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The economic impact of earthquakes: A global assessment of direct and indirect losses

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Abstract

This study examines the economic impact of earthquakes through a comparative analysis of eight major seismic events. The research evaluates both direct damages—such as the destruction of housing and infrastructure—and indirect consequences, including business interruption, supply chain disruption, and GDP contraction. Total losses per event ranged from US$8 billion (Haiti 2010) to US$510 billion (Japan 2011), with the ratio of indirect to direct losses spanning 0.42–0.60, underscoring the systemic economic consequences beyond physical destruction. Losses as a share of GDP varied dramatically, from 3% in China to 120% in Haiti, highlighting structural vulnerability in lower-income economies. On average, housing (35%) and infrastructure (25%) comprised the bulk of direct losses, while business interruption (20%), transport/logistics disruptions (12%), and spoilage (5%) accounted for other costs. High-income economies experienced elevated indirect losses due to supply chain interdependence, while low-income countries faced disproportionate economic scarring from service delays and governance gaps. These different vulnerability profiles demonstrate that post-disaster economic impacts stem not only from the magnitude of damage but also from the organizational structure of economic systems and the level of institutional capacity. Therefore, the need for more comprehensive loss accounting frameworks and integrated resilience planning that prioritize both structural safety and economic continuity is of critical importance. Earthquakes function as macroeconomic shocks whose true costs extend far beyond immediate physical destruction, particularly in a globalized economy.

1. Introduction

Earthquakes are not only considered disasters that cause widespread loss of life and serious physical destruction, but also complex socio-economic events that create deep and long-term disruptions in economic systems at local, national, and even global levels. The economic consequences of seismic disasters have a multidimensional structure and encompass both direct and indirect economic losses.

Direct economic losses are mostly related to physical damage occurring during or immediately after an earthquake. This damage includes the destruction of housing stock, commercial and industrial buildings, critical infrastructure networks (transportation, energy, communications, etc.), and public service facilities. Such losses can generally be expressed in measurable monetary terms, such as insurance claims, reconstruction costs, and emergency response expenditures.

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In contrast, indirect economic losses consist of more complex and often difficult-to-measure effects, seriously disrupting the continuity of economic activity in the post-disaster period. The cessation of production activities, disruptions in supply chains and logistics networks, bottlenecks in transportation corridors, and high losses, particularly in perishable products such as food, are the main components of these losses. Furthermore, these effects are not limited to regional economies but can also affect global trade flows and price balances.

Although it is known that indirect economic effects play a decisive role in long-term socio-economic stability, these effects have often been insufficiently considered, and in some cases completely ignored, in disaster risk management, economic assessment, and recovery planning processes. This situation reduces the effectiveness of the post-disaster recovery process and can lead decision-makers to act on incomplete or misleading information in resource allocation and policy development processes.

Over the last four decades, the economic toll of earthquakes has surged dramatically, with total losses from all natural disasters—earthquakes being a major contributor—tripling since the 1980s [1]. The 20th century alone witnessed 1,248 major earthquakes, collectively causing over US$1 trillion in damages when adjusted for inflation [2]. Recent high-profile disasters illustrate the gravity of this trend: the 2011 Great East-Japan earthquake and tsunami resulted in just direct losses of approximately US$360 billion, making it the most expensive natural disaster on record [3]. Similarly, the 2008 Sichuan earthquake in China caused direct economic damage of around US$130 billion [4], while the 2015 Nepal earthquake incurred losses equivalent to nearly 50% of the nation's GDP [5]. In the United States, annualized earthquake damage is estimated at US$14.7 billion [6].

The global economic implications of these events are particularly pronounced in urban settings, where the concentration of infrastructure, housing, and industry multiplies vulnerability. Disasters that strike densely populated and economically integrated regions (such as Tokyo, Istanbul, or Los Angeles) not only result in overwhelming property losses but also disrupt national and international supply chains, delay exports, and halt manufacturing operations. These ripple effects can depress GDP, reduce employment, and increase inflation through elevated transport and goods costs, as shown in post-disaster Japan [2, 7].

Yet, current economic impact assessments tend to privilege direct physical damage over more complex, harder-to-measure indirect effects. While quantifying collapsed buildings is straightforward, evaluating how long a port closure affects automotive exports or how power outages lead to perishable goods spoilage requires more advanced modeling frameworks, such as Computable General Equilibrium (CGE) models, Input–Output (IO) simulations, or Synthetic Control Methods [8–12]. These tools have proven essential in exposing the full scale of post-earthquake economic disruption.

This paper aims to provide a comprehensive and comparative assessment of the direct and indirect economic losses resulting from large-scale earthquakes occurring worldwide. The research is based on case studies selected from different geographical regions and various economic structures, thereby enabling it to highlight the differences in the effects of seismic disasters between developed and developing countries. The analysis examines not only direct damage to physical assets such as housing and infrastructure, but also indirect effects on the functioning of the economic system, such as disruption of transportation networks, disruption of business continuity, and disruptions in production and supply chains.

In this context, the study addresses the macroeconomic, industrial, and infrastructural dimensions of seismic disasters in a multifaceted manner, assessing their effects on both short-term economic contractions and long-term development processes. The findings emphasize that disaster preparedness plans, policy interventions, and resilient urban planning approaches must take into account not only visible physical destruction but also the invisible economic disruptions that emerge after an earthquake, which are often difficult to measure. Thus, the study aims to contribute to the development of a holistic and system-based assessment framework for disaster risk management.

The paper ultimately seeks to understand the patterns of direct and indirect economic losses resulting from major earthquakes. It aims to improve awareness for quantifying indirect costs, with a particular focus on disruptions in manufacturing, logistics, and the supply of perishable goods. Furthermore, the study utilizes comparative case studies to identify vulnerabilities and capacities within diverse economies, specifically contrasting developing and developed nations. By addressing these fundamental points, the research aims to contribute to the development of the interdisciplinary field of disaster economics and to provide actionable recommendations for various stakeholders. The outputs will guide policymakers in developing pre-disaster preparedness and post-disaster recovery strategies, urban planners in designing resilient cities, the insurance sector in properly managing risk, and global supply chain strategists in creating plans to mitigate the effects of disruptions.

2. Literature Review

The economic assessment of earthquake impacts has evolved considerably over the past several decades, shaped by growing access to empirical data, the refinement of economic modeling techniques, and a deepening awareness of the multifaceted nature of disaster-induced losses. While early studies primarily focused on direct damages (the measurable costs associated with destroyed assets, collapsed infrastructure, and emergency relief efforts) recent literature has expanded to address the indirect and systemic economic consequences that persist long after the seismic event has subsided. This section provides a critical overview of the major strands of research, the methodologies used in estimating economic losses, and the identified gaps in existing approaches.

2.1 Direct Economic Losses: Scope and Estimation

Direct economic losses from earthquakes are typically the easiest to observe and quantify. These include the destruction of housing stock, commercial buildings, transportation infrastructure, energy systems, and public facilities such as hospitals and schools. Methodologically, these losses are often assessed using engineering-based damage models, Geographic Information Systems (GIS), and scenario-based simulations such as FEMA's HAZUS-MH (Hazards U.S. Multi-Hazard), which has been widely used in the United States for estimating probable physical and financial losses from future earthquakes [6]. HAZUS integrates ground motion modeling with building inventory data and fragility curves to project structural and economic damage at the city or regional scale.

