



The cost of social vulnerability: an integrative conceptual framework and model for assessing financial risks in natural disaster management

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Abstract

Groups that are unable to prepare for disasters, or to recover from damage on their own, have a high dependency on government services, which inevitably leads to more government spending. Given this, governments can better project the entire cost of disasters and, in turn, effectively manage their finances, by proactively identifying high-vulnerable populations in anticipating financial costs of disasters. However, little attention has been paid to social vulnerability in assessing financial risks in the natural hazards or public finance studies. Thus, this article fills this gap by bringing the concept of social vulnerability from three different fields of study to propose a conceptual framework and corresponding applicable model for estimating disaster costs to inform governmental financial management: the sociological literature on disaster management, economics literature on risk management, and environmental literature of disasters. We review 134 articles on vulnerability from 1990 to 2021, assessing the different conceptualizations of social vulnerability, and the factors affecting vulnerable populations, in each literature. This study contributes to the natural hazards literature on financial and emergency management by integrating the existing literature on social vulnerability into a conceptual framework for measuring social vulnerability and relating it to efforts to assess the financial impact of disasters. Furthermore, based on this conceptual framework, we develop an applicable model for estimating the financial costs of disasters that researchers or governments may apply to assess and develop effective strategies for managing the financial risks associated with disasters. Specifically, the model, which we call the cost of social vulnerability to disasters model (CSVDM), suggests specific indicators from the literature to measure the costs of social vulnerability to more accurately predict the financial impact of disasters.

Keywords Social vulnerability · Social inequalities · Disaster management · Financial risk management

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1 Introduction

Beck (1992) highlights the reconfiguration of risk in modern society, referring to it as a “risk society.” A number of risk factors, such as environmental, economic, and political risks, are entangled with social vulnerability in the risk society that requires collective responsibility. He further develops the concept of social risk positions, meaning that people at higher socioeconomic levels can use their wealth to avoid risks more effectively than those at a lower socioeconomic level. Accordingly, the relationship between socioeconomic factors and vulnerability has been identified and applied to research in the areas of sociology, economics, and the environment to assess potential impacts of risks and prepare for them.

Social vulnerability should be considered in measuring the financial burden of disasters caused by natural hazards so that governments can accurately estimate future disaster costs and budget accordingly. Groups that are unable to prepare themselves for disasters or to recover from damage on their own have a high dependency on government services relevant to disaster preparedness and recovery (Miller and Simile 1992; Cutter et al. 2003; Fothergill and Peek 2004; Zhang and Peacock 2009), which inevitably leads to more government spending (Benson and Clay 2004). In fact, the COVID-19 pandemic substantiates this concern that disastrous events place vulnerable people at a greater risk of devastating consequences (CDC 2020; Gaynor and Wilson 2020; Anderson et al. 2021). As such, governments can better project the entire cost of disasters by proactively identifying high-vulnerable populations, and, in turn, effectively managing their finances.

However, there has been a lack of discussion on social vulnerability when assessing the economic or financial impact of a disaster in natural hazards or public finance research. To date, few studies have considered social vulnerability in their models (Ramsaran 2004; Benson and Clay 2004). In a notable exception, Benson and Clay (2004) explored the financial and economic impacts of natural disasters through the analysis of nationwide cases and addressed how socioeconomic factors determine vulnerability to hazard events. The paucity of studies on this topic presents two limitations. First, when estimating the impact of disasters on local-based revenues, regression models in previous studies assume that disasters have homogeneous effect sizes for all municipalities irrespective of their shares of highly vulnerable groups in that they do not include interactions between disaster and social vulnerability (Kere et al. 2015; Miao et al. 2018; Chen 2020). Since the highly vulnerable groups can suffer more from disaster interruption than a low-vulnerable population, there could be a gap between the estimated and actual impacts under this approach. Second, given that a high-vulnerable population has a greater demand for government spending during the disaster recovery phase, governments cannot effectively address sudden changes in expenditures without considering the social vulnerability of their communities. These limitations create obstacles to the development of financial strategies that effectively plan for future disaster costs based on precise estimation.

In sociology, economics, and environmental studies, the concept of social vulnerability is actively applied in the context of disaster and risk management. These studies conceptualize how natural disasters produce divergent damages and costs dependent upon social vulnerability and build up relevant empirical evidence to support this claim (Fothergill and Peek 2004; Kahn 2005; Cutter and Emrich 2006; Myers et al. 2008; Zhang and Peacock 2009; Landry et al. 2011). Compared to the public finance literature, the natural hazards literature has relatively well developed multifaceted indicators for measuring social vulnerability by drawing on the theories and variables discussed in these three areas (Yoon 2012;

Chang et al. 2015; Almutairi et al. 2020; Goodman et al. 2021). Yet, even in this literature, research particularly concerned with the financial and economic costs of disasters tends to be viewed in isolation from the discussion of social vulnerability (Zou and Wei 2009; Miao and Ding 2017; Zhu et al. 2021; Chen and Chang 2021).

Our research builds on these prior studies to fill a gap in the public finance and natural hazards fields and aims to answer the following questions: (1) How can public finance models better account for the financial costs of disasters given the higher costs of disasters in vulnerable communities? and (2) How can such models effectively reflect social vulnerability by improving its measurement? In response to these questions, we propose a conceptual framework for measuring social vulnerability that integrates the existing definitions on social vulnerability and relates them to academic efforts to estimate the direct and indirect costs of disasters. Furthermore, we use this conceptual framework to develop a model for assessing and projecting the financial costs of disasters that researchers and governments can apply to develop effective strategies for managing the financial risks associated with disasters.

