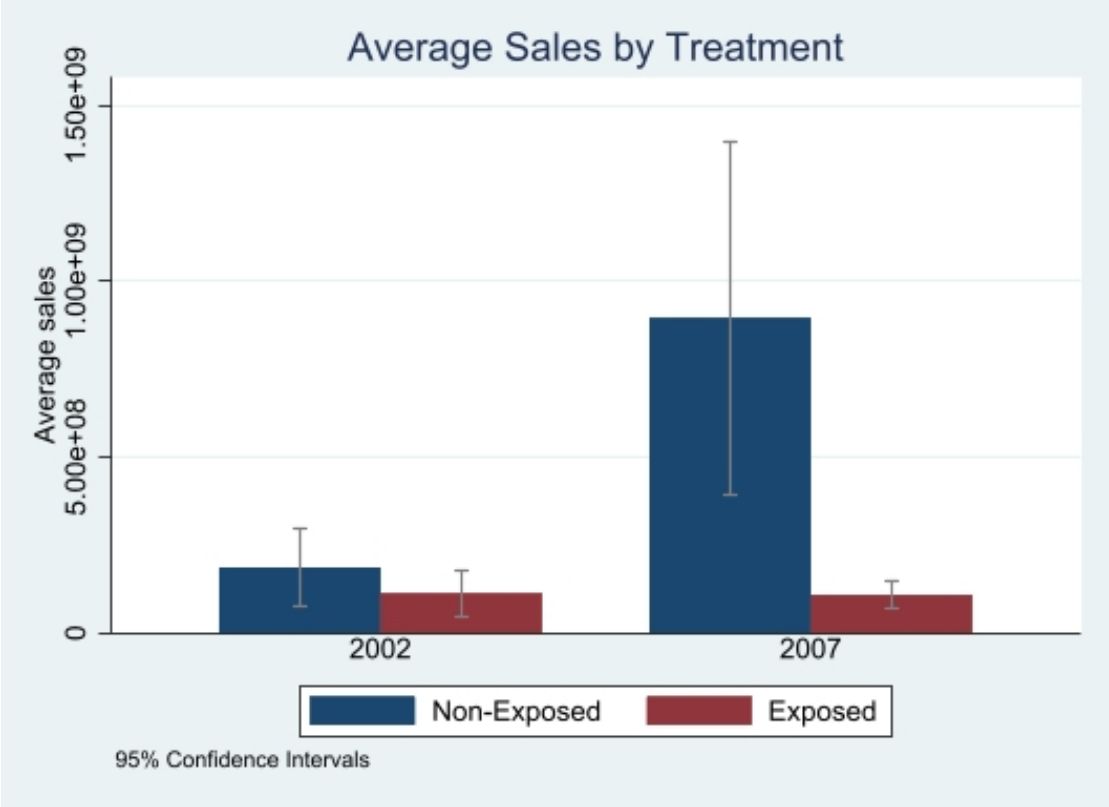


Figure 9: Sales by Exposure



Figure 10: Average Sales by Firm Size

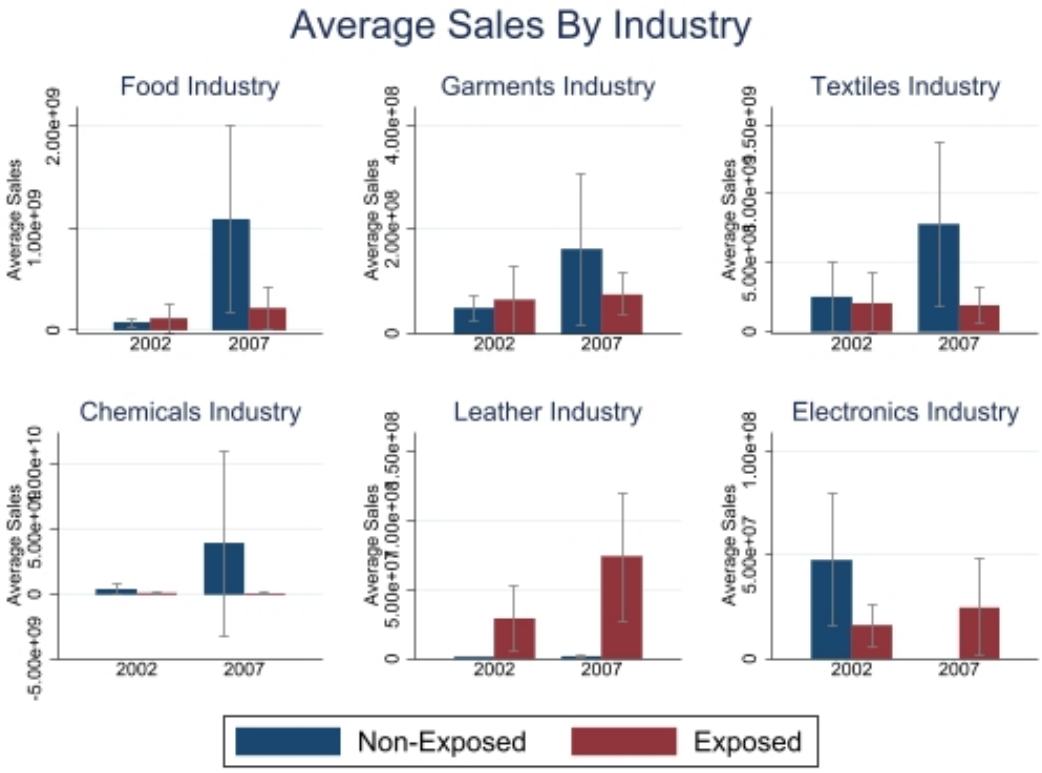


Figure 11: Average Sales by Industry

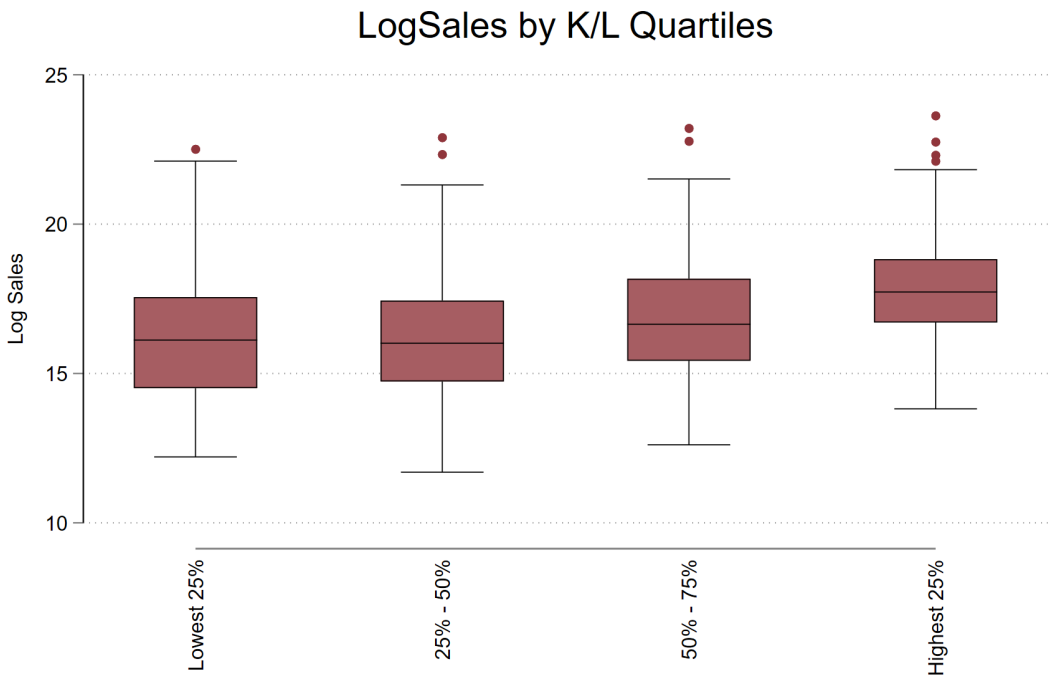


Figure 12: Log(Sales) by Capital-Labour Ratio

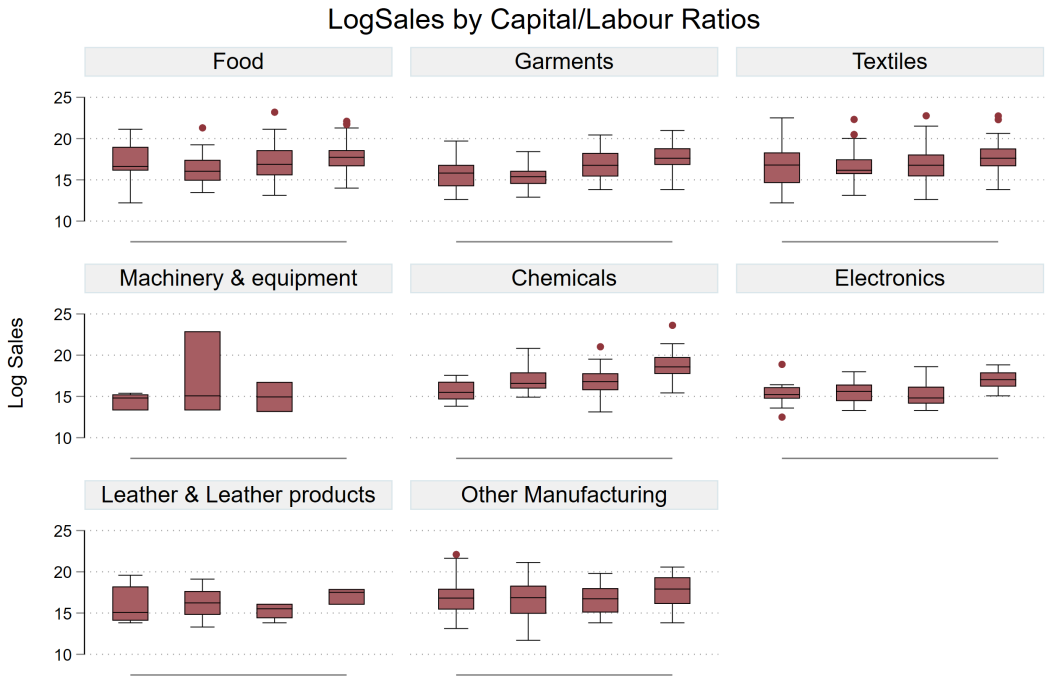


Figure 13: Log(Sales) by Capital-Labour Ratio By Industry

Table 11: Impact on Sales,Capital Stock, Buildings

	(1)	(2)	(3)
	Log Sales	Log Stock	Log Buildings
Treatment=1 × Post=1	-.794***	-5.117***	-5.117***
	(.231)	(1.350)	(1.471)
Exporter	1.275***	1.665***	2.267***
	(.154)	(.360)	(.493)
Observations	759	707	692
Firm Level Controls	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes

Note: This table reports the impact of the earthquake on Log Sales, Log Capital Stock and Log Buildings. The treatment dummy is interacted with the post dummy. Firms within 400 km of the epicenter are exposed and ones outside are not. The regression is controlling for firm level variables and industry fixed effects. Standard errors in parentheses:$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. The dataset used is the World Bank Enterprise Survey.