Numerous empirical studies have reinforced the dominant role of housing and infrastructure in the direct economic footprint of earthquakes. For instance, it is reported that in the 2008 Sichuan earthquake, housing accounted for over half of the estimated ¥845 billion in losses (~US$130 billion) [4]. Similarly, the Earthquake Commission of New Zealand estimated that residential property losses during the 2010–11 Canterbury earthquake sequence reached approximately NZ$9 billion, out of a total NZ$15 billion in overall damages [13]. These examples underscore the disproportionate burden borne by the built environment and the critical importance of building standards and retrofitting policies in reducing vulnerability.

2.2 Indirect Losses: Business Interruption, Supply Chains, and Macroeconomic Effects

Direct economic losses are usually observable immediately after a disaster and can be measured in the short term, while indirect economic losses generally emerge over a longer period of time and affect a much broader segment of the economy. Such losses are not limited to the area where the damage occurred; they encompass multidimensional processes such as the cessation or disruption of production activities, the temporary or permanent displacement of the workforce, the knock-on effects of delays in transportation and logistics networks, and, in particular, the loss of perishable goods with a short shelf life or those requiring a cold chain. According to Botzen et al., indirect effects can, in some cases, surpass direct damages in monetary terms, particularly when supply chain networks are tightly integrated or geographically concentrated [14].

Empirical evidence increasingly supports this assertion. In the aftermath of the 2011 Great East Japan Earthquake, Tokui et al. documented widespread industrial slowdowns not only in the directly affected Tohoku region but also in peripheral zones hundreds of kilometers away [7]. Disruptions to automotive and electronics supply chains caused temporary production halts in companies such as Toyota and Sony, revealing the systemic fragility of just-in-time manufacturing models. A study by the European Bank for Reconstruction and Development (EBRD) employing synthetic control methods estimated that the real GDP of Japan declined by 0.43 percentage points due to earthquake-induced disruptions, a figure notably higher than the regional share of output directly affected by the disaster. These findings align with broader evidence indicating that even five years post-quake, countries impacted by major seismic events experienced export volumes approximately 16% below counterfactual levels [2].

Similar dynamics have been observed in other regions. In Chile, the 2010 Maule earthquake disrupted ports and highways critical to the country's wine and fruit export sectors, leading to both direct product losses and reputational damage in international markets [15]. Meanwhile, in the 1999 Marmara earthquake in Turkey, damage to transport infrastructure and industrial zones in the economically vital Marmara region caused cascading effects across national production chains [16]. Yet, despite this growing body of evidence, indirect losses remain significantly underrepresented in disaster loss databases and insurance assessments, highlighting a persistent methodological and institutional blind spot.

2.3 Modeling Frameworks: From IO Tables to CGE and Econometrics

The estimation of indirect earthquake impacts requires sophisticated modeling techniques capable of capturing intersectoral linkages, substitution effects, and feedback loops. Several approaches have been developed for this purpose:

Input–Output (IO) models, based on the Leontief framework, offer a relatively straightforward way to quantify how disruptions in one sector affect others through backward and forward linkages. However, these models are inherently static and lack price dynamics, making them less suitable for capturing long-term or behavioral responses [14].

Computable General Equilibrium (CGE) models address these limitations by incorporating substitution effects, resource reallocation, and price adjustments. For example, the Shifang County study by Shi et al. employed a spatial CGE framework to simulate a hypothetical earthquake scenario, estimating a total of over US$8 billion in supply-side losses and demonstrating the resilience of economic systems through intra-regional adjustments [17].

Synthetic Control Methods, drawn from econometrics, use counterfactual comparison to estimate what a region's GDP or export levels would have been in the absence of an earthquake. This technique has been employed to great effect in quantifying long-term macroeconomic effects of earthquakes across multiple countries and time periods [2, 12, 18].

Each of these models brings distinct strengths and limitations. IO models excel in short-term, sector-specific disruption analysis, CGE models offer dynamic and policy-relevant simulations, and Synthetic Controls provide empirical validation across broader economic aggregates. The current trend in the literature suggests that hybrid approaches combining these tools may provide the most comprehensive assessments.

2.4 Research Gaps and Critical Perspectives

Despite advances in modeling and empirical analysis, several critical gaps persist in the literature on earthquake economics. First, while direct damages are generally well-documented, comprehensive and standardized assessments of indirect losses remain rare, particularly in low- and middle-income countries. This is due in part to data limitations, but also to the inherent complexity of tracing economic disruptions that often diffuse across time and geography. Many national disaster databases either exclude or inconsistently record secondary effects such as lost productivity, tourism decline, or perishables spoilage—despite their recognized impact on national GDP and livelihoods. This situation often leads to the true extent of indirect losses being systematically underreported and policymakers failing to adequately consider these effects in their risk management strategies. Furthermore, the lack of comparative international data makes it difficult to clearly analyze differences in economic vulnerability and resilience between countries.

Second, sector-specific losses (especially in logistics, agriculture, and services) have received insufficient attention. Most studies aggregate losses at the macroeconomic level or focus on manufacturing and housing, neglecting the nuanced vulnerabilities of sectors that depend on cold chains, just-in-time inventory systems, or informal labor. For instance, while food spoilage due to power outages or blocked transport routes has been reported in post-earthquake Chile and Japan, no standardized methodology exists for quantifying such losses [7, 19]. These shortcomings can lead to misallocation of resources, overlooking priority areas for intervention, and increased costs in the post-disaster recovery process.

Third, there is a lack of longitudinal analysis exploring how earthquake-induced economic shocks evolve over time. Recovery trajectories, productivity rebounds, and reconstruction-driven growth (often referred to as the "build back better" effect) are inconsistently modeled, leading to conflicting interpretations about whether earthquakes merely displace growth or cause permanent economic scars. Moreover, while some studies have shown a post-disaster boost in GDP due to infrastructure investment others argue that such effects are often overstated and benefit only certain economic strata or urban centers [8].

Finally, cross-country comparative studies remain limited, particularly those that adjust for institutional quality, resilience capacity, or disaster preparedness. Developing countries tend to experience higher relative losses, not only because of weaker infrastructure but also due to inadequate social safety nets, slower response mechanisms, and limited access to international insurance markets [2, 20, 21]. However, most global loss estimates fail to adjust for these variables, limiting the generalizability of findings.

While the literature on earthquake-induced economic losses has matured considerably, important conceptual, empirical, and methodological deficiencies remain. Future research must prioritize multidimensional loss accounting, sectoral disaggregation, and standardized methodologies that allow for global comparability. This approach aims to reveal the full extent of losses by measuring not only physical damage but also the ripple effects across sectors such as manufacturing, services, agriculture, logistics, and others. Furthermore, basing data collection, classification, and analysis processes on a common methodology will enhance the reliability of scientific studies and the feasibility of policy recommendations, enabling comparisons between countries. A more granular and integrated approach, spanning engineering, economics, and social science, will be essential to capturing the true economic burden of earthquakes and informing more equitable and resilient recovery strategies.

3. Methodology

The methodological framework for assessing the economic impact of earthquakes must reflect the multifaceted and often nonlinear ways in which seismic events disrupt economic activity. Unlike narrowly defined physical damage assessments, the economic effects of earthquakes span both visible and latent dimensions—including physical asset losses, sectoral production shocks, transportation bottlenecks, and cascading supply chain failures. In this study, a comparative case study approach is employed, integrating qualitative insights with quantitative estimations to analyze the economic impact of major earthquakes across a range of geographical, temporal, and developmental contexts. The methodological design is structured to incorporate both direct and indirect losses, drawing from multiple data sources and modeling strategies to provide a holistic and globally relevant perspective.