This study begins with a review of the public finance literature on the potential risk of disasters. We then review 134 existing articles on vulnerability in three different fields of study from 1990 to 2021: the sociological literature on disaster management, the economics literature on risk management, and the environmental literature of disasters. We investigate the different theoretical perspectives used in these studies. Then, we further draw on them to propose an integrated theoretical framework and an applicable model that can be used in public finance or natural hazards management scholarship and practice to estimate the financial impact of disasters. Our model has the advantage of taking into account social vulnerability in broader public finance models. Economic studies have developed projection models to estimate the damage of disasters using micro- and macroeconomic approaches to elaborately measure the cost of disasters (Van der Veen 2004). Our model is developed on the basis of a comprehensive view that assumes that the damage of a disaster can be determined not only in economic terms at the individual or group level but also in a social or institutional context. Thus, it can be a tool to parse out the role of socioeconomic factors, community effects, and institutions/systems in shaping disaster costs and, in practice, assess the moderating effects of social vulnerability in the association between natural hazards and their manifested financial impacts.

2 Social vulnerability in assessing the financial impacts of natural hazards

The literature on public finance and financial stability has discussed sudden financial distress caused by natural disasters and economic recessions (e.g., Sobel and Holcombe 1996; Douglas and Gaddie 2002; Gonzale and Paqueo 2003; Hou 2006; Phaup and Kirschner 2010; Ghesquiere and Mahul 2010; Miao et al. 2018; Chen 2020). Previous studies on disaster management in this literature can be categorized into two main bodies of work. The first is a discussion of how government financial decisions change when an unexpected financial shock occurs. Typically, this literature emphasizes how disasters affect government spending and revenues (e.g., Benson and Clay 2004; Kere et al. 2015; Miao et al. 2018). Second, prior research has explored what optimal financial strategies should be implemented to reduce the potential risk of disasters and emergency incidents and to recover a variety of damages from them (e.g., Hou 2006; Phaup and Kirschner 2010;

Ghesquiere and Mahul 2010). These two streams of research suggest that precise evaluation of the impact of hazardous events is a crucial part of disaster management since ex ante or ex post activities—disaster prevention or recovery—are based on the assessment of risk for natural hazards (Somers and Svava 2009).

2.1 Effects of disasters on financial behaviors

Previous studies on the financial impact of disasters have provided empirical evidence on how disasters affect government spending and tax revenues through local economies (e.g., Chernick and Haughwout 2006; Fannin et al. 2012; Kere et al. 2015; Miao et al. 2018). Research on government expenditures finds that disasters drastically increase spending in the short term (e.g., Noy and Nualsri 2011; Ouattara and Strobl 2013; Miao et al. 2018). Regarding revenues, previous studies generally find that economic recession or natural disasters have a negative impact on government revenues (Chang 1983; Hildreth 2009; Kere et al. 2015; Miao et al. 2018). For example, in the case of New Orleans, there was a strong negative relationship between Hurricane Katrina and state revenues (Hildreth 2009).

However, some studies of the impact of disasters on tax revenues show conflicting results, suggesting that the effects of disasters may have variation across various forms of tax structure and revenue sources of the government (Benson and Clay 2004). Hurricane Frederic negatively influenced city government tax revenues in Alabama, but there is evidence that it had a short-term positive relationship with sales tax revenues (Chang 1983). These mixed results may have resulted from an increase in certain types of taxes according to the temporarily increased volume of transactions after a disaster. Alternatively, the inconsistent results across models may be caused by omitted variables such as social vulnerability in the relationship between disaster damage of local communities and the revenue responses to them. More precisely, at the community level, the increase in transactions and tax revenues might be determined by the proportion of vulnerable groups in the community. When vulnerable groups are a small share of the community, the overall effect of vulnerability is mitigated at the community level and, in turn, disasters can be a positive shock raising the amount of post-disaster consumption as a whole. In line with this, Chen and Chang (2021) find that the negative influence of natural hazards on the financial system, such as stock markets and insurance systems, is higher in countries with relatively lower income than their counterparts. Although only the single economic dimension of vulnerability is considered from a macroeconomic perspective, the results indicate the cost of a disaster can be contingent on vulnerability factors.

2.2 Budgeting to mitigate disaster risk

Since disaster events are repetitive, disasters can be regarded as one of many risk factors that should be considered in the budgetary process so that an effective financial strategy can mitigate the disaster damage (e.g., Phaup and Kirschner 2010; Ghesquiere and Mahul 2010). Previous studies suggest that building budget reserves is one of the most important ex ante budgeting tools for governments to preemptively cope with disasters. According to Kirschner et al. (2018), the majority of state governments with rainy-day funds (RDF) are likely to prefer such reserves over municipal bonds or other financial means. The RDF refers to the official reserves that the state accumulates as a form of government saving for the purpose of stabilizing budgets in disaster and emergency situations (Hou 2004; Wang and Hou 2012). Recent evidence shows that disaster experiences are associated with

reserves in a way that reduces RDF in the short term (Pope and Leland 2019) and accumulates it in the long term (Lee and Chen 2021). With respect to the effectiveness of RDF in stabilizing financial conditions, a large body of research on RDFs provides evidence that states holding high levels of reserves are more likely to reduce the sudden volatility of expenditures with less burden of general expenditures during the economic downturns than other states (e.g., Sobel and Holcombe 1996; Douglas and Gaddie 2002; Gonzalez and Paqueo 2003; Hou 2006).

