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BRINGING HAZARD AND ECONOMIC MODELLERS TOGETHER: A SPATIAL PLATFORM FOR DAMAGE AND LOSSES VISUALISATION

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TABLE OF CONTENTS

ABSTRACT

Estimating potential damage and losses as a result of natural disasters is challenging, as it entails a multi-disciplinary approach. Since the estimation of potential damage broadly initiates with the identification of the source as well as determination of the probability of the occurrence of disasters, hazard-modellers along with civil engineers generally lead the whole process to estimate the potential destruction—either fully or partially—of infrastructures against a set of scenarios. When it comes to the estimation of losses from natural disasters, economists step in mainly using an empirical econometric approach. However, to the best of our knowledge, no acceptable method has been devised to combine these two disciplines to estimate potential damage and losses coherently. In this paper, a methodology to connect the multi-hazard disaster damage assessment approach with an empirical econometric strategy of estimating disaster losses in one spatial platform is proposed. Enabling the visualisation of potential damage and losses of natural disasters through this approach acts as a crucial decision support tool for both the federal and state governments to prioritize budget allocation across different economic sectors.

1. INTRODUCTION

Rapid economic growth along with complex urban planning and development processes tend to accelerate economic vulnerabilities highlighting the ever-growing need for disaster risk reduction (DRR) interventions. In this vein, judging the potential damage and losses from natural disasters remains crucial in designing pre-disaster mitigation plans and formulating post-disaster recovery strategies. In practice, civil engineers—who mainly focus on the infrastructure sector—and hazard modellers assess the potential damage of physical assets using mapping tools. Economists, on the other hand, concentrate on estimating losses in economic flows due to natural disasters either at the state or national level using econometric methodologies. This divergence in approach makes it particularly challenging to provide a spatially enabled DSS in the DRR field, that can visualise not only damage of physical assets but also map overall economic effects of natural disasters. This paper bridges the gap between hazard modellers and economists by proposing a spatial platform which provides inputs to the economic model at a finer geographic unit level at the initial stage and then displays the estimated damages and losses from the economic model on interactive maps at the final stage. Precisely, this paper provides a novel methodology on estimating and visualizing disaster-specific losses at a spatial level which would be beneficial to the end users and policy makers in making informed decisions.

Another important contribution of this paper is that it provides a method on how to map the overall effects of natural disasters by economic sector and by smaller geographical unit. This will be of particular relevance to the economic policymakers in that they can prioritize budget allocation across the economic sectors as well as geographical areas in terms of their relative disaster risks. Moreover, the proposed method is helpful in identifying appropriate public policy and development programmes to mitigate detrimental effects on economic performance and public well-being due to catastrophic events.

It is worthwhile mentioning that the main objective of this paper is to provide a spatial method for estimating and visualising damage and losses of natural disasters. The rest of the paper is structured as follows. Section 2 presents overall methodology of assessing potential damage and losses of natural disasters through a spatial framework. Section 3 describes the data and some measurement issues related to the variables required for our proposed estimation process. Section 4 describes our visualisation tool of presenting damage and losses estimation. Section 5 emphasises on how our spatially enabled damage and losses estimation would be beneficial for decision-makers. Finally, section 6 concludes.

2. METHODOLOGY OF RESEARCH

The fundamental aim of this paper is to provide a method for estimating the localised economic effects of a disaster event as they propagate through economic sectors. In order to do this, the following methodology is proposed as articulated in Figure 1. The methodology consists of five steps: defining the geographic zone (i.e., the destination zone) that would be used as a cross-sectional unit in both spatial and economic analyses; disaggregating sector-specific gross state product (GSP) at DZN level; categorizing the sector-specific GSP into four broader groups—i.e., production, infrastructure, social, and cross-cutting, and finally, estimating disaster losses for 19 disaggregated economic sectors as well as four broader groups.