3.1 Case Selection and Comparative Framework

The selection of earthquake case studies is purposive, designed to capture a diversity of contexts in terms of economic structure, governance capacity, and exposure to seismic risk. The study focuses on eight major earthquakes occurring between 1995 and 2023, including events in both high-income countries (e.g., Japan, New Zealand) and lower-income economies (e.g., Nepal, Haiti). Criteria for selection include: (i) the availability of disaggregated economic data on direct and indirect losses, (ii) the representativeness of the event in terms of global seismicity, and (iii) its relevance to policy and scholarly discourse on economic resilience. The events are analyzed comparatively along dimensions such as total monetary loss, loss as a percentage of GDP, estimated recovery time, and distribution of damage across economic sectors.

3.2 Definitional and Analytical Framework

To ensure conceptual clarity, the study distinguishes between direct economic losses and indirect economic losses, following standard definitions from the United Nations Office for Disaster Risk Reduction (UNDRR) and the World Bank [22]. Direct losses are defined as the measurable monetary value of physical damage to assets such as buildings, roads, utilities, and industrial facilities. These are typically one-time, spatially concentrated losses that can be documented through structural assessments and engineering surveys. Indirect losses refer to the secondary and tertiary economic disruptions caused by the earthquake, including but not limited to lost income, decreased productivity, business interruption, elevated transportation costs, spoilage of perishable goods, and long-term effects on investment and trade. These losses are often distributed across time and space, and require modeling approaches to estimate. Both types of losses are considered essential for capturing the full economic footprint of each event. Where available, monetary values are reported in inflation-adjusted U.S. dollars to facilitate comparability.

3.3 Data Sources

The study synthesizes data from multiple sources to ensure robustness and triangulation. These include:

- Official reports from national disaster agencies (e.g., FEMA, AFAD, EQC, NDMA) and international organizations (e.g., EM-DAT, GFDRR, World Bank, UNDP)
- Peer-reviewed academic studies analyzing specific events or employing relevant modeling techniques
- Media and news archives, particularly for estimates of sectoral and short-term losses
- Scholarly databases such as ScienceDirect, Scopus, etc., for empirical and methodological literature
- Open-source encyclopedic platforms (e.g., Wikipedia), used cautiously and only for cross-verifying baseline event data (e.g., magnitude, location, affected population)

The synthesis of these heterogeneous sources allows for a multi-layered understanding of how earthquake losses are recorded, modeled, and interpreted across different institutional and national contexts.

3.4 Assumptions and Limitations

Like any interdisciplinary disaster economics study, this methodology is constrained by several assumptions and inherent limitations:

Data incompleteness and inconsistency: National and sectoral loss data vary significantly in availability and precision, especially for indirect effects. In some cases, figures are extrapolated from partial assessments or third-party estimates, introducing potential bias.

Cross-context comparability: Although monetary standardization is applied, institutional, cultural, and economic differences among case countries may affect the comparability of disaster response and loss accounting.

Model dependency: For indirect losses, reliance on CGE, IO, or econometric estimates means that findings are subject to model assumptions (such as elasticity values, substitution effects, or production function structures) that may not hold across all contexts.

Temporal variation: The impacts of earthquakes evolve over time, and many studies provide only snapshots (e.g., 6 months or 1 year post-disaster). This study captures mid-range effects (1–5 years), but not the full long-term trajectory of economic recovery or decline.

Sectoral aggregation: While every effort is made to disaggregate data, some sector-specific losses (e.g., informal labor markets, micro-enterprises) are not available in a quantifiable format and are discussed qualitatively.

Nonetheless, these limitations are mitigated by the triangulation of diverse data sources and the transparency of methodological choices. Rather than offering a deterministic model of earthquake economics, this study aims to illuminate the complex, interconnected pathways through which earthquakes affect economies, highlighting patterns and vulnerabilities that are often masked in single-event or single-country analyses.

4. Case Study Summaries

To elucidate the real-world economic implications of earthquakes, this section presents a set of comparative case studies focusing on eight major seismic events that occurred between 1995 and 2015. These cases were selected not only for their geographic and economic diversity but also for the availability of disaggregated data on both direct and indirect losses. The objective is to identify recurring patterns, sectoral vulnerabilities, and variations in economic impact across different national contexts. Each case study synthesizes damage assessments, sectoral losses, and macroeconomic consequences within a standardized framework, allowing for meaningful cross-case comparison. Emphasis is placed on housing and infrastructure damage, business and supply chain disruption, GDP impact, and recovery timelines.

4.1 The Great East Japan Earthquake (2011)

The magnitude 9.1 The Great East Japan Earthquake, followed by a massive tsunami, stands as the costliest natural disaster in recorded history, with total direct economic damages estimated at US$360 billion (adjusted for year 2023) [3, 23]. Direct damages were immense, including the destruction of over 120,000 buildings, substantial damage to critical infrastructure (including roads, ports, and the Fukushima Daiichi nuclear power plant) and widespread disruption of energy and water supply systems. Indirect losses were equally devastating: rolling blackouts, transport delays, and disruptions to automotive and electronics supply chains significantly impaired Japan's industrial output [7]. Estimates suggest that indirect economic losses reached US$150 billion, and the national GDP declined by approximately 0.43 percentage points in the fiscal year following the disaster [2]. Recovery and reconstruction efforts spanned over a decade, with significant financial stimulus allocated through the Reconstruction Agency of Japan.

4.2 Sichuan Earthquake, China (2008)

With an epicenter in Sichuan province, the earthquake caused direct economic losses of ¥845 billion (~US$130 billion), with more than 4.8 million people left homeless and widespread destruction of educational, health, and transportation infrastructure [4]. Housing damage accounted for the majority of the loss, with entire urban districts reduced to rubble. Indirect economic consequences included agricultural losses, export disruptions, and diminished industrial output in Sichuan's manufacturing hubs. Although detailed econometric evaluations are scarce, Food and Agriculture Organization (FAO) estimates put agricultural damage alone at over US$6 billion [24]. The Chinese government launched a multi-year, trillion-yuan reconstruction plan, partially offsetting longer-term macroeconomic shocks.

4.3 Canterbury Earthquake Sequence, New Zealand (2010–2011)

The series of earthquakes that struck Christchurch and its surrounding areas—most notably the February 2011 event—resulted in US$40 billion in total damages, with NZ$9 billion attributed to residential property losses alone [13]. Despite New Zealand's high level of disaster preparedness, significant disruption occurred in the Central Business District (CBD), which was cordoned off for months due to building collapse and infrastructure failure. Business interruption claims surged, and indirect losses—though difficult to quantify precisely, were estimated in the range of US$15–20 billion, encompassing tourism decline, service sector shutdowns, and reconstruction delays. Insurance penetration was high, which accelerated economic recovery but revealed new vulnerabilities in the financial underwriting of seismic risk.