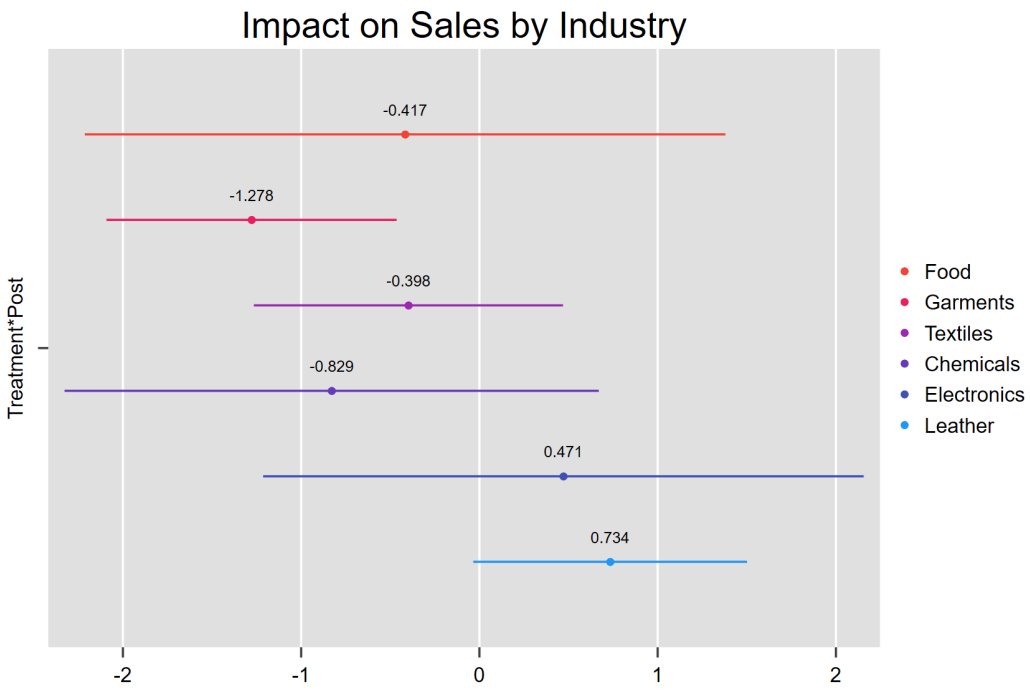


Figure 14: Heterogeneous Impact on Sales by Industry

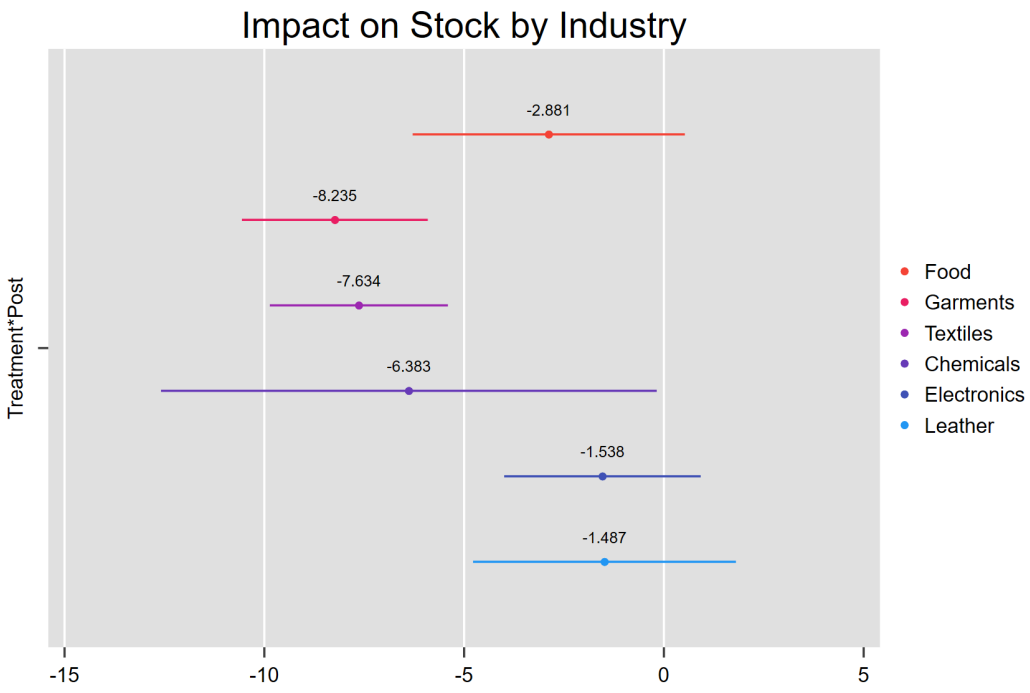


Figure 15: Heterogeneous Impact on Capital Stock by Industry

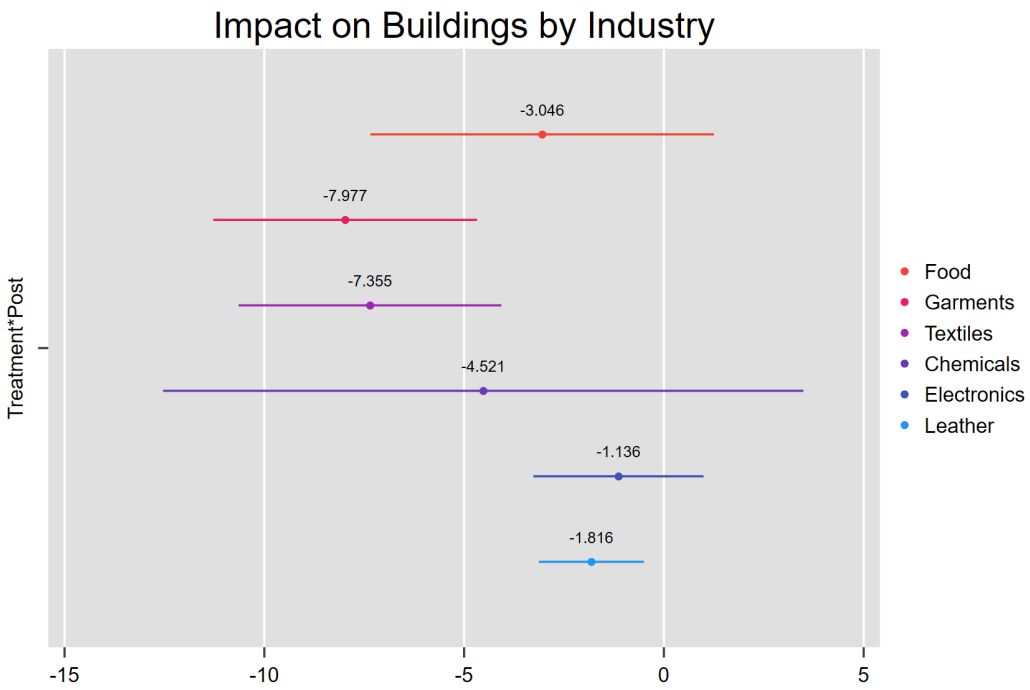


Figure 16: Heterogeneous Impact on Land and Buildings by Industry

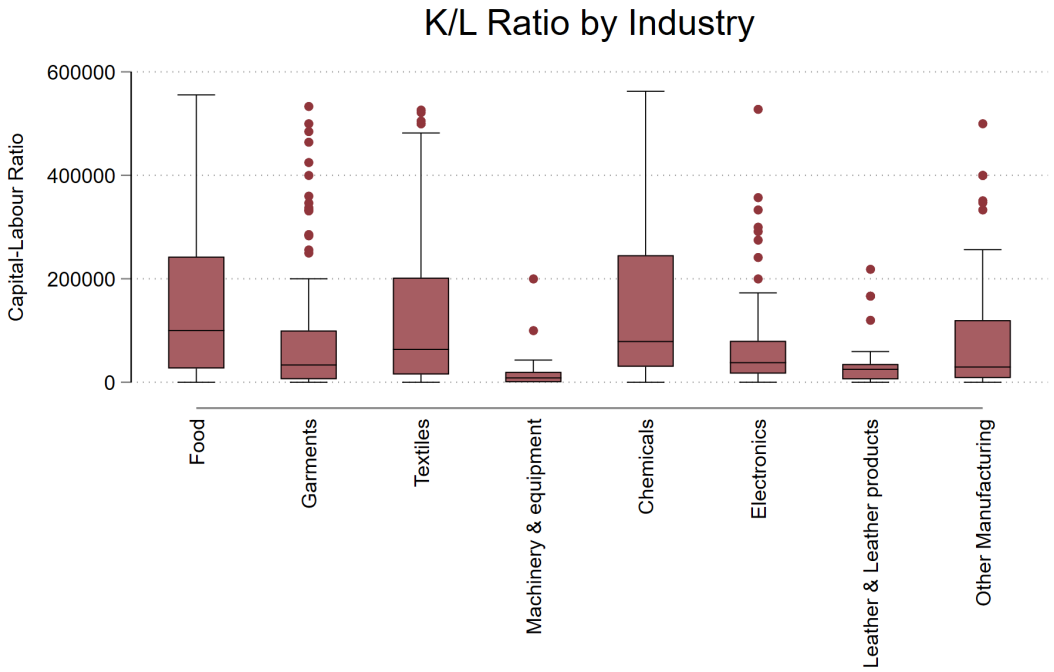


Figure 17: Capital-Labour Ratio by Industry

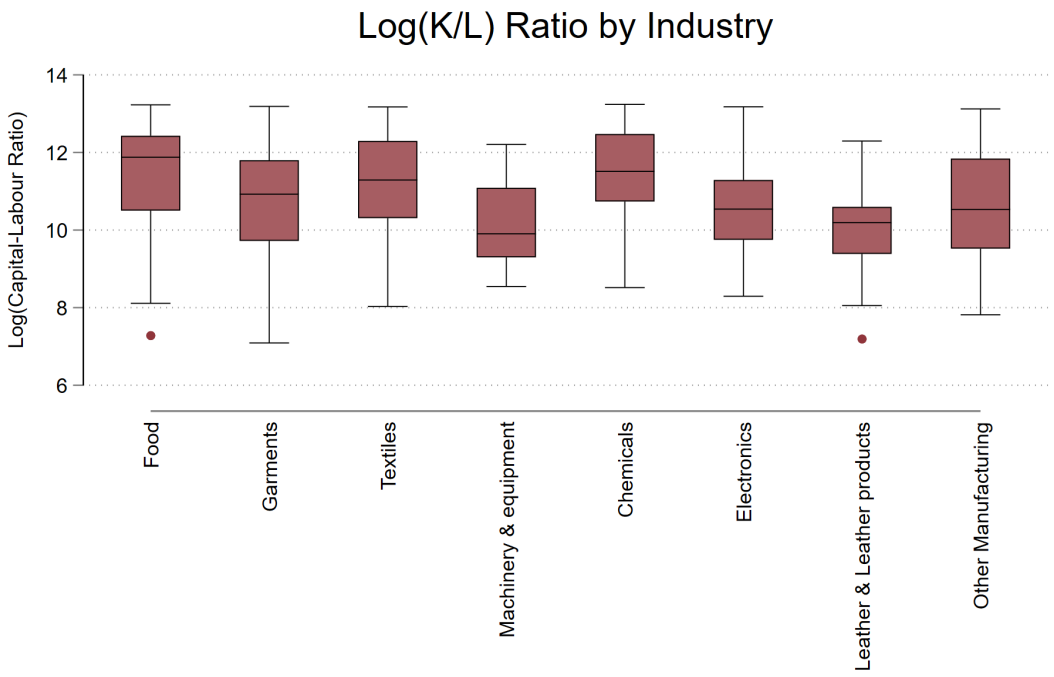


Figure 18: Log(Capital-Labour) Ratio by Industry

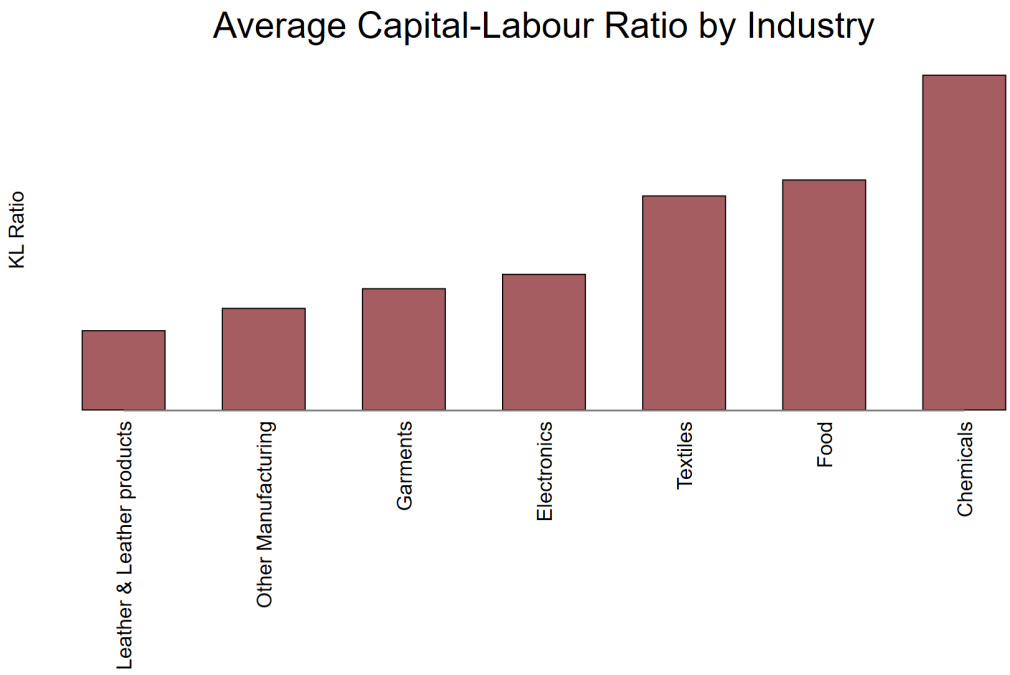