2.3 Social vulnerability and financial burden

The volatility of expenditures following disasters is likely to be determined by social demands for government spending to compensate for damages. Yet, discussions of the vulnerability factors that can shape social demand are sparse in previous studies, which mainly consider financial indicators, institutional factors, political environments, and macroeconomic conditions as determinants of financial behaviors and government's budgetary decision (Hou 2004; Hendrick 2006; Rose 2008; Rodríguez-Tejedo 2012; Elder and Wagner 2013; Su 2019; Miao et al. 2018), excluding social vulnerability.

However, it is important to note that social demand and the entire costs of natural disasters can vary depending on vulnerability factors. According to the sociological and economics literature on disaster management, the socioeconomic characteristics of the community and vulnerability resulting from them could determine the likelihood of exposure to disasters, the magnitude of the damage, and the capacity to recover (Vatsa 2004; Kahn 2005; Landry et al. 2011; Tesso 2014; Vickery 2018), which may further directly affect the government's immediate financial response. Thus, models of financial risk must take social vulnerability into account to generate more accurate projections of future disaster costs and more effective budgeting strategies for disaster management. The vulnerable populations of localities could be the major target of government spending. Furthermore, assuming that the volatility of tax revenues and expenditures determines the level of optimal savings for budget stability (Joyce 2001; Rodríguez-Tejedo 2012; Su 2019), one needs to account for social vulnerability when setting the level of reserves to mitigate disasters of local governments.

3 Review of vulnerability in sociology, economics, and environment

Risk or disaster management studies in the areas of sociology, economics, and the environment have different theoretical perspectives from which they develop explanations for social vulnerability. Each thus provides specific measures of social vulnerability informed by a variety of theoretical perspectives (see Table 1).

In this section, we will review each literature in the order presented in the table to lay the groundwork for a conceptual framework for measuring social vulnerability. Specifically, our review used the following criteria to select relevant articles. First, we collected articles that contain key search words, such as “vulnerability” and “vulnerable groups,” and various synonyms. For example, we reasoned that “resilience” is the flip side of “vulnerability” in the sense that these terms share a mechanism by which a certain social factor makes people susceptible to risk or protects them from it. Then, we judged whether each article addressed a specific issue relevant to our research questions. Once we selected the articles, we analyzed the text to identify five main themes: definition of vulnerable groups,

Table 1 Summary of factors to identify vulnerable populations

Factors to identify social vulnerability	Explanation	Theoretical perspectives
<i>Sociology</i>		
Individual-level demographic and socioeconomic factors	Age, gender, race, ethnicity, religion, language, culture, economic status	Feminist theory Discrimination theory Group-centric policy theory Intersectionality theory
Community-level contextual and relational factors	Civic capacity, similar industry (community's familiarity), neighborhood characteristics, network density, community participation, collective efficacy, commercial density, local social groups and ecological communities, trust, social norms, collective culture	Network theory Social movement theory Conflict theory Ethnography and neighborhood theory Political ecology theory Trust theory
<i>Economics</i>		
Economic factors	Income (median income, GDP per capita), poverty (% of population below poverty line, financial capital, Gini index), single-sector economic dependence, employment rate (occupations), the quality and ownership of housing	Utility theory Preference theory Asset theory Resource dependence theory
<i>Environmental management</i>		
Geographic factors	Location in dangerous regions (coastal areas)	-
Governmental factors	Government capacity (government earnings, resources, and trained professionals), public policy, municipal politicians	An integrated theory (a framework for theoretical integration, the context-sensitive approach, etc.)
Institutional factors	System quality (insurance, technological development-digital divide)	

Source Factors and theories are retrieved from previous studies in the three different studies

measurement of vulnerability, mechanisms of why social factors raise vulnerability, the relationship between vulnerability and other social phenomena, and the resilience of members of a society after a particular disaster.

3.1 Sociology

In sociology, social vulnerability is considered one of the by-products of social inequity (Cutter et al. 2003). As such, the sociological literature on disaster management is mixed with various theoretical perspectives explaining social inequalities as shown in Table 1. The different theoretical views provide different explanations of why groups marginalized by certain variables are more vulnerable to natural disasters than others.

At the individual level, the sociological literature includes various factors that define vulnerable populations such as race/ethnicity, gender, age, religion, and personal wealth (e.g., Stallings 2002; Cutter et al. 2003; Browning et al. 2006; Donner and Rodríguez 2008; Elliot and Pais 2010; Reid 2013).

There is evidence that victims with minority backgrounds received a lack of support for recovery after Hurricane Katrina (Reid 2010; Haney et al. 2010; Weber and Messias 2012). A similar case is found with Hurricane Andrew; disaster-affected rental homes in minority areas recovered more slowly than those in majority areas during financial shortages (Zhang and Peacock 2009; Reid 2013). Recent studies show that even in the case of human-induced disasters, such as COVID-19, racially identified vulnerable groups are more likely to be exposed and vulnerable to those types of disasters (Mladenov and Brennan 2021; Anderson et al. 2021).