4.4 Gorkha Earthquake, Nepal (2015)

The Gorkha earthquake had devastating consequences for Nepal, a low-income country with limited infrastructure resilience. Total damages were estimated at US$10 billion, equivalent to nearly 50% of the country's GDP [5]. Housing destruction was severe, with more than 500,000 homes either destroyed or damaged, particularly in remote and rural areas. Infrastructure failures hampered emergency relief and post-quake reconstruction. Indirect losses included a collapse in tourism revenues, delays in agricultural exports, and food spoilage due to blocked roads and power outages. The lack of diversified income sources and high reliance on foreign aid further prolonged the recovery process, highlighting the asymmetric burden borne by vulnerable economies.

4.5 Haiti Earthquake (2010)

The magnitude 7.0 earthquake that struck Haiti's capital region resulted in an estimated US$8.5 billion in damages, including the collapse of 250,000 residences and widespread destruction of government buildings and public services [16, 18, 25]. Indirect economic losses were difficult to quantify, due in part to the country's large informal sector and the destruction of baseline statistical infrastructure. Nevertheless, disruptions to food supply chains, imports via the damaged Port-au-Prince, and widespread displacement likely added billions in indirect economic costs. International assistance temporarily filled some economic voids, but chronic underdevelopment and political instability hindered long-term recovery, leading many to characterize the economic impact as permanently regressive.

4.6 Maule Earthquake, Chile (2010)

The Maule earthquake, registering a magnitude of 8.8, struck central Chile and caused economic damages exceeding US$30 billion, representing around 18% of the national GDP [15, 16, 26]. While the event occurred in a seismically prepared and economically middle-income country, the high intensity and widespread reach of the earthquake overwhelmed even Chile's relatively robust building codes. Direct damage included the collapse of over 370,000 homes and serious impairment to ports and road infrastructure, particularly in regions critical to Chile's wine and fruit export industries. Perishable spoilage from export delays and the temporary shutdown of cold storage and logistics hubs resulted in substantial, though poorly quantified, indirect agricultural losses. These disruptions highlighted the sensitivity of globally integrated supply chains to infrastructure vulnerability.

4.7 Marmara Earthquake, Turkey (1999)

Striking the industrial heartland of Turkey, the 1999 Marmara earthquake caused US$17.1 billion in direct damages and claimed over 17,000 lives. Much of the loss was concentrated in housing and urban infrastructure, with widespread destruction in the cities of İzmit, Adapazarı, and parts of Istanbul. Indirect losses were severe due to the disruption of the Gebze and Kocaeli industrial zones, where automotive, textile, and manufacturing plants were temporarily shut down. Transport networks were also heavily affected, with damage to highways and bridges impeding relief and commercial flows. While comprehensive CGE or IO modeling of indirect losses has not been published for this event, post-quake economic indicators suggest output in key sectors contracted sharply, and recovery required years of financial intervention and international lending [2, 16].

4.8 Kashmir Earthquake, Pakistan (2005)

The 2005 Kashmir earthquake, though smaller in absolute economic terms, had catastrophic human and fiscal impacts in Pakistan's Azad Kashmir and Khyber

Pakhtunkhwa regions. Estimated losses totaled US$5.2 billion, equivalent to roughly 5% of Pakistan's GDP [27]. The region's rugged terrain and limited infrastructure exacerbated access problems and emergency response times, inflating the economic impact. Direct damages included widespread housing collapse, school and hospital destruction, and road failures. Indirect effects included labor displacement, reduced agricultural productivity, and long-term educational discontinuity due to school closures. The humanitarian nature of the crisis attracted international aid, but systemic vulnerabilities and administrative delays undermined efficient reconstruction.

4.9 Comparisons and Insights

The comparative review of these eight case studies is listed in Table 1 and 2. Please, note that the "Economic Loss (% of GDP)" column in Table 1 includes direct and indirect losses combined and sources given in Table 1 are valid for Table 2, as well. Values given in both tables illustrates a number of important patterns. First, the magnitude of an earthquake does not alone determine its economic impact; rather, the structural vulnerabilities, economic integration, and resilience capacity of the affected region play a critical role. Countries with pre-existing economic fragility, such as Haiti or Nepal, tend to suffer disproportionately in relative GDP terms, whereas highly industrialized nations, like Japan or New Zealand, may incur higher absolute losses but often exhibit more rapid recoveries due to insurance penetration and institutional capacity.

Second, across nearly all cases, housing and infrastructure consistently emerge as the largest components of direct damage, while indirect losses, particularly related to business interruption, supply chains, and perishables, are both substantial and underreported. Where CGE or IO models are applied, such as in Japan and New Zealand, indirect losses frequently rival or exceed physical damages, indicating the need for more systematic incorporation of these elements in economic loss assessments.

Third, the tables show that sectoral dependence matters. Countries with economies heavily reliant on tourism, agriculture, or manufacturing exhibit particularly acute vulnerabilities. For example, Nepal's post-earthquake GDP contraction was driven not only by physical damage but also by plummeting tourism and remittance flows. Chile's and Japan's export sectors similarly faced multi-billion dollar losses due to port closures and logistics breakdowns, suggesting that economic globalization can amplify the reach of local disasters. These insights underscore the need for a holistic and sector-sensitive approach to earthquake economic impact assessment—one that considers not only the collapse of buildings but the complex socioeconomic systems they support.

5. Results & Analysis

The comparative evaluation of eight major earthquake events reveals a complex interplay between direct structural damages, indirect economic disruptions, and the broader macroeconomic resilience of affected regions. By analyzing both numerical data and contextual features across case studies, several critical themes emerge regarding the scale, composition, and distribution of earthquake-induced economic losses. These findings deepen our understanding of how seismic events shape not only the physical landscape but also the economic trajectories of nations and communities.

Table 1. Estimated economic impacts of major earthquakes (direct losses)

Earthquake (Year)	Country	Mag.	Direct Loss (USD, Billion)	Housing Damage	Infrastructure Damage	Deaths	Injured/Homeless	Economic Loss (% of GDP)	Sources
Tohoku (2011)	Japan	9.1	360	Severe; over 120,000 buildings destroyed	Extensive: ports, power plants, roads, nuclear disaster	19,759	~450,000 homeless	~6%	[3, 7, 23]
Sichuan (2008)	China	7.9	130	~5 million homeless	Roads, rail, dams, schools	87,000	~375,000 injured	~3%	[4, 24, 28]
Christchurch (2011)	New Zealand	6.2	40	Major in CBD and residential areas	Infrastructure and water systems	185	~50,000 homeless	~8%	[13, 29]
Gorkha (2015)	Nepal	7.8	10	Over 500,000 houses destroyed	Roads, bridges, public services	9,000	~3 million affected	~50%	[5, 29, 30]
Haiti (2010)	Haiti	7	8.5	Collapsed 250,000 residences	Government buildings, roads, port	230,000	1.5 million homeless	~120%	[18, 23, 25]
İzmit/Kocaeli (1999)	Turkey	7.4	17.1	Widespread residential collapse	Infrastructure, bridges, industrial areas	17,000	~250,000 displaced	~7%	[2, 16, 29]
Maule (2010)	Chile	8.8	30	>500,000 houses damaged	Power grid, highways, ports	525	>2 million affected	~18%	[15, 26, 29]
Kashmir (2005)	Pakistan	7.6	5.2	Over 400,000 houses	Schools, hospitals, roads	86,000	3.5 million homeless	~5%	[27, 29]