Figure 19: Average Capital-Labour Ratio by Industry

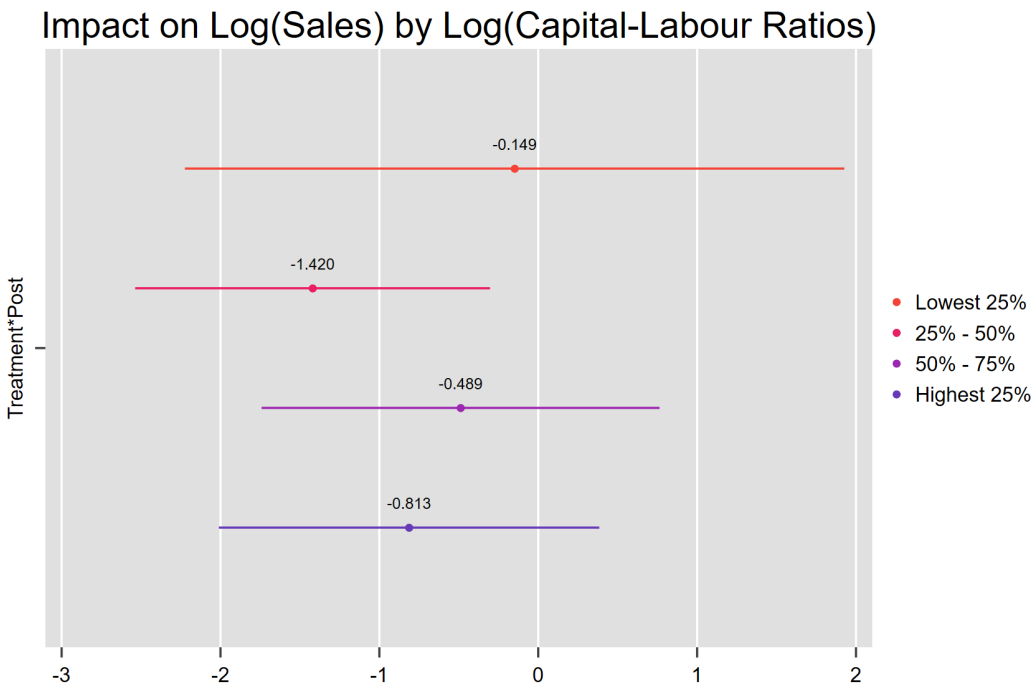


Figure 20: Impact on Sales by Capital-Labour Ratio

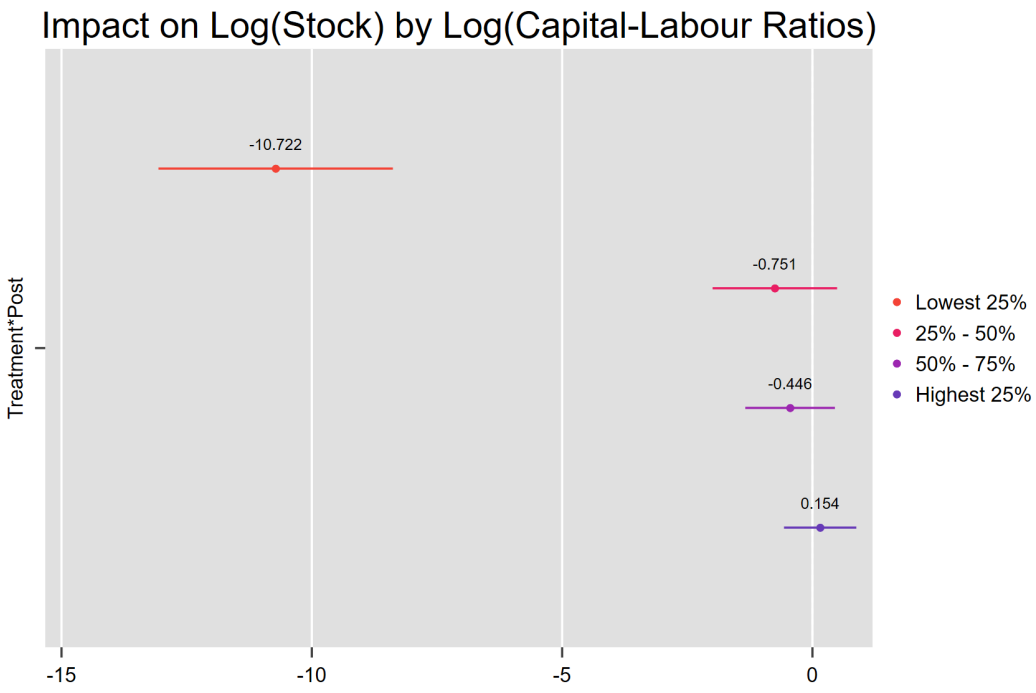


Figure 21: Impact on Capital by Capital-Labour Ratio

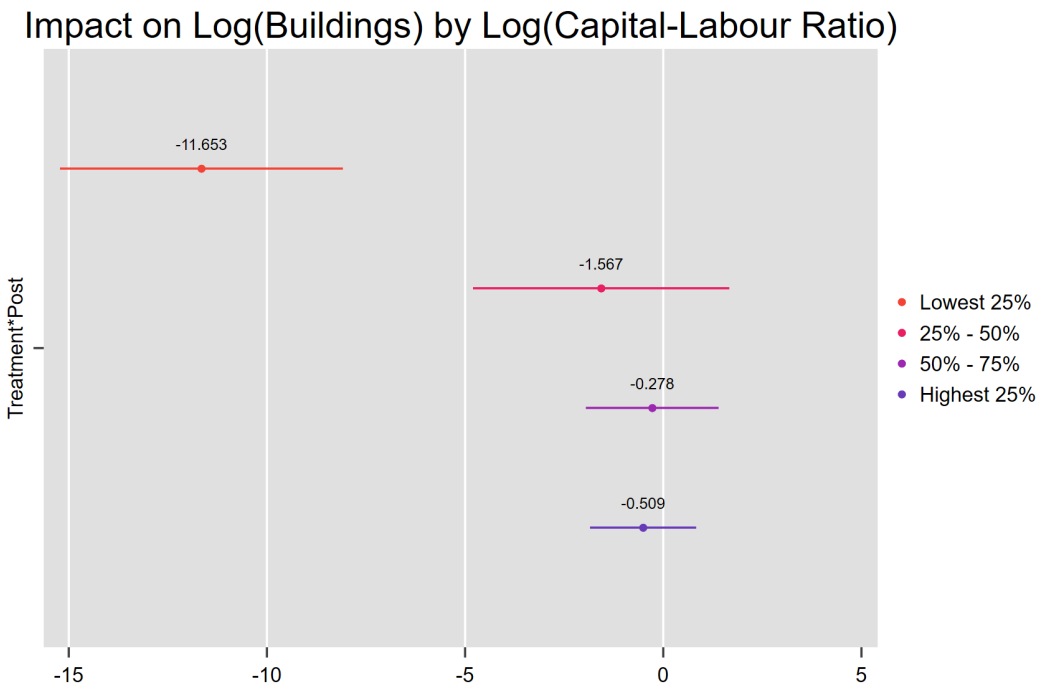


Figure 22: Impact on Buildings by Capital-Labour Ratio

Table 12: Impact on Salesforce

	(1) Production	(2) Non-Production	(3) Skilled	(4) Unskilled
Treatment=1 × Post=1	.01	-.59***	.07	-.46***
	(.14)	(.12)	(.13)	(.17)
Observations	692	777	778	761
Firm Level Controls	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes

Note: This table reports the impact of the earthquake on Labour Employed. The Treatment dummy is interacted with the Post dummy. Firms within 400 km of the epicenter are exposed and ones outside are not. The regression is controlling for firm level variables and industry fixed effects. Standard errors in parentheses:$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. The dataset used is the World Bank Enterprise Survey.