Prior research also points out that women can be more vulnerable than men as seen through the lens of family and gender ideology (Enarson and Meyreles 2004; Peek and Fothergill 2008; Weber 2013). Peek and Fothergill (2008) reveal that parents prioritize the evacuation of their children and the delivery of vital resources even when they are at risk, and this was largely done by mothers as an extension of their caregiving roles. Besides, increased post-disaster stresses have amplified domestic violence against women (Enarson 1999; Faust and Ven 2014).

Language and cultural contexts provide another explanation to address why ethnicity relates to vulnerability. For example, immigrants have communication problems derived from their language skills (Fothergill et al. 1999; Norris and Alegría 2008; Grineski 2009; Kroll-Smith and Brown-Jeffy 2013). The problem of language communication experienced by immigrants and foreigners creates difficulties in understanding emergency messages in the event of disasters and emergencies (Fothergill et al. 1999). Thus, vulnerable people who lack language skills cannot properly understand and implement public health and safety guidelines. In a cultural context, when minority groups feel that post-disaster relief programs are not appropriate for their culture and intentionally do not participate in the necessary activities, they may be more vulnerable than others in the disaster recovery process (Fothergill et al. 1999; Norris and Algeria 2008; Reid 2013). Undocumented immigrants also have a tendency not to engage in disaster preparedness and recovery plans because of fear of deportation (Grineski 2009; Menjívar and Abrego 2012; Reid 2013). Norris and Algeria (2008) provide a theoretical framework of cultural competence to explain the relationship between culture and vulnerability. Specifically, as service and policy providers deepen their understanding of cultural backgrounds and experiences of beneficiaries, they can provide high-quality services and, ultimately, improve satisfaction with services.

The concept of social vulnerability has also developed in close association with economic inequality, namely poverty, in the sociological literature (e.g., Vatsa 2004; Elliot and Pais 2010). Scholars suggest that poor groups are exposed to greater economic loss and psychological pain caused by disasters such as earthquakes, floods, and hurricanes (Fothergill and Peek 2004; Cutter and Emrich 2006). People with low economic status may lack the economic resources required to implement guidelines for effectively responding to disasters and emergencies (Vatsa 2004; Reid 2013). Furthermore, low-wage workers cannot afford to take leave from work during a disaster, which makes them more susceptible to risks. Housing insecurity and loan difficulties also increase the vulnerability of the poor (Vatsa 2004).

Notably, past research has substantiated that the factors presented above can interface with each other (e.g., Enarson and Hearne 1997; Peek and Fothergill 2008; Reid 2010). For example, through interviews with women from different classes, Enarson and Hearne (1997) show that mothers of low-income families have more psychological and physical problems than mothers of high-income families in disaster situations. Low-income African-American women struggle to stay in shelters during disaster recovery, while middle-class white women can turn evacuation into a sort of leave (Peek and Fothergill 2008). Reid's (2010) work of post-Katrina housing policies also shows that intersecting oppressions may be more disadvantageous for poor women of color. That is, poor women of color are more marginalized from policy than men of color or women of other ethnic groups because of discrimination in mortgage lending.

Individual-level vulnerability indicators are meaningful in that the vulnerability factors can collectively explain variation in particular social phenomena in disaster mitigation or recovery, but they are limited in explaining how each individual factor may increase or weaken vulnerability in different contexts. For instance, when individual vulnerability factors lie in the context of high-level social networks, will networks moderate or intensify the impact of individual vulnerability? In order to answer this question, it might be more effective to delve into how individual-level vulnerability factors work differently within heterogeneous community characteristics, for example, by comparing the vulnerability of ethnic minority communities in high- and low-density network settings. However, to date, there are few studies that provide empirical evidence of interactions between the community- and individual-level vulnerability factors in the context of disaster.

Meanwhile, scholars working on community-level factors explain vulnerability as a feature of social relations such as network density, community participation, trust, collective culture, and neighborhood characteristics (e.g., Kirschenbaum 2004; Fitzgerald and Fitzgerald 2005; Browning et al. 2006; Wright and Boudet 2012; Hossain 2012). For example, Browning et al. (2006) use neighborhood theory to parse out the disparities of mortality in the case of the 1995 Chicago Heat Wave. They evidenced that communities with richer commercial activities were less vulnerable to mortality during the heat wave. In addition, collective participation might contribute to the development of management plans for different types of natural disasters and reduce the damage from them (Hossain 2012). Studies focusing on the community level largely use qualitative methods, including case studies and comparative analysis, to investigate how community attributes relate to the susceptibility to disasters (e.g., Browning et al. 2006; Wright and Boudet 2012), or provide literature reviews for understanding the contribution of community participation to resilience (e.g., Fitzgerald and Fitzgerald 2005; Hossain 2012).

Many community-level studies examining the societal attributes of vulnerability provide insights into the social contexts affecting vulnerability that have been overlooked by research focusing on individual vulnerability. Further, individual- and community-level

contexts are intertwined; in fact, many case studies of Hispanic and African-American families in New Orleans suggest the possibility that community-level social support mitigated the race-related individual vulnerability in relation to Hurricane Katrina (e.g., Real 2007; Hawkins and Maurer 2010). Since the cost of a disaster to be borne by the government is determined by the entire social costs, it is necessary to comprehensively reflect both individual and community-level factors that interactively determine the society's vulnerability.