Table 2. Estimated indirect economic impacts and disruptions

Earthquake (Year)	Indirect Loss (USD, Billion)	Business Interruption	Transport Disruption	Manufacturing Halt	Perishable Goods Spoilage	Notable Supply Chain Effects
Tohoku (2011)	~150	National-scale outages, auto and electronics	Ports & roads unusable	Toyota, Sony, etc. halted production	Food, pharma losses in cold chains	Global ripple; auto/electronics shortages
Sichuan (2008)	~65	Regional factories, agriculture exports	Mountainous roads collapsed	Local mining & construction paused	Large agricultural losses (FAO)	China's cement industry delayed
Christchurch (2011)	~15–20	Downtown closed for months	Minor but persistent detours	Local retail and service sectors halted	Low, mostly local	CBD inactivity affected tourism & insurance
Nepal (2015)	~6	Tourism, trekking halted	Rural access roads blocked	Handicraft and exports delayed	Food, aid spoilage in warehouses	Remittances hit, aid logistics delayed
Haiti (2010)	~5	Almost total commerce halt in capital	Port collapsed; imports delayed	Informal sector lost income	Cold storage failure for aid & food	Relied heavily on external food imports
İzmit/Kocaeli (1999)	~8	Industrial downtime in Marmara Region	Rail and road network blocked	Major industry (Ford, Arçelik) halted	Not well documented	Long-term reduction in exports from region
Maule (2010)	~10–15	Ports closed; wine industry losses	Major roads and ports disrupted	Food processing plants stopped	Wine, fruit exports delayed/spoiled	Losses in agro-export value chains
Kashmir (2005)	~2–3	Remote villages isolated	Landslides, blocked roads	Minimal industry	Local food losses in mountains	Aid and recovery delayed by access issues

5.1 Distribution of Losses: Direct vs. Indirect

A key finding from the case analysis is the consistent dominance of housing and infrastructure losses in the direct damage category, typically comprising 50–70% of total direct losses. For instance, in the 2008 Sichuan earthquake, housing alone accounted for over half of the ¥845 billion in total losses [4] while in New Zealand's Canterbury earthquakes, residential property losses reached NZ$9 billion out of NZ$15 billion in total damages [13]. This pattern highlights the concentration of economic value in built environments and the heightened exposure of residential areas in seismic zones.

However, the data also indicate that indirect losses—particularly those associated with business interruption, supply chain breakdowns, and logistics failures can rival direct physical damage. In Japan's 2011 Tohoku earthquake, indirect losses stemming from power outages, factory shutdowns, and disrupted global supply chains were estimated at approximately US$150 billion, almost half the total economic cost [2, 7]. Similarly, indirect effects in Chile's 2010 Maule earthquake, though less well quantified, were substantial in sectors like agriculture and export logistics, where shipping delays and spoilage disrupted revenue streams for weeks.

This evidence supports the growing consensus in the literature that disaster loss accounting systems underestimate the full economic impact when indirect effects are excluded [14]. Particularly in industrialized economies with complex supply chains and service-driven sectors, indirect economic consequences are magnified by interdependencies across infrastructure networks and just-in-time production systems.

5.2 Economic Resilience and Recovery Dynamics

Another important finding concerns the variation in recovery speed and resilience across countries. High-income nations with robust institutional frameworks, insurance markets, and financial capacity (such as Japan and New Zealand) demonstrated relatively faster economic rebounds. In contrast, low-income countries like Nepal and Haiti faced prolonged reconstruction periods, dependency on external aid, and slow economic recovery, even years after the disaster.

For example, New Zealand's high insurance penetration facilitated capital inflows and rebuilding after the Canterbury earthquake, cushioning macroeconomic impacts despite the disaster's large cost relative to GDP [21]. Conversely, in Nepal, where losses reached nearly 50% of GDP, the recovery was hampered by administrative bottlenecks and limited domestic financing options [5]. Haiti's situation was even more severe; with economic losses exceeding 100% of GDP, the country became reliant on external donor financing, and the rebuilding process was mired in governance challenges and political instability.

These contrasting experiences underscore the importance of pre-existing institutional capacity, financial instruments, and governance quality in shaping the economic aftermath of earthquakes. Countries with integrated disaster risk financing strategies and efficient administrative structures tend to absorb and distribute losses more equitably and rapidly. Furthermore, strong institutional structures and financial mechanisms not only accelerate post-disaster recovery but also contribute to maintaining long-term economic stability. Conversely, in countries lacking such mechanisms, disasters can deepen economic vulnerabilities, leading to permanent setbacks in the development process.

5.3 Sectoral Sensitivities and the Role of Global Integration

The results also highlight the differential vulnerability of economic sectors to seismic shocks. Manufacturing and heavy industry often suffer immediate output losses due to damage to production facilities and logistical networks. However, sectors such as tourism, agriculture, and retail (especially those reliant on seasonal flows and perishables) face unique vulnerabilities that are frequently overlooked in aggregate economic assessments.

In Nepal, the tourism sector, a key source of foreign exchange and employment, collapsed following the 2015 earthquake, contributing to a steep decline in GDP and household income [31]. In Chile, blocked transport routes and port closures led to fruit and wine spoilage, resulting in temporary export shortfalls. Similarly, in Japan, the disruption of semiconductor and automotive parts supply chains echoed globally, temporarily halting production lines as far afield as the United States and Germany [7].

These findings point to the increasingly globalized nature of disaster impacts. In a world where supply chains span continents and industries rely on tightly scheduled deliveries, localized seismic events can generate transnational economic ripple effects. This further complicates post-disaster recovery, as firms must manage not only local reconstruction but also upstream and downstream coordination failures. Particularly in sectors integrated into the global value chain, such as high technology, automotive, and food, such disruptions make it difficult to quickly restore production capacity and increase costs. Furthermore, these disruptions in international trade flows directly affect not only the country where the disaster occurred but also other countries that are economically dependent on it.

5.4 GDP Impact and Long-Term Economic Scarring

A final dimension of analysis concerns the macroeconomic consequences of major earthquakes. As shown in the case studies, GDP losses vary significantly in both absolute and relative terms. Japan's Tohoku disaster caused a 0.43 percentage point decline in GDP growth in 2011 [2], a significant macroeconomic event in a high-income country. In contrast, the same magnitude of loss in a country like Haiti (estimated at over 100% of GDP) represented a near-complete erasure of annual economic output, with long-term effects on investment, employment, and public finances.

While some studies suggest that reconstruction efforts may produce a short-term GDP boost, this so-called "build back better" phenomenon is often overstated. Many reconstruction programs are constrained by absorptive capacity, lead to inefficient allocation of resources, or create dependency on donor funds. Furthermore, temporary growth may mask underlying structural damage, especially in labor markets and informal economies. Thus, while macroeconomic statistics may eventually return to pre-disaster levels, the distributional and sectoral scars often persist much longer. For this reason, in post-earthquake economic recovery assessments, it is crucial to consider the lasting effects on different sectors of the economy rather than focusing solely on growth figures.

5.5 Theoretical Interpretation and Implications

The empirical findings from the case studies resonate strongly with insights from disaster economics and system resilience theory. In particular, the "cascading failure" model—where damage in one subsystem (e.g., transport infrastructure) triggers failures in others (e.g., production, logistics, service delivery)—is repeatedly borne out in the observed dynamics of post-earthquake economies [32]. The extent to which these cascades lead to systemic breakdown or are absorbed and redirected depends on the structural flexibility and redundancy of the affected system.