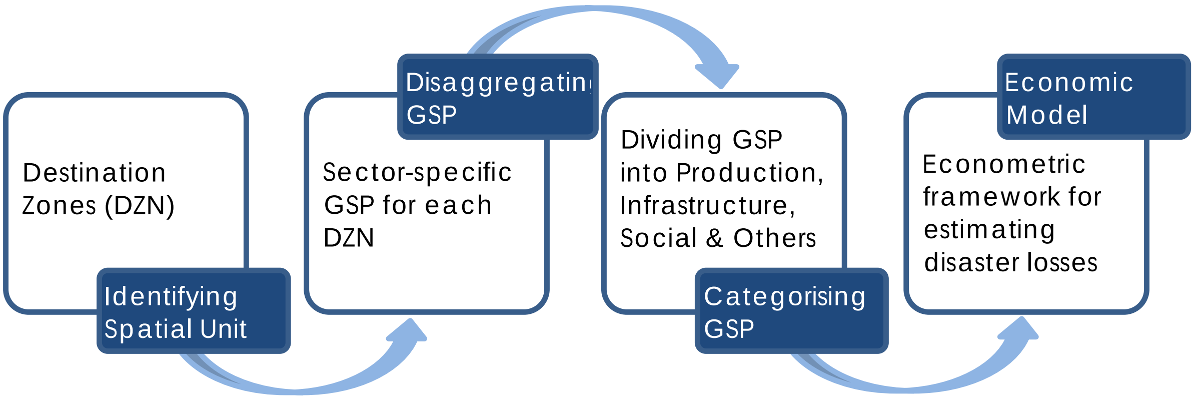

FIGURE 1: SPATIALLY ENABLED ECONOMIC MODELLING PROCESS

2.1. DEFINING THE SPATIAL UNIT OF ANALYSIS

To have a better understanding of where jobs in different sectors are located, the Place of Work (POWP 2011) dataset collected by ABS is utilised as one of the key inputs. Replacing the erstwhile Journey to Work (JTW) 2006 database, POWP provides information on the actual work location of employed people (15+ years old) of each sector in the week prior to Census Night. Generated from written responses to the 'Business name' and 'Workplace address' questionaire about the main place of work last week, the POWP is coded to geographic areas known as Destination Zones (DZNs), which are defined by the relevant State Transport Authority (STAs) from each state or territory, in conjunction with the ABS. POWP is a hierarchical field and for 2011 can be broken into State, SA2 and DZN. Currently, DZN is the smallest spatial unit for POWP.

In POWP 2011, a total of 3157 DZNs are defined for Victoria. However, not all of them are spatial and therefore, cannot be represented geographically. In particular, as illustrated in Figure 2, there are 2755 DZNs, each of which provides the total number of employees by sector.

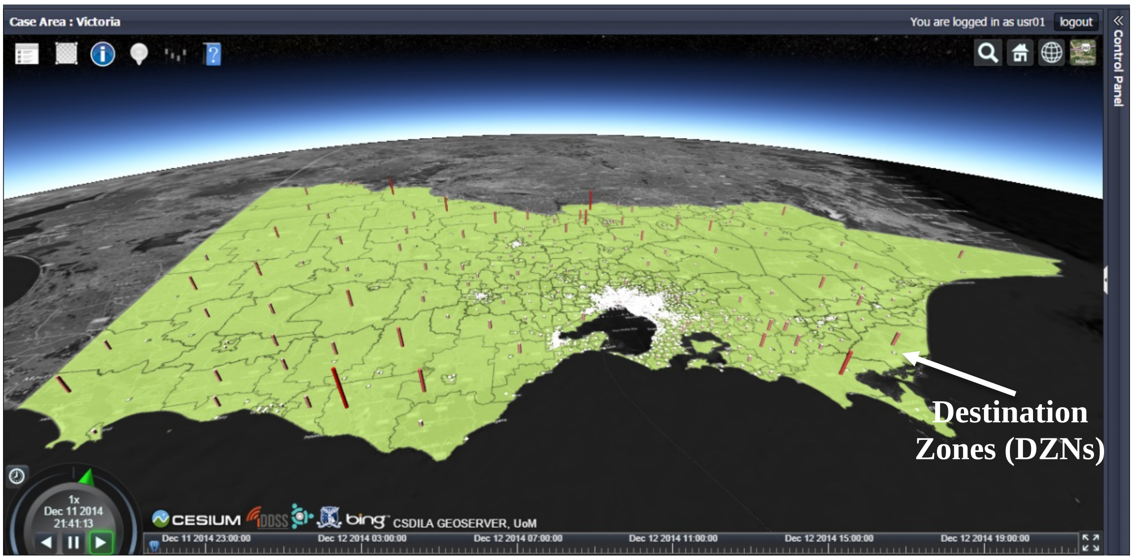

FIGURE 2: NUMBER OF EMPLOYEES IN AGRICULTURE BY DESTINATION ZONES, VICTORIA, 2011

2.2. DISAGGREGATING GSP AT DZN LEVEL

Since GSP data is not available at the spatial level, we devise an approach to disaggregate sector-specific GSP for Victoria. In particular, we have GSP data for each of the 19 economic sectors, which are decomposed into DZN level using the following formula:

$$TP_{ist} = \frac{TP_{st} \times Employment_{ist}}{Employment_{st}}$$

where *i* stands for DZN unit, *s* economic sector, and *t* year. *TP* denotes total production and *Employment* shows the total number of jobs available in the respective sector. That is, we use sector-specific employment size in each DZN as a weighting scale to disaggregate sector-specific GSP at DZN level. This approach imposes an assumption that all employees in a sector produce, on an average, the same quantity of goods and services in a given year. This is a reasonable assumption as it is highly likely to have similar pattern in the average productivity of employees in a sector across DZNs. Further, instead of using employment size, as a robustness check, we try other variables— such as night lights data (see Henderson et al., 2012; Keola et al., 2015)—as a proxy to measure the size of each economic sector at DZN level.

2.3. CATEGORIZING ECONOMIC SECTORS AT DZN LEVEL

According to the Australian national accounting system, there are 19 economic sectors that comprises the whole economy. Australian Bureau of Statistics (ABS) provides total annual production of each sector at state level from 1990 onwards.

Following damage and losses assessment (DaLA) approach as indicated in ECLAC (2012), one can categorise these 19 economic sectors in Australia and Victoria (as per ABS) into four broader groups such as production, infrastructure, social and cross-cutting sectors, as highlighted in Figure 3. Such categorisation provides several advantages in designing risk mitigation interventions. For example, the policymakers may not require designing risk mitigation strategies for all 19 economic sectors separately; rather, they can focus on the social sector for emergency responses, infrastructure sector for post-disaster reconstruction phase, and finally production and cross-cutting sectors for longrun recovery phase. That is, the policymakers are enabled to design economic policies in accordance with the heterogeneous effects of disasters across production, infrastructure, social and cross-cutting sectors.

There underlies a potential caveat with such aggregation of sectors. This also reduces visibility of capturing disaster impacts on different economic sectors and their interactions between each other. These interactions are a key aspect for understanding and ascertaining the potential damage associated with these sorts of systemic hazards. Therefore, we suggest that one should perform loss estimation analysis based on both approaches—i.e., by considering 19 sectors and 4 broader sectoral groups—that can provide more freedom to the policymakers to design risk reduction strategies.

Production	Infrastructure	Social	Cross-cutting
Agriculture Mining Manufacturing Wholesale Trade Retail Trade Accommodation and Food Services Rental, Hiring and Real Estate Services Professional, Scientific and Technical Services Arts and Recreation Services	Electricity, Gas, Water and Waste Services Construction Transport, Postal and Warehousing Information Media & Telecommunication	Education and Training Health Care and Social Assistance Public Administration and Safety	Financial and Insurance Services Administrative and Support Services Other Services

FIGURE 3: NATIONAL ACCOUNTING SYSTEM OF AUSTRALIA: ECONOMIC SECTORS

2.4. ESTIMATING ECONOMIC IMPACTS OF DISASTERS

Generally, two criteria are widely used for macroeconomic policy simulations under the simultaneous equation modelling approach. First, a macroeconomic system can be simulated under a well-specified *structural model* involving all economic sectors where feedback from one sector on another sectors output is not specified. Second, the *vector-autoregressive model* (VAR) is the vectorgeneralization of autoregressive models and can be regarded as an unrestricted reduced form of a structural model, where the specification is capable of addressing inter-sectoral linkages between economic activities. In regards to the policy simulation, both of the above approaches suffer from misspecification issues as they either do not incorporate inter-sectoral feedback of economic activities or do not address possible correlation of residuals in presence of the same disaster shocks across different sectors. To circumvent these problems, the newly proposed econometric techniques in the field work through pinning down the causal relationships over estimating statistical correlation, and hence, exogenous shocks such as natural disasters are modelled using single-equation estimators (e.g., IV-2SLS) instead of the earlier used system settings (see Cavallo et al 2010, Dell, Jones, and Olken, 2014). In accordance, the single-equation reduced form approach is employed which incorporates both inter-sectoral feedback as well as cross-equation correlation of residuals in presence of the same disaster shocks traversing to all sectors of the economy. The proposed economic model is estimated using the Seemingly Unrelated Regression (SUR)[1] estimation technique to decipher the effect of natural disasters on sector-specific GSP at DZN level (*see* Wooldridge, 2010). Our economic model has the following specification:

$$\boldsymbol{TP_{it}^{s1} = \alpha_0 + \beta_1 X_{it} + \beta_2 TP_{it}^{s2} + \beta_3 TP_{it}^{s3} + \cdots + \beta_{19} TP_{it}^{s19} + \varepsilon_{it}}$$

$$\boldsymbol{TP_{it}^{s2} = \alpha_0 + \gamma_1 X_{it} + \gamma_2 TP_{it}^{s1} + \gamma_3 TP_{it}^{s3} + \gamma_4 TP_{it}^{s4} + \cdots + \gamma_{19} TP_{it}^{s19} + \epsilon_{it}}$$

$$\boldsymbol{TP_{it}^{s3} = \alpha_0 + \delta_1 X_{it} + \delta_2 TP_{it}^{s1} + \delta_3 TP_{it}^{s2} + \delta_4 TP_{it}^{s4} + \delta_5 TP_{it}^{s5} + \cdots + \delta_{19} TP_{it}^{s19} + \vartheta_{it}}$$

$$\vdots$$

$$\boldsymbol{TP_{it}^{s19} = \alpha_0 + \mu_1 X_{it} + \mu_2 TP_{it}^{s1} + \mu_3 TP_{it}^{s2} + \cdots + \mu_{18} TP_{it}^{s18} + \omega_{it}}$$

where the script *i* denotes DZN units; *s* represents broad sectors such as production, infrastructure, social and cross-cutting denoted by Arabic numerals; and *t* depicts year. *TP* stands for total production and *X* denotes a set of variables measuring disaster shocks. In particular, one can measure disaster shocks in at least four ways. In econometric modelling, the best measure of disasters is gauging them by its physical attributes. For instance, the height of water during a flood event is a very close proxy to measure its intensity. However such data for each historical disaster events are rarely available. The second best available measure of disasters is its bearing on human dimension (e.g., number of people killed, injured, homeless and affected). This measure needs to be used with caution in that one has to normalise the data by considering population size of each DZN. The next best measure of disasters is an account of physical damages in monetary terms, provided that such calculation generally suffers with exaggeration in most of the occasions. Finally, the crudest way of measuring

[1] See Wooldridge (2010) for technical details about this approach.

disasters is counting them in terms of its occurrence only. There is a potential caveat with this later measure, as it does not capture the intensity of disasters.

The coefficients of interests are β, γ, δ and μ which provide the estimates of disaster impacts on total production at the sector level. Finally, $\varepsilon, \epsilon, \vartheta$ and ω denote error or disturbance terms which are stochastic in nature but guided by well-founded theoretical assumptions in order to minimize their possible confounding effects. The inter-sectoral feedbacks are captured by total productions of different sectors (say, 2, 3, ………, 19 as in the first line) as explanatory variables for a particular sector (say, 1 as in the first line).

Estimation method using historical data is unlikely to capture the effect of any future event that has not been experienced before. However, this caveat prevails in every economic model that is based on ‘regression’ analysis, and hence we leave this issue for further studies.

3. DATA AND MEASUREMENT

Given its multi-disciplinary scope, a wide range of datasets are used in this paper. To estimate the econometric model as indicated in section 2.4, data on the occurrence and location of historical disaster events is required, in addition to climatic variables, GDP data and total number of employment in each sector. These data were sourced from various sources. First, annual data on sector-specific Gross State Product (GSP) for the period 1990-2013 is taken from the Australian Bureau of Statistics (ABS, 2014). Second, for disaggregating these sector-wise GSP to a smaller geographic level, the total number of employment in each sector at a finer spatial unit—Destination zones (DZNs) —is taken from the Place of Work database (POWP, 2011).

This historical series of natural disaster events are sourced from Australian Emergency Management Knowledge Hub (AEM, 2014) that provides data on the location of incidence and its intensity in terms of human mortality and casualties (see Figure 4). Finally, to identify the exogenous sources of natural disasters, time-series gridded data on various climatic features such as monthly rainfall, temperature, and wind speed were collected from the Bureau of Meteorology, Australia (BOM, 2015).