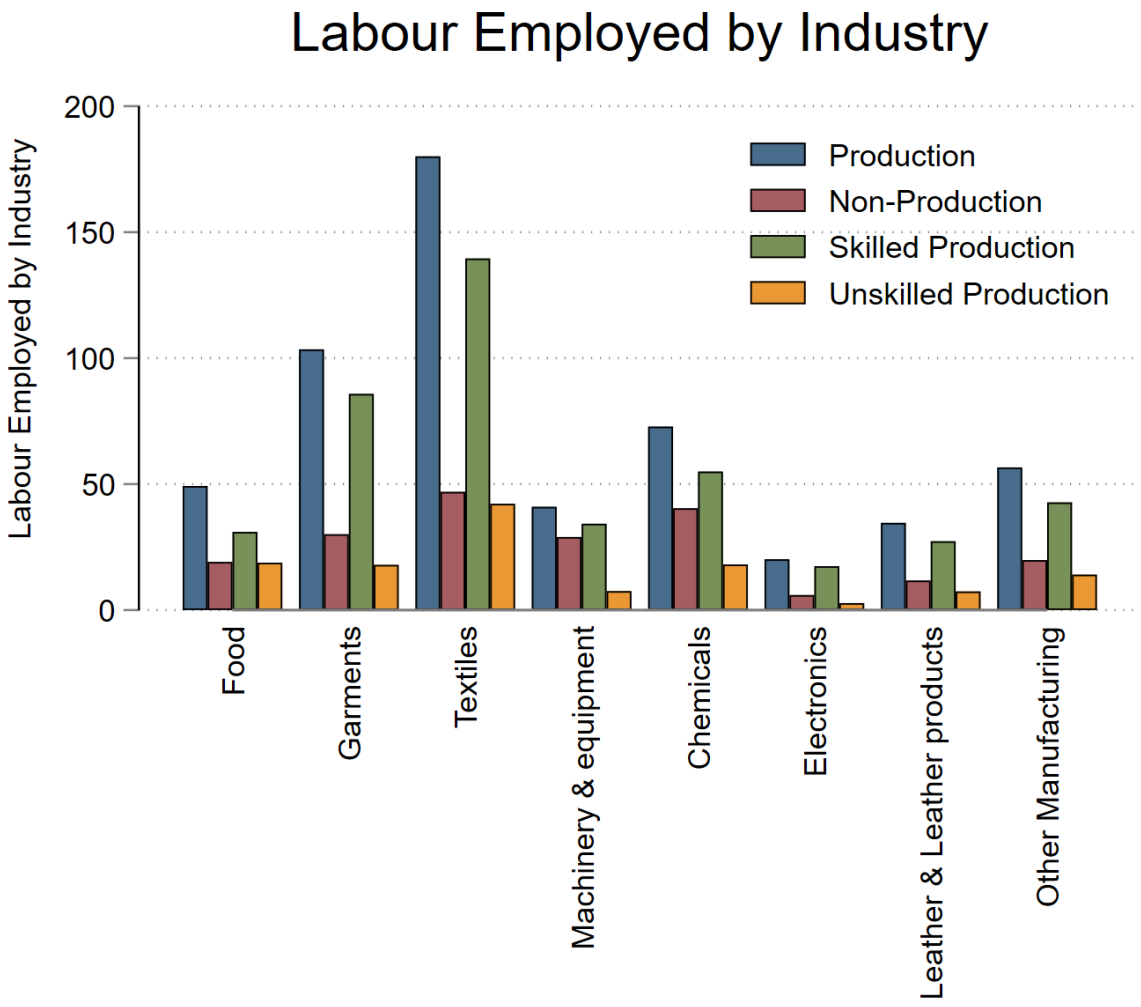


Figure 23: Labour employed by Industry

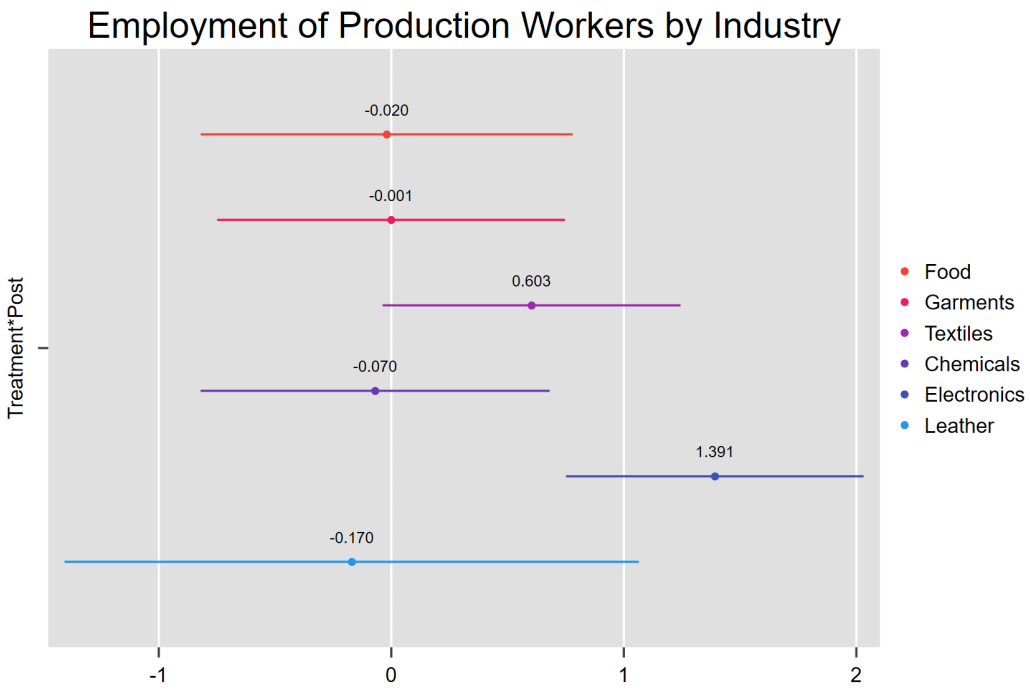


Figure 24: Impact on Employment of Workers by Industry

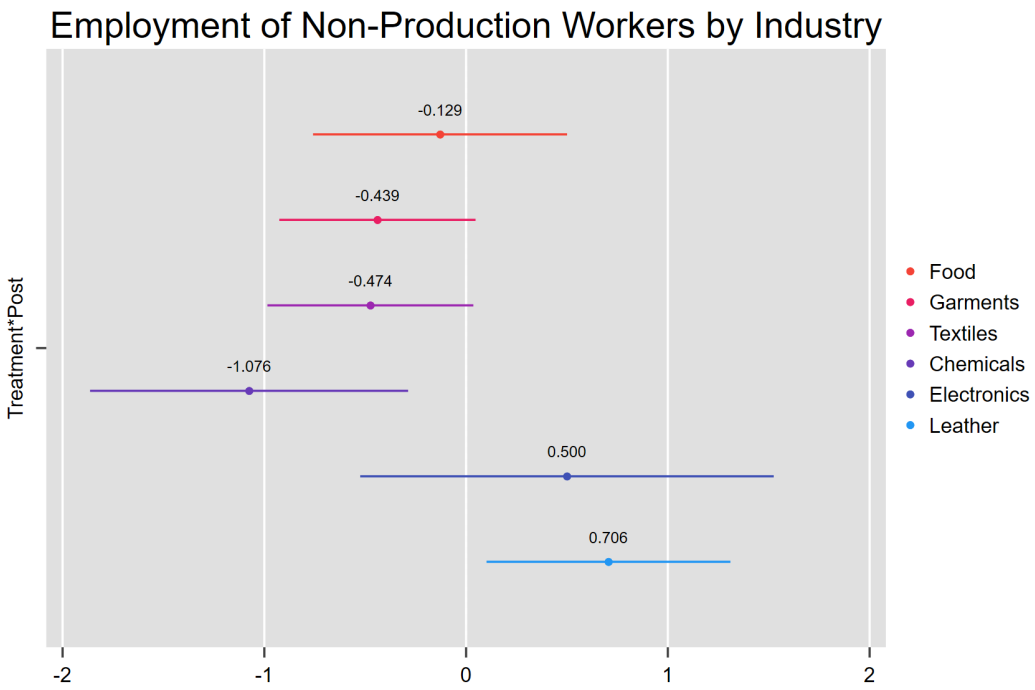


Figure 25: Impact on Employment of Workers by Industry



Figure 26: Impact on Employment of Workers by Industry

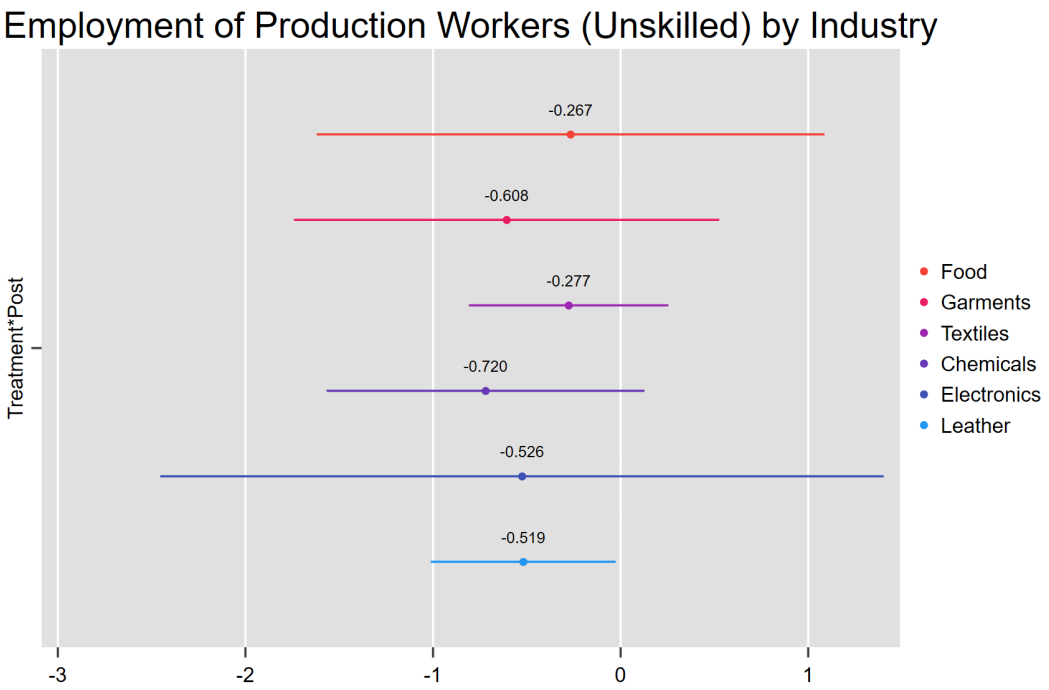


Figure 27: Impact on Employment of Workers by Industry

Table 13: How did Firms Adapt?