For example, the ability of firms to reallocate production, source inputs from alternative suppliers, or switch to substitute goods and services determines the overall scale of indirect losses. This underscores the value of economic diversification and supply chain redundancy as resilience strategies. In regions with high dependence on a single sector or supplier chain, earthquakes tend to cause more sustained economic contractions.

Conversely, economies that exhibit high degrees of adaptive capacity, supported by efficient institutions, flexible labor markets, and robust monetary frameworks, are better positioned to recover.

These findings also lend empirical support to the use of Computable General Equilibrium (CGE) models in disaster planning, which emphasize substitution effects and market dynamics rather than linear propagation of losses assumed in traditional input–output models [8]. The ability of CGE frameworks to simulate behavioral responses, such as shifts in consumer spending or government investment, provides a more nuanced view of post-disaster recovery paths, particularly when combined with empirical calibration using case study data.

Finally, the variation across countries in terms of loss-to-GDP ratios, recovery timelines, and indirect loss magnitudes highlights the need for context-sensitive disaster policy frameworks. One-size-fits-all approaches fail to account for local economic structures, governance regimes, and social vulnerability profiles. The evidence suggests that countries must design tailored risk mitigation strategies, combining retrofitting and zoning policies with economic instruments such as contingent credit lines, catastrophe bonds, and business interruption insurance to enhance resilience comprehensively.

6. Discussion

The findings of this study reinforce and extend a growing body of scholarship that repositions earthquakes not solely as geophysical disturbances but as systemic economic shocks with wide-ranging consequences for development, financial stability, and social well-being. This section critically examines the implications of the empirical results through the lens of established literature on disaster economics, with particular attention to the comparative dynamics of direct and indirect losses, the mediating role of institutional and financial capacity, and the broader contours of economic resilience.

6.1 Earthquakes as Economic Shocks

Numerous scholars have emphasized that natural disasters like earthquakes should be understood not only in terms of physical destruction but as external macroeconomic shocks that disturb production functions, labor supply, and consumption [33, 34]. This study's comparative analysis supports this view, illustrating how earthquakes produce asymmetric economic consequences that depend more on institutional and sectoral configuration than on magnitude alone. For instance, although both Japan and Haiti experienced catastrophic seismic events, the economic outcomes were vastly different due to differences in GDP structure, financial systems, and governance quality.

The results align with the findings of Felbermayr and Gröschl [35], who show that large disasters can have long-term negative effects on GDP, particularly in low-income countries. In Nepal and Haiti, where the Gorkha and Port-au-Prince earthquakes respectively caused losses equivalent to half or more of annual GDP, the limited absorptive capacity of public institutions hindered both immediate response and long-term recovery. This stands in contrast to countries like New Zealand and Japan, where institutional mechanisms, including insurance frameworks and reconstruction agencies, helped buffer macroeconomic volatility and stabilize post-disaster growth trajectories [36].

The comparative data also underscores how the macroeconomic burden of earthquakes is deeply unequal across countries. As visualized in Figure 1, which shows the total economic losses as a percentage of national GDP, low-income countries such as Haiti and Nepal experienced losses equivalent to 120% and 50% of GDP, respectively, compared to 6% in Japan and just 3% in China. These extreme proportional losses indicate not only physical vulnerability but a lack of economic buffers, diversified income sources, and financial resilience.

This gradient supports finding by Noy and Felbermayr and Gröschl, who have shown that disasters impose greater proportional costs on countries with smaller, less diversified economies, despite possibly lower absolute damage [33, 35]. Thus, even modestly sized disasters can destabilize entire economies in low-income contexts.

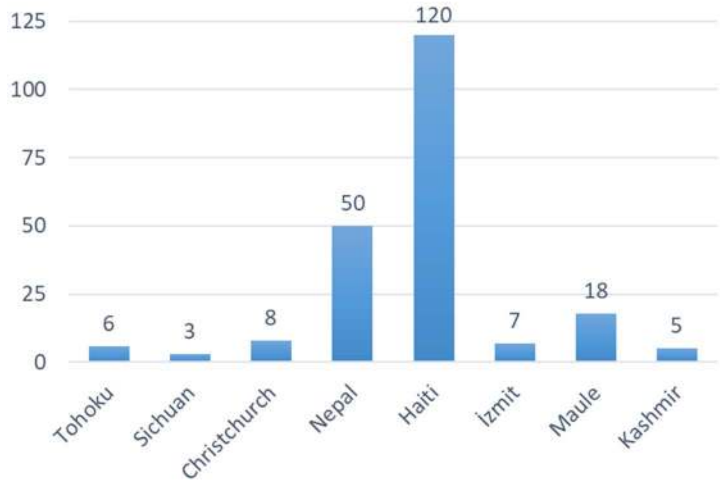

Figure 1. Total economic losses from earthquakes as % of national GDP

6.2 Balance of Direct and Indirect Losses

While direct damages to housing and infrastructure are typically well-documented in global disaster databases [37], this study confirms the literature's long-standing concern that indirect economic losses remain underrepresented in risk assessments [8, 38]. In high-income, industrialized contexts, indirect losses, such as production halts, lost wages, and disruptions to supply chains, often rivals the initial valuation of direct damage. This was especially evident in the 2011 Great East Japan Earthquake, where business interruption and global supply chain failures contributed to indirect losses estimated at nearly US$150 billion [7].

These findings are consistent with the synthetic control analysis by Cavallo et al. [34], which demonstrated that countries exposed to large earthquakes typically suffer sustained export losses and reduced industrial output unless offset by substantial reconstruction investment. The results also echo those of Koks et al. [39], who argue that traditional disaster models systematically underestimate economic risk by neglecting the compounding effects of indirect losses, particularly in interconnected systems.

To illustrate the significance of these secondary effects, Figure 2 presents the ratio of indirect to direct losses for the eight earthquake events analyzed. Across all cases, the ratio ranges between 0.42 and 0.60, with the highest ratios recorded in Nepal (0.60) and Haiti (0.59), both low-income countries with severe institutional and logistical limitations. Interestingly, even in high-income settings like Japan and New Zealand, indirect losses still comprise over 40% of total economic impact.

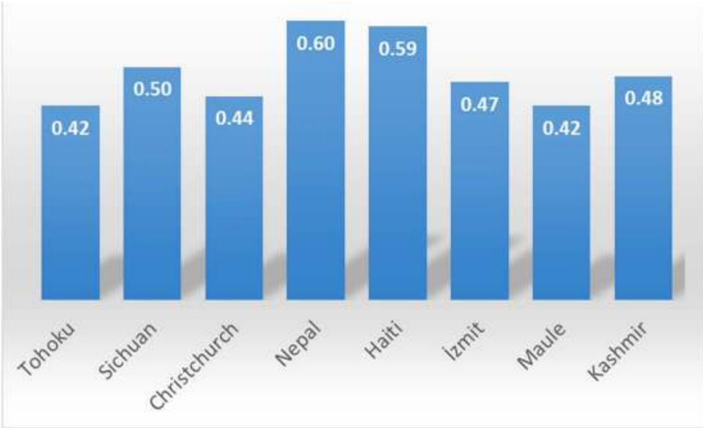

Figure 2. Ratio of indirect to direct economic losses in major earthquakes

These findings challenge the assumption that indirect losses are marginal or secondary. Rather, they are consistently comparable in scale to direct losses, regardless of national income level. This reinforces prior modeling work by Okuyama and Santos [38] and Koks et al. [39], who argue that indirect effects, especially in supply chains and services, are not residual, but co-primary components of disaster economics.