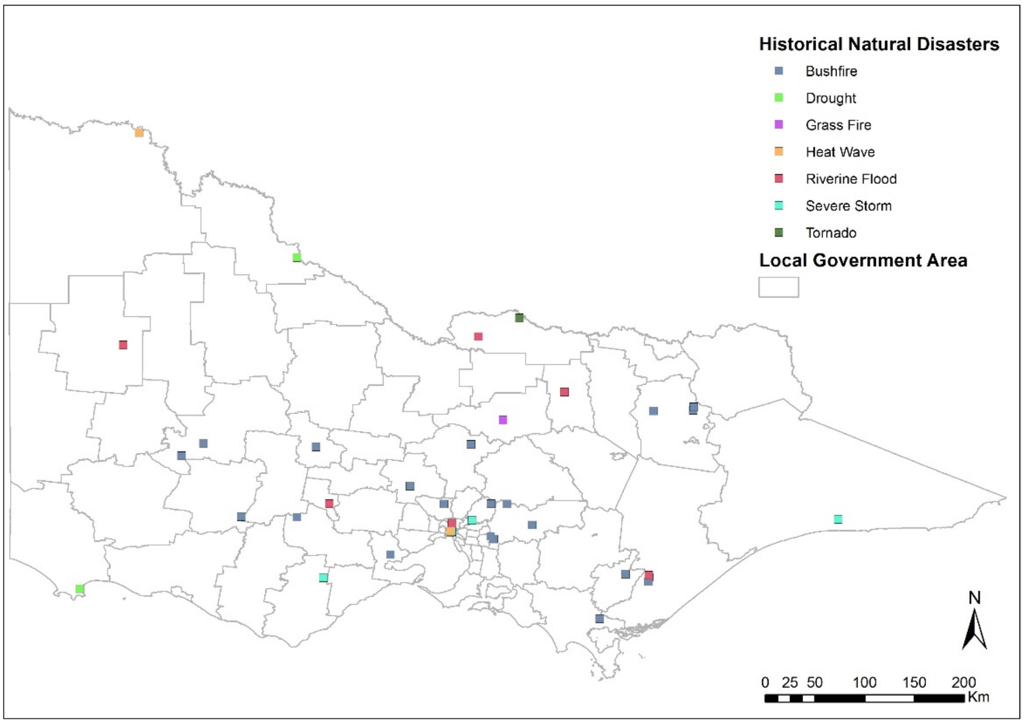

FIGURE 4: LOCATION OF HISTORICAL NATURAL DISASTER EVENTS IN VICTORIA

4. PHILEP: A SPATIALLY ENABLED DECISION SUPPORT SYSTEM

The platform developed and utilised for this work is the Pre-disaster Hazard Loss Estimation Platform (PHiLEP). The PHiLEP platform is particularly suitable for this specific research purpose since it is devised to facilitate the decision making process in Disaster Risk Reduction (DRR) field by utilising a combination of spatial data management, disaster modelling, optimisation technologies and visualisation. The PHiLEP conceptual model is shown in Figure 5 and a short description is provided below.

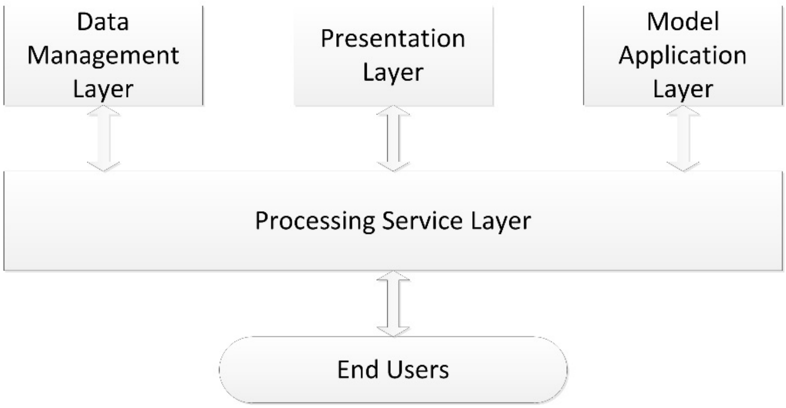

FIGURE 5: CONCEPTUAL MODEL OF PHILEP

One of the most important issues in the disaster decision making process is extracting effective information from heterogeneous data sources to enhance decision makers' situational awareness. The PHiLEP has the capability of aggregating and analysing related data from multiple channels simultaneously from participants as diverse as the authority agencies (e.g. ABS, BOM, VicRoads, DEPI), sensor networks (e.g. river meters, pedestrian counters), Volunteered Geographic Information (VGI) platforms (e.g., Ushahidi, Warnwave) as well as social media (e.g. Twitter). The aggregated data then can be populated into the processing chain to develop a series of time-based scenarios to increase the cognitive abilities of decision makers when facing with disasters of large magnitude and uncertainty. This part of work is abstracted as "Data Management Layer" as shown in Figure 5.