	(1)	(2)
	Hours of Operations	Level of utilisation of facilities
Treatment=1 × Post=1	58.297***	56.659***
	(4.603)	(5.197)
Exporter	2.279**	-1.898
	(.983)	(2.516)
Observations	780	780
Firm Level Controls	Yes	Yes
Industry FE	Yes	Yes

Note: This table reports the impact of the earthquake on Firm Level Adaptation. The Treatment dummy is interacted with the Post dummy. Firms within 400 km of the epicenter are exposed and ones outside are not. The regression is controlling for firm level variables and industry fixed effects. Standard errors in parentheses:$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. The data used is from the World Bank Enterprise Survey.

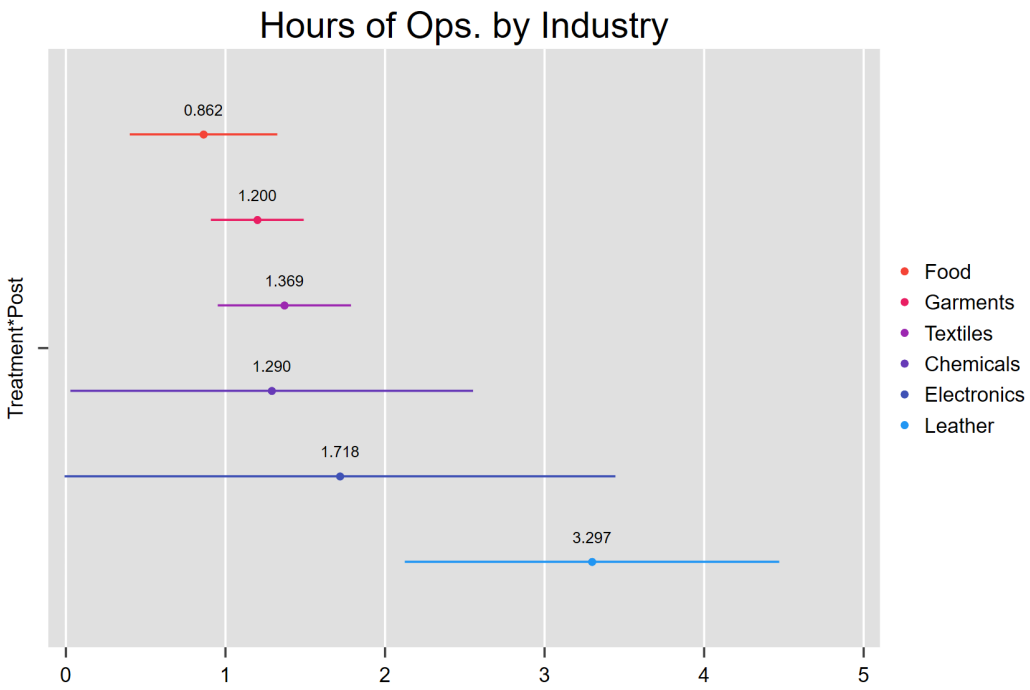


Figure 28: Impact on Hours Of Operations by Industry

Table 14: Infrastructure Impact and Adaptation

	(1) Electricity	(2) Percent electricity from generators
Treatment=1 × Post=1	1.421***	11.753***
	(.164)	(2.143)
Observations	779	534
Firm Level Controls	Yes	Yes
Industry FE	Yes	Yes

Note: This table reports the impact of the earthquake on Infrastructure Adaptation. The Treatment dummy is interacted with the Post dummy. Firms within 400 km of the epicenter are exposed and ones outside are not. The regression is controlling for firm level variables and industry fixed effects. Standard errors in parentheses:$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. The data used has been sourced from World Bank Enterprise Surveys.

Table 15: Do Firms Diversify Markets?

	(1) Diversify?
Treatment=1 × Post=1	.106*
	(.059)
Observations	647
Firm Level Controls	Yes
Industry FE	Yes

Note: This table reports the impact of the earthquake on Firm's Market Diversification. The treatment dummy is interacted with the post dummy. Firms within 400 km of the epicenter are exposed and ones outside are not. The regression is controlling for firm level variables and industry fixed effects. Standard errors in parentheses:$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. The dataset used is the World Bank Enterprise Survey.

Table 16: Do Firms Innovate?

	Innovate
Treatment=1	-.204***
	(.060)
Observations	401
Firm Level Controls	Yes
Industry FE	Yes

Note: This table reports the impact of the earthquake on Firm's Innovation. The treatment dummy is interacted with the post dummy. Firms within 400 km of the epicenter are exposed and ones outside are not. The regression is controlling for firm level variables and industry fixed effects. Standard errors in parentheses:$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. The dataset used is the World Bank Enterprise Survey.

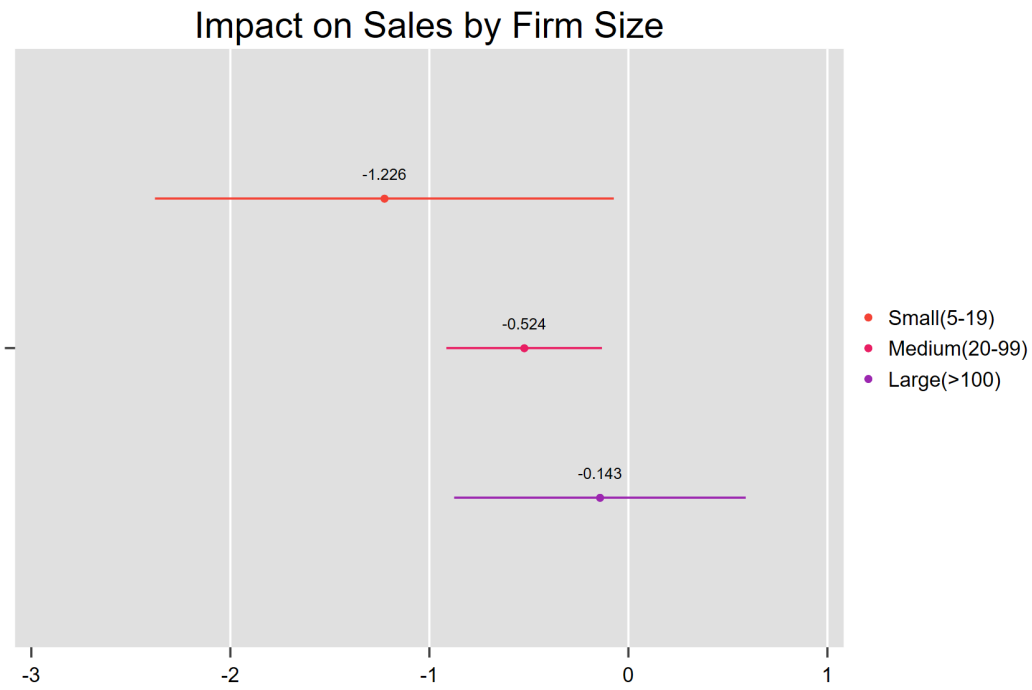


Figure 29: Impact on Sales by Firm Size



Figure 30: Impact on Stock by Firm Size

Table 17: Grants

	(1) SMEDA	(2) EPB	(3) BOI	(4) Others
Treatment=1	.050***	-.082***	-.026*	.016
	(.016)	(.025)	(.013)	(.015)
Observations	395	396	396	236
Firm Level Controls	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes

Note: This table reports the impact of the earthquake on grants utilised. The treatment dummy is interacted with the post dummy. Firms within 400 km of the epicenter are exposed and ones outside are not. The regression is controlling for firm level variables and industry fixed effects. Standard errors in parentheses:$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. The dataset used is the World Bank Enterprise Survey.

Table 18: Robustness Check: Impact on Sales and Capital Stock

	(1) Log Sales	(2) Log Stock
Post=1 × Distance	.001***	-.000
	(.000)	(.001)
Observations	760	708
Firm Level Controls	Yes	Yes
Industry FE	Yes	Yes

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: This table reports the impact of the earthquake on sales and capital stock using continuous treatment measure. The treatment dummy is interacted with the post dummy. The regression is controlling for firm level variables and industry fixed effects. Standard errors in parentheses:$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. The dataset used is the World Bank Enterprise Survey.

Appendix B

A Theoretical Model Derivation

This appendix provides a detailed, step-by-step derivation of the theoretical model described in the paper. The model illustrates how firms adapt to natural disasters when they expect minimal government aid, introducing the concept of *adaptive misallocation*, where firms over-invest in short-term protective measures at the expense of long-term growth.

A.1 Step 1: Pre-Disaster Production Function

The firm's production function is given by the standard Cobb-Douglas form:

$$Y_t = AK_t^{\alpha} L_t^{\beta},$$

where:

- Y_t: Output in time period t,
- A: Total factor productivity (TFP),
- K_t: Capital stock in period t,
- L_t: Labor employed in period t,
- α: Elasticity of output with respect to capital,
- β: Elasticity of output with respect to labor.