6.3 Financial Mechanisms and Institutional Capacity in Recovery

The literature strongly supports the observed correlation between insurance coverage, institutional robustness, and recovery efficacy. Studies by Cummins and Mahul [40] and Hallegatte et al. [36] have shown that countries with developed catastrophe risk financing instruments recover faster and with less social disruption. This study confirms those findings, as evidenced by New Zealand’s relatively swift post-earthquake rebound, underpinned by the Earthquake Commission’s insurance scheme, compared to the prolonged fiscal crisis in Haiti, where insurance coverage was negligible.

In line with Melecky and Raddatz [41], the analysis also suggests that governments in low-income countries often face a financial trap: lacking pre-disaster savings or contingent credit, they must reallocate scarce development funds for emergency response and reconstruction, thereby delaying long-term investments and compounding vulnerability. Such trade-offs underscore the urgent need for integrating financial resilience into national disaster strategies, particularly in fragile contexts.

6.4 Sectoral Vulnerability and Globalization of Risk

The study's findings reaffirm concerns raised by Henriet et al. [42] and Hallegatte [36] about the sector-specific nature of disaster exposure, particularly in supply-chain dependent and export-oriented industries. For example, the Maule earthquake's disruption of agricultural exports revealed the fragility of value chains that depend on functional ports, roads, and refrigeration infrastructure. Similarly, Japan’s loss of electronic components production affected automotive manufacturing across East Asia and North America.

These effects are magnified in an era of economic globalization, where even localized disruptions can generate transnational ripple effects. Rose [32] and Santos & Haimes [43] have previously modeled such “ripple effects” in economic systems, stressing that resilience is not only a local property but one embedded in the configuration of trade, logistics, and inter-firm networks. The present study supports these insights and further argues that countries must view earthquake risk as not only a domestic challenge but a potential contributor to global economic instability.

6.5 Geography, Development, and the Type of Losses

The location of an earthquake, both in geographical and economic terms, has a profound influence on the composition of economic losses. Figure 3 illustrates the distribution of direct and indirect economic losses across the eight case studies, highlighting how the relative shares vary with development level, urbanization, and economic structure.

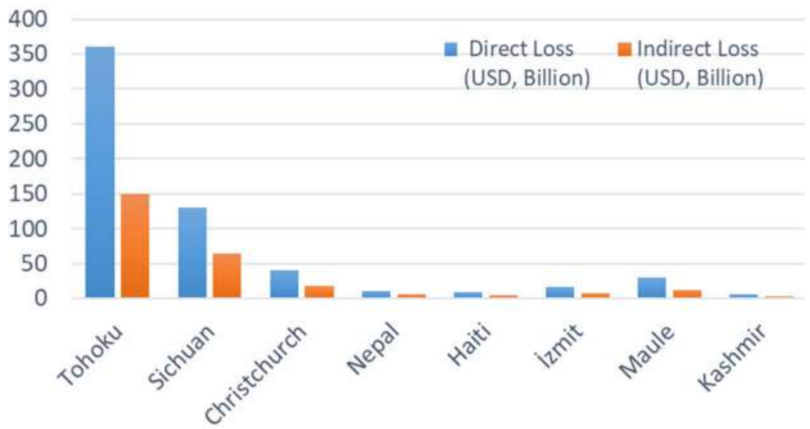

Figure 3. Comparison of direct and indirect earthquake losses by country

High-income countries such as Japan (Tohoku) and New Zealand (Christchurch) show high absolute direct losses due to the high asset value in urban environments, but they also exhibit significant indirect losses, largely attributable to tightly integrated supply chains and dense service sectors. In Japan, for example, indirect losses (US$150 billion) accounted for over 42% of the total, due to disruptions in automotive and electronics production that affected markets worldwide [7].

By contrast, in lower-income countries such as Nepal and Haiti, indirect losses are also proportionally high (59–60%), but the mechanisms differ. Here, indirect effects stem not from complex supply chains but from prolonged business closures, tourism declines, and aid delivery inefficiencies. These contexts lack logistical redundancy and functional insurance systems, which delays recovery and deepens economic scarring [34, 41].

Middle-income countries such as Turkey (İzmit) and Chile (Maule) occupy an intermediate position, where the damage is more evenly distributed. This suggests that the balance between direct and indirect losses is shaped by both economic complexity and governance capacity.

In sum, the considered cases support a geographically differentiated damage distribution of earthquake economics:

- In high-income contexts, indirect losses are driven by supply chain interdependence
- In low-income settings, indirect losses are amplified by governance and service bottlenecks
- In middle-income contexts, the composition depends on industrial density and disaster preparedness

These distinctions underscore the necessity for context-specific resilience strategies that align with local economic structures and institutional capacities.

6.6 Disaggregating Economic Losses: A Functional Typology

Understanding the full spectrum of earthquake-related economic losses requires disaggregation beyond the standard categories of “direct” and “indirect” damage. Figure 4 illustrates the conceptual composition of earthquake-induced economic losses, averaged from considered earthquake events, post-disaster studies and modeling literature [7, 15, 22, 31, 37, 38, 44, 45]. The distribution is not universally fixed but reflects common trends observed across high-profile seismic events.

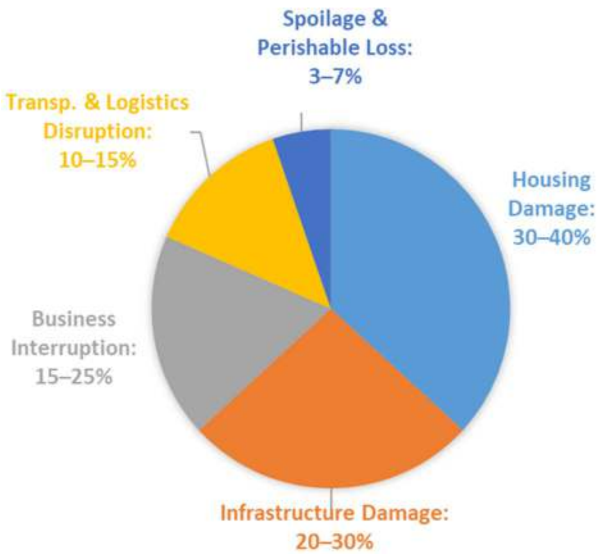

Figure 4. Average composition of earthquake-related economic losses by category

Housing Damage (30–40%)

This category includes the destruction or severe damage of private residential buildings (both owner-occupied and rented) along with temporary shelter costs and full or partial reconstruction expenditures. Housing losses are generally the largest single component of direct damages, particularly in countries with outdated building stock or poor zoning enforcement, as seen in Haiti and Nepal. Methodologies such as HAZUS-MH and GEM typically estimate these using building inventory databases and unit replacement costs.

Infrastructure Damage (20–30%)

Infrastructure losses encompass public belongings such as transport networks (roads, bridges, ports), lifeline utilities (electricity, water, sanitation), and social infrastructure (schools, hospitals). In urban or industrially dense areas like Christchurch (2011) or Tohoku (2011), infrastructure damages were particularly high due to dense asset concentration and the cascading cost of service restoration. These losses often trigger long-term economic strain on municipalities and national governments.