The core of most disaster decision support systems (DDSS) has built-in modelling capabilities such as flood, bushfire propagation and traffic simulation. The PHiLEP platform has been enabled to plug-in with any existing models easily by implementing a universal interface for model integration. This design provides the flexibility to bring in new information and makes the system loose-coupled with these models. In other word, it means the PHiLEP and its models could run as separate applications but still communicate with each other using data exchange protocols. This is particularly important for enhancing system extendibility and fits perfectly well in the cross-agency collaboration framework during disasters. The part is denoted as "Model Application Layer" in the conceptual model diagram.

The "Presentation Layer" provides decision makers with a user-friendly interface to interact with data and models outputs. The PHiLEP offers multiple rendering capabilities to adapt with various data sources and can easily be accessed in a multiuser environment. The system has been built upon a mature web mapping technologies to support data presentations from diverse perspectives, for example, real-time volunteered geographic information (VGI) and sensor network data, live video streams, charts and diagrams of analysis results, disaster propagation animations, etc., to enrich situational-awareness of decision makers. In particular, as the outcome of our economic analysis will be the estimation of overall effects of disasters on each economic sector by DZN, we can plug and present such estimated losses in a DZN based map.

Typically, a disaster event happens within a specific time and location; hence, we ascertain particular data extents and modelling methodologies for a scenario-based decision making process in disaster management contexts. The centre of the PHiLEP conceptual model sits the "Processing Service Layer", which serves as a middleware among the other layers. Its main function is to manage the life cycle of a scenario-based decision making process by preparing related data sets for the processing chain, communicating with designated model applications and aggregating the modelling outputs and analysis results for the presentation layer.

5. UTILITY OF RESEARCH

The proposed loss estimation method as outlined in this paper would have usefulness to a cross-agency collaborative team during emergency, recovery and mitigation. Consequently, a decision support system has been designed to contain the analysis, which is based on a web-based open source model that allows multiple agencies to simultaneously access and interact with the system, and to enable better communication across agencies through a single platform for data exchange and visualisation. For example, the proposed *spatial platform* can assist end users in estimating localised economic costs of natural disasters in the state of Victoria. To be specific, our proposed method is the first of its kind to deliver the following outcomes at the state level:

a) Estimation of the effects of natural disasters on local economic growth of Victoria by economic sectors
b) Identification of the economic sectors at the local level that are vulnerable to natural disasters
c) Identification of the economic sectors at the local level that experience natural disasters positively (in that economic incentives increase in these sectors as a consequence of the disaster)
d) Identification of the economic sectors at the local level that are unlikely to get affected by natural disasters
e) A ranked list of the economic sectors at the local level that seek more attention for policy intervention to minimise potential negative effects of natural disasters

Precisely, this approach is novel in that it provides the effects of natural disasters on each economic sector by DZN. This enables us to embed the disaster losses in a DZN based map in our proposed spatial platform, which can act as a decision support system by identifying vulnerable economic sectors followed by economic policy intervention (e.g., budgeting and resource allocation) for minimising potential disaster losses.

6. CONCLUSION

Disaster risk reduction remains a key focus for policy makers in presence of the continuing and often recurring natural disasters of various magnitudes. Apart from the pertinent physical damage to infrastructure, natural disasters wreak widespread havoc in economic activities. To date, hazard modellers and economists simulate and estimate differential effects of disasters which do not necessarily help the end users in the sense that an overarching impact of the disasters cannot be fully integrated within a single framework which can be used to formulate effective disaster mitigation strategies.

The main contribution of this paper is that the empirical strategy for predicting sectorial productivity declines from disaster events is connected with a novel spatial platform that can be used to display the sectoral effects of natural disasters on a map at the DZN level once they are estimated. This would be of utmost importance to end users for formulating effective preparedness and mitigation policies. Enabling the visualisation of potential damage and losses in natural disasters through this approach acts as a crucial decision support tool for both the federal and state governments to prioritize budget allocation across different economic sectors.

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