Assumptions: 1. The production function exhibits constant returns to scale ($\alpha+\beta = 1$). 2. TFP (A) reflects baseline productivity unaffected by external shocks.

A.2 Step 2: Post-Disaster Adjustments

After a disaster, the firm experiences reductions in capital stock and TFP due to physical damage and operational disruptions. The post-disaster production function becomes:

$$Y_t' = A'(K_t')^{\alpha} L_t^{\beta},$$

where:

$$A' = (1-\gamma)A, \quad K_t' = (1-\delta)K_t.$$

Here:

- γ: Fractional reduction in TFP due to disaster,
- δ: Fractional reduction in capital stock due to disaster.

Substituting these adjustments into the production function gives:

$$Y_t' = (1-\gamma)A\left((1-\delta)K_t\right)^{\alpha} L_t^{\beta}.$$

Expanding:

$$Y_t' = (1-\gamma)A(1-\delta)^{\alpha} K_t^{\alpha} L_t^{\beta}.$$

This represents the immediate reduction in output due to disaster-induced losses in capital and productivity.

A.3 Step 3: Incorporating Adaptation Efforts

Firms can partially offset the negative impacts of disasters by investing in adaptation efforts (A_t), which improve TFP but exhibit diminishing returns. The production function with adaptation is:

$$Y_t = A_0\left(1+\theta A_t^{\gamma}\right) K_t^{\alpha} L_t^{\beta},$$

where:

- A_0: Baseline TFP post-disaster,
- A_t: Adaptation efforts by the firm in period t,
- θ: Marginal effect of adaptation on productivity,
- γ: Parameter governing diminishing returns to adaptation ($\gamma < 1$).

Assumptions: 1. Adaptation efforts (A_t) are costly, and their marginal productivity decreases as A_t increases. 2. The baseline TFP (A_0) reflects post-disaster conditions before adaptation efforts are applied.

A.4 Step 4: Including Government Aid Expectations

Firms anticipate future government aid ($E_t[G_{t+1}]$), which reduces their need for adaptation. The production function incorporating government aid expectations is:

$$Y_t = A_0\left(1+\theta A_t^{\gamma}\right)\left(1-\lambda E_t[G_{t+1}]^{\delta}\right) K_t^{\alpha} L_t^{\beta},$$

where:

- λ: Sensitivity of output to government aid,
- δ: Elasticity of output with respect to government aid expectations.

Explanation: - Higher expected government aid ($E_t[G_{t+1}]$) reduces the firm's reliance on private adaptation efforts (A_t). - λ and δ determine the magnitude of this substitution effect.

A.5 Step 5: Adaptive Misallocation

Firms expecting minimal government aid over-invest in adaptation, resulting in inefficiencies. These inefficiencies are represented by the misallocation term (τ_A):

$$Y_t = A_0 \left(1 + \theta A_t^{\gamma}\right) \left(1 - \lambda E_t[G_{t+1}]^{\delta}\right) K_t^{\alpha} L_t^{\beta} \left(1 - \tau_A\right),$$

where:

- $\tau_A = \eta A_t^{\zeta}$,
- $\eta > 0$: Scaling parameter for misallocation,
- $\zeta > 1$: Degree of non-linearity in misallocation costs.

Explanation: - τ_A increases with A_t, reflecting rising inefficiencies as firms over-adapt.

A.6 Step 6: Government Aid Function

Government aid (G_{t+1}) is a decreasing function of adaptation efforts and is subject to stochastic shocks:

$$G_{t+1} = G_0 - \kappa A_t + \varepsilon_t,$$

where:

- G_0: Baseline government aid,
- $\kappa > 0$: Reduction in aid due to increased adaptation,
- $\varepsilon_t \sim N(0, \sigma^2)$: Stochastic disaster shock.

Assumptions: 1. Governments respond to firm adaptation by reducing aid, reflecting resource reallocation. 2. Stochastic shocks (ε_t) capture disaster severity and government response uncertainty.

A.7 Step 7: Firm's Profit Maximisation

Firms maximise profits over the finite time horizon ($T = 5$):

$$\max_{A_t} \sum_{t=0}^{T} \beta^t \Pi_t,$$

where:

$$\Pi_t = A_0 \left(1 + \theta A_t^{\gamma}\right) \left(1 - \lambda E_t[G_{t+1}]^{\delta}\right) K_t^{\alpha} L_t^{\beta} \left(1 - \tau_A\right) - \psi A_t^2 - w L_t.$$

Explanation of Terms: - The first term represents output net of misallocation inefficiencies. - ψA_t^2: Quadratic adaptation costs. - wL_t: Labor costs.

A.8 Step 8: Optimal Adaptation Effort

The first-order condition for adaptation (A_t) is:

$$\frac{\partial \Pi_t}{\partial A_t} = \frac{\partial F}{\partial A_t} K_t^{\alpha} L_t^{\beta} (1 - \tau_A) - \frac{\partial \tau_A}{\partial A_t} F K_t^{\alpha} L_t^{\beta} - 2\psi A_t = 0.$$

Substituting $\tau_A = \eta A_t^{\zeta}$:

$$\frac{\partial \tau_A}{\partial A_t} = \eta \zeta A_t^{\zeta - 1}.$$

Simplifying:

$$A_t^* = \frac{\frac{\partial F}{\partial A_t} K_t^{\alpha} L_t^{\beta} - \eta \zeta A_t^{\zeta - 1} F K_t^{\alpha} L_t^{\beta}}{2\psi}.$$

A.9 Step 9: Bayesian Updating

Firms update their expectations about government aid using historical observations:

$$P_t(b|\text{history}) = \frac{P(b_t) P(b_{t+1}|b_t)}{P(G_t) P(b_{t+1}|G_t) + P(b_t) P(b_{t+1}|b_t)}.$$

A.10 Step 10: Steady-State Solution

At steady state, adaptation (A^*) and government aid expectations ($E[G^*]$) stabilise:

$$A^* = \left(\frac{A_0 \theta \gamma (1 - \lambda E[G^*]^\delta) K^\alpha L^\beta (1 - \tau_A)}{\psi \zeta} \right)^{\frac{1}{\zeta - \gamma}},$$

$$E[G^*] = \frac{G_0}{1 + \kappa (A^*)^\eta}.$$

Appendix C

Dynamic Extension to the Theoretical Model: Adaptive Misallocation

The model extends the static framework by incorporating an infinite time horizon. Firms optimise their profits over $t = 0, 1, 2, \ldots, \infty$ while considering the dynamic interaction between adaptation efforts and government aid.

Dynamic Production Function

The production function for firm i in period t is given as:

$$Y_{it} = F(A_{it}, E_t[G_{t+1}])K_{it}^{\alpha} L_{it}^{\beta}(1 - \tau A_{it}),$$

where:

- A_{it}: Adaptation effort by the firm.
- $E_t[G_{t+1}]$: Expected government aid in the next period.
- τA_{it}: Misallocation term reflecting inefficiencies from over-adaptation.

Objective Function

Firms maximise the present value of profits:

$$\max_{A_{it}, L_{it}} \sum_{t=0}^{\infty} \beta^t \left[Y_{it} - \psi A_{it}^2 - w L_{it} \right],$$

subject to the following dynamics:

$$K_{it+1} = (1 - \delta)K_{it} + \phi I_{it}, \quad E_t[G_{t+1}] = (1 - \rho)G_t + \epsilon_t,$$

where:

- β: Discount factor.
- δ: Depreciation rate of capital.
- ϕ: Efficiency of investment I_{it}.

- ϵ_t: Stochastic term for government aid.

First-Order Conditions

The optimal adaptation effort A_{it} satisfies:

$$\frac{\partial Y_{it}}{\partial A_{it}} - \frac{\partial \tau}{\partial A_{it}} Y_{it} - 2\psi A_{it} = 0,$$

and the optimal labor input L_{it} satisfies:

$$\frac{\partial Y_{it}}{\partial L_{it}} = w.$$

Feedback Loop

The feedback loop arises as follows:

1. Increased A_{it} reduces $E_t[G_{t+1}]$.
2. Lower $E_t[G_{t+1}]$ reinforces the need for higher A_{it+1}, perpetuating inefficiencies.
3. This leads to a breakdown of the social contract, where firms over-compensate for government inaction.

Policy Implications

- Introduce pre-committed government aid to reduce uncertainty.
- Implement co-financing schemes to align firm adaptation with public investments.
- Incentivise innovation to counteract the inefficiencies of adaptive misallocation.