Business Interruption (15–25%)

This refers to the loss of revenue or productivity due to temporary or extended shutdowns in commerce, manufacturing, and services. Particularly vulnerable are SMEs, whose liquidity and risk buffers are limited. These losses are often difficult to measure directly and are estimated using input–output (IO) or computable general equilibrium (CGE) models, as well as insurance claim data. For example, in the Tohoku earthquake, halted operations in electronics and auto manufacturing accounted for billions in unrealized output [7].

Transport & Logistics Disruption (10–15%)

These losses stem from damage to key transport nodes and networks, particularly ports, rail systems, and road corridors. The impact is not limited to the immediate region; it can reverberate through global supply chains. The 2011 Japan earthquake, for instance, caused automotive production halts in the United States and Europe due to missing components.

These costs include delays, rerouting, and increased transport premiums, and are often embedded in broader business interruption metrics but deserve discrete attention.

Spoilage & Perishable Goods Loss (3–7%)

An often underreported category, this includes losses due to cold storage failures, transport delays, and distribution bottlenecks affecting food, pharmaceuticals, and agricultural exports. These are especially critical in agriculture-dependent or export-oriented economies like Chile, Turkey, and Pakistan, where produce loss directly affects trade balances and rural income. Because such losses are seldom captured in traditional damage assessments, their presence in insurance records and humanitarian logistics data serves as a proxy.

The figure 4 highlights that while housing and infrastructure consistently dominate the damage profile, indirect and functional economic effects account for at least one-third of total losses. These latter categories, business interruption, transport disruption, and spoilage, are often underestimated or omitted in official assessments, which skews policy priorities and underfunds resilience in non-structural domains. For example, investing in supply chain redundancy or cold-chain stabilization may yield high resilience returns but receives less attention than retrofitting housing.

Moreover, the distribution underscores the multisectoral nature of earthquake risk, necessitating disaster preparedness strategies that go beyond physical reconstruction. This typology encourages policymakers to view earthquake economics not only through the lens of engineering, but through systems thinking—identifying interdependencies across critical services and market functions.

6.7 Toward an Integrated Economic Resilience Paradigm

The literature increasingly promotes a shift from post-disaster response to pre-disaster resilience, and this study provides additional empirical justification for that transition. Hallegatte et al. [46] propose a systems approach to disaster resilience, wherein adaptive capacity, economic diversification, and institutional redundancy serve as core pillars. The cases analyzed in this study affirm this model, particularly in the differential outcomes observed in recovery timelines and GDP stabilization.

Importantly, resilience must be understood not only as the ability to rebuild but as the capacity to sustain economic function during and after disruption. As Rose [32] notes, economic resilience includes behavioral responses such as resource reallocation, production substitution, and market adaptation, all of which can significantly mitigate disaster impacts when institutions are capable of enabling such responses.

7. Conclusion

The economic consequences of earthquakes are far more than the sum of collapsed structures and disrupted roads. As this study has demonstrated through a comparative, cross-national analysis of eight significant seismic events, earthquakes function as systemic economic shocks, with repercussions that extend beyond immediate physical damage into the realms of production, trade, livelihoods, and long-term development. Systemic economic shocks are chain reactions and multidimensional disruptions that can affect not only the affected region but also other regions and global markets through economic networks. Such shocks serve as critical stress tests that challenge both the continuity of economic activities and the social and financial resilience of societies. The findings affirm and extend prior literature in disaster economics, suggesting that the scale and structure of a nation's economic system, rather than the seismic magnitude alone, largely determine the depth and duration of economic disruption. The findings affirm and extend prior literature in disaster economics, suggesting that the scale and structure of a nation's economic system, rather than the seismic magnitude alone, largely determine the depth and duration of economic disruption.

One of the study's key contributions lies in emphasizing the overlooked importance of indirect economic losses, echoing the arguments of Okuyama and Santos and Koks et al. [38, 39]. While direct damages, particularly to housing and infrastructure, dominate early assessments, this study shows that indirect effects such as business interruption, supply chain failures, transport disruptions, and perishables spoilage often account for 40–60% of total economic losses. As shown previously, indirect-to-direct loss ratios consistently range from 0.42 to 0.60 across varied income contexts. These findings demand a recalibration of both disaster loss accounting frameworks and financial preparedness strategies, especially in countries where traditional assessments omit economic system-level impacts. In this context, the systematic measurement of indirect losses will contribute to understanding the true economic scale of the disaster and to the more effective allocation of resources. Furthermore, such comprehensive assessments will facilitate the development of policy designs that will accelerate the post-disaster recovery process and reduce economic vulnerabilities.

Moreover, the comparative evidence reinforces the view, advanced by previous studies that earthquake impacts are highly unequal across income groups [33, 35]. While Japan's Tohoku earthquake resulted in US$510 billion in damages but only ~6% GDP loss, Haiti's earthquake caused damage exceeding 120% of its GDP. Low-income countries not only lose more in relative terms but also experience prolonged and uneven recoveries, due to limited financial space, weak insurance markets, and institutional fragility. Earthquakes in such contexts compound structural vulnerabilities and can reverse years of development progress. Furthermore, this situation systematically erodes resilience to disasters, increasing countries' vulnerability to the economic and social impacts of future shocks.

In addition to loss magnitude, the composition of losses offers insight into risk concentrations. On average, housing (30–40%) and infrastructure (20–30%) comprise the majority of direct damage, while business interruption (15–25%), transport and logistics delays (10–15%), and spoilage of perishable goods (3–7%) are considerable but often excluded from formal evaluations. The high share of non-structural losses underscores the need for broader resilience strategies that protect not just physical assets, but also the economic systems that depend on them. This situation necessitates the development of comprehensive and multi-layered resilience strategies aimed at protecting economic systems dependent on physical assets, such as manufacturing, trade, logistics, and service sectors. Such strategies should aim not only to mitigate the effects of direct damage, but also to accelerate the post-disaster recovery process and protect long-term development goals by ensuring the continuity of economic activities.

Institutional and financial capacity emerge as central mediators in this dynamic. Countries with established disaster financing instruments, catastrophe insurance, and contingency planning, such as New Zealand and Japan, tend to recover more rapidly and equitably [36, 40]. In contrast, economies dependent on unplanned aid flows or external loans taken after disasters often face delayed reconstruction processes, increased fiscal pressures, and unsustainable debt cycles. These patterns demonstrate that effective disaster resilience is not limited to the level of exposure to hazards; it is also directly related to the ability to absorb shocks, redistribute resources effectively, and sustain post-crisis recovery capacity. Therefore, strengthening institutional capacity should be a key priority in disaster risk management strategies.

These findings argue strongly for a paradigm shift in disaster risk management—from reactive, asset-focused approaches to proactive, system-wide economic resilience planning. This involves integrating seismic risk into macroeconomic and spatial policy, enforcing adaptive zoning and building codes, and expanding access to financial risk transfer tools. Moreover, it requires rethinking earthquakes not as isolated events, but as stress tests for national economic systems, capable of revealing hidden fragilities, structural weaknesses and capacity gaps under pressure.

As global supply chains grow more interdependent and urban regions concentrate increasing economic value, the risk landscape is evolving in both scale and complexity. The evidence presented in this study supports recent calls in the literature for multi-scalar, interdisciplinary approaches to resilience, grounded in empirical data, modeling, and localized knowledge systems. While earthquakes are geophysically inevitable, their economic devastation is not. With the right data infrastructure, strong institutional capacity, and effective risk governance strategies, countries can not only mitigate the effects of disasters but also move toward building lasting and sustainable economic resilience.

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