3.2 Economics

The economics literature on risk management defines vulnerability in terms of economics, thereby regarding groups with low levels of economic income or low accumulative assets as vulnerable (e.g., Pritchett et al. 2000; Christiaensen and Subbarao 2005; Chaudhuri et al. 2002; Hoddinott, and Quisumbing 2003). Hoddinott and Quisumbing (2003) categorized vulnerability into three approaches: vulnerability as expected poverty (VEP), vulnerability as low expected utility (VEU), and vulnerability as uninsured exposure to risk (VER). VER refers to the extent to which a negative shock causes a reduction in consumption and a welfare loss as an ex post outcome (Hoddinott and Quisumbing 2003; Gallardo 2018). This concept is similar to VEP¹ and VEU² because it is based on income and consumption but differs in that it is more practical for applying a post-assessment approach to economic shocks than predicting the likelihood of future poverty or utilities.

As such, based on the theoretical concept of VER, prior studies often present empirical evidence (e.g., Kahn 2005; Gaither et al. 2011). Kahn (2005) suggest that richer countries are less vulnerable to disasters because economic development provides high-quality institutions (such as insurance for natural disasters) and greater investments in information processing of hazard storms and enforcement of zoning codes to insure against disasters. On the other hand, poorer communities are more vulnerable, e.g., they suffer more from wildland fires even compared to communities located in higher fire risk areas because of the lack of participation in mitigation programs (Gaither et al. 2011). Similarly at the individual level, income accounts for the level of participation in activities that individuals need to mitigate risk (Hoddinott and Quisumbing 2003). Willingness to pay at the individual level is determined by the utility function, and a lack of insurance increases exposure to risk (Kunreuther and Pauly 2006; Cafiero and Vakis 2006; Gallardo 2018).

The economic literature provides a strong conceptual background on class-related vulnerability. In particular, the VER approach is relevant for estimating how social vulnerability affects disaster costs because it enables us to measure the response to natural disasters

¹ Vulnerability as expected poverty (VEP) refers to the risk that a household will fall below the poverty line in the future (Christiaensen and Subbarao 2001; Chaudhuri et al. 2002). It suggests that a household's vulnerability can be predicted by poverty thresholds that determine the level of consumption expenditure. As such, the effort to quantify vulnerability in the literature is in line with how to accurately measure "poverty" (e.g., Foster et al., 1984; Pritchett et al. 2000; Christiaensen and Subbarao 2005; Chaudhuri et al. 2002; Kamanou and Morduch 2002; Hoddinott and Quisumbing 2003).

² A body of studies has taken a utilitarian approach to defining and measuring vulnerable groups in risk situations (e.g., Ligon and Schechter 2003; Calvo and Dercon 2013; Gallardo 2018). For economists, it is important to understand utility because the utility is the theoretical basis for explaining the fundamental behavior of humans consuming goods and services. Poor people are more likely to have difficulty spending on (1) investing for risk mitigation (Kahn 2005; Landry et al. 2011), (2) reserving resources to respond to unexpected disasters and emergency events (Hoddinott and Quisumbing 2003; Thornton et al. 2008), and (3) participating in activities required to recover from the damage of such events (Masozera et al. 2007).

as a backward-looking concept. The VER provides the convenience of measurement in that it takes advantage of observable actual values such as the reduction of consumption or income level as a result of risk events (Ligon and Schechter 2003; Gaiha and Imai 2006; Moret 2014). Furthermore, the concept is in line with the sociological literature's effort to gauge the economic dimension of social vulnerability using indicators such as per capita income and percent living below poverty line (Cutter et al. 2003). Therefore, our conceptual model also includes economic status as one of the individual-level vulnerability factors.

3.3 Environment

The environmental literature can provide a variety of insights into research on vulnerability, particularly for public sector researchers. First, it goes beyond the discussion of vulnerability in the realm of individuals and communities by giving attention to government capacity, social systems such as insurance, and public policy (Smit and Skinner 2002; McEntire et al. 2010; Adelekan 2010; Agustrihardaning 2014; Mann et al. 2014; Birkholz et al. 2014; Ashraf and Azad 2015; Prospero et al. 2016; Lyth et al. 2016). Since the vulnerability of individuals or communities can be increased or decreased by these institutional aspects, the variables presented in this literature need to be further considered in accurately estimating the entire disaster costs of the local population. In particular, the development of social systems for disaster mitigation can help a high-vulnerable population effectively reduce government spending.

Second, the literature asserts that vulnerability to risk should be considered in terms of time, as risks are computed based on accumulated damages from iterative events (Buckle 2005; Keskitalo 2008; Hall et al. 2013; Hill and Engle 2013). As such, efforts to identify vulnerability in the environmental literature cover the ability to respond to disasters at the present time and the adaptive ability to mitigate potential risks in the long run. Adaptations can be undertaken at individual, group, or organizational levels (Keskitalo 2008), particularly government agencies (Agustrihardaning 2014; Rickards et al. 2014). In the context of adaptation, human and material capacity of governments, such as earning, resources, and trained professionals, are presented and measured as contributing factors to vulnerability (Myers et al. 2008; McEntire et al. 2010).