Details: Dynamic Model Extension and Explanation

1. Intertemporal Optimisation

The dynamic model expands the static framework by introducing optimisation over an infinite time horizon. Firms maximise the present value of profits:

$$\max_{A_{it}, L_{it}} \sum_{t=0}^{\infty} \beta^t \left[Y_{it} - \psi A_{it}^2 - w L_{it} \right],$$

where β is the discount factor. This formulation forces firms to balance immediate survival efforts with their long-term growth objectives, creating trade-offs that are absent in the static model.

2. Dynamic Capital Accumulation

The inclusion of capital dynamics allows for the modeling of recovery and growth over time:

$$K_{it+1} = (1 - \delta)K_{it} + \phi I_{it},$$

where δ is the depreciation rate and ϕ represents the efficiency of investment. This equation links current investment decisions to future production capacity, enabling the analysis of long-term resilience-building efforts.

3. Government Aid as a Stochastic Process

The model captures the uncertainty in government response through a stochastic process:

$$E_t[G_{t+1}] = (1 - \rho)G_t + \epsilon_t,$$

where ϵ_t introduces randomness. This reflects the unpredictable nature of government behavior in post-disaster scenarios, which firms must consider dynamically when planning their adaptation efforts.

4. Feedback Mechanism

A core feature of the dynamic model is the feedback loop:

1. Increased adaptation effort (A_{it}) reduces future expected government aid ($E_t[G_{t+1}]$).
2. Lower government aid prompts further adaptation, creating a reinforcing cycle.

This feedback leads to a breakdown of the social contract, perpetuating inefficiencies as firms bear a disproportionate share of disaster recovery costs.

5. Time-Consistent Behavior

By considering the temporal dimension, firms face intertemporal trade-offs:

- Over-adaptation in the short term may reduce current misallocation costs but exacerbates inefficiencies in future periods due to diminished public support.

- This creates a dynamic tension between immediate recovery and sustainable long-term growth.

6. Bayesian Belief Updating

Firms dynamically revise their expectations of government aid using Bayesian inference:

$$P_t(b|history) = \frac{P(b_t)P(b_{t+1}|b_t)}{P(G_t)P(b_{t+1}|G_t) + P(b_t)P(b_{t+1}|b_t)}.$$

This process captures the evolution of trust in the government based on past aid responses, influencing firms' future strategies and adaptation decisions.

This extension adds to the existing theory on disaster response and adaptation.

Appendix D

Author Statement

I, Maha Rehman, am the sole author of this manuscript. I was solely responsible for the conception, design, material preparation, data collation, analysis, and manuscript writing. I have reviewed and approved the final version of the manuscript for submission.

References

Andrabi, Tahir, Benjamin Daniels, and Jishnu Das ((2023)). "Human capital accumulation and disasters: Evidence from the Pakistan earthquake of 2005". In: *Journal of Human Resources* 58.4, pp. 1057–1096.

Andrabi, Tahir and Jishnu Das ((2017)). "In aid we trust: Hearts and minds and the Pakistan earthquake of 2005". In: *Review of Economics and Statistics* 99.3, pp. 371–386.

Balboni, Clare, Johannes Boehm, and Mazhar Waseem ((2023)). *Firm Adaptation in Production Networks: Evidence from Extreme Weather Events in Pakistan*. Tech. rep. Working Paper.

Basker, Emek and Javier Miranda ((2018)). "Taken by Storm: Business Financing and Survival in the Aftermath of Hurricane Katrina". In: *Journal of Economic Geography* 18.6, pp. 1285–1313.

Bento, Pedro and Diego Restuccia (2017). "Misallocation, Establishment Size, and Productivity". In: *American Economic Journal: Macroeconomics* 9.3, pp. 267–303.

Bilal, A. and D.R. Kanzig (2024). "The Macroeconomic Impact of Climate Change: Global vs. Local Temperature". In: *National Bureau of Economic Research Working Paper Series* 32450.

Bloom, Nicholas et al. (2013). "Does Management Matter? Evidence from India". In: *The Quarterly Journal of Economics* 128.1, pp. 1–51.

Born, Patricia and W. Kip Viscusi (2006). "The Catastrophic Effects of Natural Disasters on Insurance Markets". In: *Journal of Risk and Uncertainty* 33, pp. 55–72.

Bruggeman, Valerie, Michael G. Faure, and Klaus Fiore (2010). "The Government as Reinsurer of Catastrophe Risks?" In: *The Geneva Papers on Risk and Insurance* 35.3, pp. 369–390.

Caselli, Francesco and James Feyrer (2007). "The Marginal Product of Capital". In: *The Quarterly Journal of Economics* 122.2, pp. 535–568.

Castro-Vincenzi, Julio (2022). *Climate Hazards and Resilience in the Global Car Industry*. Unpublished manuscript.

Cavallo, Eduardo and Ilan Noy ((2011)). "The Economics of Natural Disasters: A Survey". In: *International Review of Environmental and Resource Economics* 5.1, pp. 63–102.

Cohen, Charles and Eric Werker ((2008)). "The Political Economy of "Natural" Disasters". In: *Journal of Conflict Resolution* 52.6, pp. 795–819.

Dell, Melissa, Benjamin F. Jones, and Benjamin A. Olken ((2012)). "Temperature Shocks and Economic Growth: Evidence from the Last Half Century". In: *American Economic Journal: Macroeconomics* 4.3, pp. 66–95.

Ellis, Mia et al. ((2023)). "What Predicts the Growth of Small Firms? Evidence from Tanzanian Commercial Loan Data". In: *Journal of Globalization and Development* 0.

Frankenberg, Elizabeth et al. ((2011)). "Mortality, the family and the Indian Ocean tsunami". In: *The Economic Journal* 121.554, F162–F182.

Fuest, Clemens, Andreas Peichl, and Thilo Schaefer (2008). "Is a Flat Tax Feasible in a Grown-Up Welfare State?" In: *International Tax and Public Finance* 15.5, pp. 620–636.

Hallegatte, Stephane and Vincent Przyluski ((2010)). "The Economics of Natural Disasters: Concepts and Methods". In: *World Bank Policy Research Working Paper* 5507.

Hsiang, Solomon M. and Amir S. Jina ((2014)). *The Causal Effect of Environmental Catastrophe on Long-Run Economic Growth: Evidence from 6,700 Cyclones*. NBER Working Paper 20352. National Bureau of Economic Research.

Hsiao, Allan ((2024)). "Sea Level Rise in Jakarta: Impacts and Adaptation". In: *Working Paper*. Accessed: 2024-05-13. URL: https://allanhsiao.com/files/Hsiao_jakarta.pdf.

Hsieh, Chang-Tai and Peter J. Klenow (2009). "Misallocation and Manufacturing TFP in China and India". In: *The Quarterly Journal of Economics* 124.4, pp. 1403–1448.

Huppertz, Maximilian (2023). *Firm Reactions to Extreme Weather and Implications for Climate Change Policy*. Unpublished manuscript.

Kahn, Matthew E. ((2005)). "The Death Toll from Natural Disasters: The Role of Income, Geography, and Institutions". In: *The Review of Economics and Statistics* 87.2, pp. 271–284.

Khanna, Gaurav et al. ((2022)). "The Productivity Consequences of Pollution-Induced Migration in China". In: *American Economic Journal: Applied Economics* 14.4, pp. 244–276. DOI: 10.1257/app.20220655. URL: https://www.aeaweb.org/articles?id=10.1257/app.20220655.

Kousky, Carolyn (2010). "Learning from Extreme Events: Risk Perceptions After the Flood". In: *Land Economics* 86.3, pp. 395–422.

Kunreuther, Howard and Erwann Michel-Kerjan ((2009)). "The Development of New Catastrophe Risk Markets". In: *Annual Review of Resource Economics* 1.1, pp. 119–137.

Noy, Ilan (2009). "The macroeconomic consequences of disasters". In: *Journal of Development Economics* 88.2, pp. 221–231.

Olson, Mancur ((1996)). *The Logic of Collective Action: Public Goods and the Theory of Groups*. Harvard University Press.

Our World in Data (2024). *Natural Disasters*. URL: https://ourworldindata.org/natural-disasters (visited on 05/14/2024).

Pelli, Martino (2020). "Firm Adaptation in Production Networks". In: *Journal of Economics* 5.4, pp. 79–102.

ReliefWeb ((2005)). *Kashmir Earthquake - October 8, 2005: Impacts in Pakistan*. URL: https://reliefweb.int/report/pakistan/kashmir-earthquake-october-8-2005-impacts-pakistan (visited on 05/10/2024).

Schumpeter, Joseph A. ((1942)). *Capitalism, Socialism and Democracy*. New York: Harper & Brothers.

Tol, Richard S. J. and Gary W. Yohe ((2008)). “Natural disasters impacting a macroeconomic model with endogenous dynamics”. In: *Ecological Economics* 68.1-2, pp. 582–592. DOI: 10.1016/j.ecolecon.2008.01.024. URL: https://ideas.repec.org/a/eee/ecolec/v68y2008i1-2p582-592.html.