Thus, such discussion from a dynamic perspective can be supportive of the argument that government capacity and politics may also affect disaster mitigation strategies (Keskitalo 2008; Agustrihardaning 2014; Lyth et al. 2016). Different political environments or government capacities can produce divergent responses to recurring disasters. For instance, Keskitalo (2008) foregrounds the importance of financial and political contexts such as financial resources and municipal politics, showing how adjacent communities are differentially affected by disasters depending upon their higher capacity and more effective strategies. Communities with low government capacity may not be able to take timely and appropriate actions despite repeated damage from disasters. Political orientation can be associated with how risk-averse decision-makers. Thus, these factors also need to be considered in accounting for social vulnerability and estimating disaster costs.

Third, geographical location is one of the vulnerability factors in the environmental literature. Behind this approach, there exists statistical evidence that people living in dangerous regions, such as coastal areas that are easily exposed to floods and hurricanes, are more vulnerable. For example, Chakraborty and Armstrong (1995), Forbes et al. (2004), and Myers et al. (2008) all assess vulnerability using data on distributions of residence. Such

research does not investigate the root cause of why such distributions are made. Yet, it can capture realistic vulnerability factors since such easily observed factors such as residential distribution can intuitively represent a gap in vulnerability. In line with this, Rifat and Liu (2021) substantiate that there exist disparities in the outcomes of COVID-19 between urban and rural communities, presenting disproportionate mortality rates from the pandemic.

Lastly, integrative perspectives, for instance, the multidisciplinary features of research on vulnerability, might be increasingly in demand given the more complicated and intertwined disruptive events that a single actor cannot address alone. For example, McEntire et al. (2010) incorporate a variety of factors from social science, engineering, and physical science to highlight that planning for mitigation, law and policy, and disaster management systems all influence vulnerability, pointing out that the model of social vulnerability presented in prior research is incomplete. Vulnerability to global environmental problems such as climate change could be addressed in terms of local and regional situations rather than at the individual level (Keskitalo 2008). The same applies to the case of natural disasters. Detrimental consequences of unpredictable disasters expand with the growth of interdependence between regions or nations.

4 Comprehensive framework and practical model for estimating disaster cost

The sociological, economic, and environmental literature all provides important insights for public finance and natural hazards scholars when assessing the social vulnerability of a local population to disaster risk and estimating disaster costs as a result.

First, the sociological literature goes beyond economic factors and presents social demographic factors, such as race/ethnicity and gender. It also discusses social networks and community participation as community-level factors influencing the vulnerability of individuals and communities. The sociological studies account for the social vulnerability of both individuals and communities because they provide a more in-depth picture of how social context, such as social network and capital, makes individuals or groups more or less vulnerable to natural hazards. Furthermore, intersectionality studies provide critical insights about the interactions between different social vulnerabilities, explaining how one vulnerability factor intertwines with others, thus exacerbating the vulnerability of specific groups at the intersection of multiple vulnerabilities (Enarson and Hearne 1997; Peek and Fothergill 2008; Reid 2010; Vickery 2018). It is important to identify such groups as they are primary targets of social services and financial aid programs by the government after disasters.

Second, the economic literature presents a rationale for including variables such as poverty and personal income to assess the vulnerability of individuals and estimate their economic costs stemming from natural disasters. Since income level relates to satisfaction with consumption associated with the reduction of risk, individual economic factors shape the probability of participating in risk-mitigation activities, such as investment in insurance, at the individual level. When economic vulnerability is high in an area, we would expect greater financial risk for local governments, who would be responsible for providing assistance to mitigate exposure to disasters and also aid in disaster recovery efforts.

Lastly, the environmental literature incorporates real-world factors influencing the vulnerability of both individuals and communities. It recognizes, for instance, that governments' financial vulnerability to risk—as a result of the social vulnerability of individuals

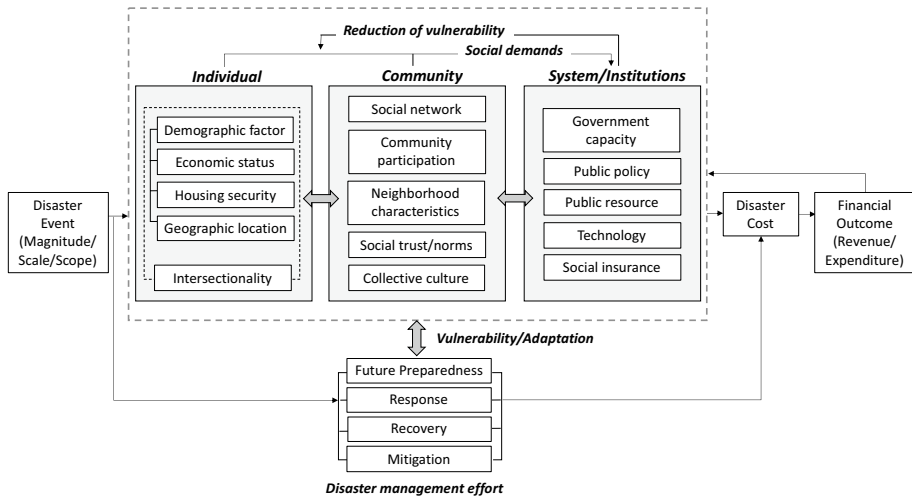


Fig. 1 A comprehensive framework of social vulnerability

and communities—can be increased or decreased by government capacity, social systems, and public policy. Furthermore, geographic characteristics offer an alternative explanation for the social vulnerability of the local population that goes beyond individual and even community vulnerability factors.

In sum, each of these three bodies of the literature addresses the limitations of the others. While the economic literature confines itself to a focus on economic variables not allowing such indicators to vary within different social contexts, the sociological and environmental literature addresses this limitation with their emphases on collective forms of vulnerability and the capacity of society to address both individual and collective vulnerability factors. Similarly, sociological studies highlight the vulnerability of both individuals and communities, but overlook the ways in which responsibility for reducing vulnerabilities can move from individual to society. To address this issue, variables from the environmental field draw attention to government capacity and public policy. If public policies can be regarded as a factor that makes people or groups more or less vulnerable, it becomes clear that governments can make specific interventions to reduce social vulnerability and ultimately the costs of disasters to governments. When theoretical models omit these system–institutional factors, responsibility for addressing vulnerability falls—in a limited way in our view—on individuals or communities. As such, the environmental literature advances the premise that governments are responsible for reducing vulnerability through the effective management of public systems.

Using these complementarities, we develop an integrative model of social vulnerability useful for comprehensively estimating the financial and economic impact of disasters. Figure 1 shows our framework, which incorporates three different areas of social vulnerability: individual, community, and system/institution. Each dimension includes several factors for measuring vulnerability and how they interact with one another to create a level of financial vulnerability within a given jurisdiction. We do not propose that any single study alone addresses all of the vulnerability factors and their interactions, but rather we propose a comprehensive model that provides an overview of the range of possible factors to consider that can inform future research. Any individual empirical project could, for instance,

focus on certain social vulnerability factors and their interactions to determine the influence on disaster cost and the ability of governments to mitigate the financial outcome, and over time a body of work could advance the framework overall. Lee and Chen (2021) have begun this project using the framework to show how government capacity moderates the financial impact of natural disasters in the saving context.

In Fig. 1, disaster events indicate an external shock that occurs naturally, and may have various features including magnitude, scale, and scope, which would make vulnerable people more vulnerable. That is, a disaster could increase the level of social vulnerability at individual, community or system/institutional levels. Over time, hazard events shape the future preparedness effort in different ways and affect the levels of disaster response, recovery, and mitigation depending on the severity of the disaster event.

The square denoted by the dotted line represents the level of social vulnerability as a whole and—with the degree of disaster management efforts—determines the ultimate cost of a disaster. Within the square, preexisting individual, community, and societal levels of vulnerabilities interact. Specifically, individual-level vulnerable characteristics—including demographic factors, economic status, housing security, and spatial location—can emerge out of and be moderated at the community and societal levels. For example, according to the VER approach in the economics literature, a lack of self-insurance mechanisms resulting from an individual's low economic status can shape welfare loss at the aggregated level. Demographic factors of individuals presented in the sociological literature determine individual-level vulnerability because, for instance, individuals experience low political power or collective alienation arising from their minority backgrounds. The sociological literature further suggests that the possibility of the intersection of different factors can reinforce individual vulnerability.

As Fig. 1 shows, community-level vulnerability can interplay with individual-level vulnerability in the sense that the level of trust and network of communities can serve as a buffer to compensate for social vulnerability of individuals. Similarly, the environmental literature provides a perspective on how vulnerability at the community level can be reduced or amplified by systemic and institutional features such as government capacity, public policy, and social insurance. The vulnerability of individuals and communities may determine the social demand for such policies and relevant systems, and inversely, the high quality of systems and institutions could serve as a tool to compensate for the vulnerable groups.

Social vulnerability as a whole has a feedback relationship between the four phases of disaster management. On the one hand, given the same level of magnitude of a disaster, the extent to which individuals and groups are exposed to, respond to, and recover from disasters are likely to depend on the preexisting level of social vulnerability, which would affect their capacity to cope with hazard events. On the other hand, individuals, communities, and social systems can improve their capacity to learn and adapt through recurring experiences of disasters and corresponding relevant activities, thus affecting social vulnerability after a disaster recovery. Through the interplay between disaster management and social vulnerability, the total cost of a disaster is ultimately identified. For example, programs aimed at removing debris from disasters could be a direct cost caused by a disaster, and greater social vulnerability might spill over to other areas of society, resulting in indirect costs.³ The total cost of disaster could have an impact on the government's financial outcome such

³ However, in practice, despite the uneven capacity to cope with disasters by vulnerability, only the estimated consequent damage of a disaster is considered in the decision-making of allocating disaster relief funds. For example, social vulnerability is not a consideration in the process of FEMA's Public Assistance program that accounts for the largest portion of federal aid for disaster relief.

as revenues and expenditures. Under financial distress, governments may produce different investment decisions toward reducing social vulnerability to future disasters through various programs, policies, and technology development depending on their financial condition.

This framework calls for more analysis on the relationship between the various dimensions of social vulnerability, on the one hand, and the financial impact of disasters, on the other. Grounded on the framework, we further develop the applicable model for estimating the financial impact of disasters that can effectively account for disaster damage and social vulnerability. In general, a typical public finance model follows the form:

$$Y_{it} = \alpha + \beta D_{it} + \gamma X_{it} + v_{it}, \quad (1)$$

where Y_{it} denotes the financial accounts (revenues, expenditures, or financial condition) for region i in time t ; D_{it} represents disaster damage that occurred in region i at time t ; X_{it} is a vector of control variables that affect financial accounts, such as intergovernmental aid and financial condition in prior years; and v_{it} represents an error term. As shown in Fig. 1, disaster damage is often measured by features of disasters such as the magnitude, scope, and scale.

We propose the following revised model to investigate potential interactions of disaster impact with social vulnerability, based on Eq. (1).

$$Y_{it} = \alpha + \beta D_{it} + \gamma SV_{it} + \delta(D_{it} \cdot SV_{it}) + \theta X_{it} + v_{it}, \quad (2)$$

where SV_{it} denotes a measure of social vulnerability and $D_{it} \cdot SV_{it}$ represents the potential interactions between the initial damage as a natural force and social vulnerability for region i in time t . Given our framework, the function of SV_{it} can be expressed as follows:

$$SV = f(I, C, S),$$

$$I \in \{i_1, i_2, \dots, i_k\}, C \in \{c_1, c_2, \dots, c_m\}, S \in \{s_1, s_2, \dots, s_n\}$$

where I , C , and S represent a measure of social vulnerability at the individual, community, and societal levels, respectively; I is a $1 \times k$ vector of individual-level variables that vary over region and time; C denotes a $1 \times m$ vector of community-level variables that vary over region and time; and S refers to a $1 \times n$ vector of societal-level variables that vary over region and time. Table 2 shows the selected indicators and variables that can be used for measuring social vulnerability that integrates these three different dimensions.

The applicable model presented in Eq. (2) and the social vulnerability indicators in Table 2 can also be used for governments to develop disaster mitigation plans. We purposely pick indicators in Table 2 that can be constructed using publicly available data sources (except for some variables related to information technology and social insurance), so that policymakers at various levels of government can easily apply the concept of social vulnerability in practice. For example, the Centers for Disease Control (CDC) and the Hazards Vulnerability & Resilience Institute (HVRI) developed individual social vulnerability indicators using various social factors collected from the US Census. They evaluated the

Table 2 Selected indicators and variables in the social vulnerability index for the cost of social vulnerability to disasters model (CSVDM)

No.	Level	Indicator	Variable
1	Individual	Race/ethnicity	% of the population with ethnic minority backgrounds
2		Gender	% of female
3		Age	% of the population over age 60; % of the population under age 18
4		Religion	% of believers in nonmainstream religions
5		Language competency	% of population proficient English speakers
6		Economic status	Per capita income; % of population below poverty line
7		Private insurance	% of the total population with private insurance
8		Housing security	% of mobile home; % of household with more people than rooms; % of multi-unit structure
9	Community	Geographic location	% of the total population living in high risk areas
10		Participation in religious activities	Number of religious organizations per capita
11		Participation in civic activities	Number of civic organizations per capita
12		Participation in charitable activities	Number of charitable organizations per capita
13	Society (System; Institutions)	Political participation	% of the population who are eligible for voting
14		Collective culture	% of union members; % of fraternal association members
15	Society (System; Institutions)	Government capacity (Personnel capacity; financial capacity)	% of personnel specialized in financial or emergency/disaster management in the total workforce; % of own-source revenues in total revenue; revenue diversification index
16		Public policy	Number of policy programs associated with emergency/disaster mitigation, preparedness, response, and recovery, and the corresponding budget share
17	Society (System; Institutions)	Public financial resources for disaster management	Disaster account; budget stabilization fund, unassigned general fund balance
18		Information technology for disaster management	Availability of multi-hazard early warning systems; the adoption of social media platforms; AI-powered system for natural disasters
19	Society (System; Institutions)	Social insurance	Number of disaster-related insurance programs offered by the government; number of public benefits programs; insurance coverage levels

Source Indicators and variables are retrieved from the literature review

social vulnerability of all US counties and disclose the data publicly.⁴ In current practice, although many governments have developed Hazard Mitigation Plans for “identify hazards and vulnerabilities” and to “develop a long-term strategy to reduce risk and future losses” as part of their emergency management process (FEMA 2015), we find that most of those plans only identify the frequency and intensity of natural hazards. The vulnerability concept in hazard mitigation plans mostly focuses on physical vulnerability of buildings, infrastructure, and critical facilities,⁵ with little attention to social vulnerability. In some states’ mitigation plans (e.g., New York State 2019), a social vulnerability index developed by the HVRI is used to describe vulnerable populations. However, social vulnerability is not integrated to the estimation of disaster costs (as in the interaction term $D_{it} \cdot SV_{it}$ in Eq. 2). Also, HVRI’s index only includes variables at the individual level and excludes the community and society levels that we propose incorporating in Eq. 2 as shown in Table 2. An examination of several other state and local mitigation plans⁶ also shows that most focus mainly on individual-level vulnerability factors while neglecting the system and institutional factors similar to those we list in Table 2. Thus, we provide a more comprehensive approach to measuring social vulnerability than existing practical models used routinely in disaster financial risk management. This suggests that more accurate approaches to measuring the costs of social vulnerability could be integrated into governments’ efforts to assess disaster risk and prepare for future disasters.

5 Discussion and conclusion

The increasing risk of natural and human-induced disasters increases the financial burden of governments and challenges the stable provision of public services. A key financial strategy in disaster management is accurately estimating the proneness of disasters and their impacts on government revenues and expenditures as it serves as a basis for allocating budgetary resources to maintain financial stability. As such, this study attempted to answer the question of how public finance models can produce better estimates of the financial costs of disasters by reflecting the costs of multi-dimensional social vulnerability, as our CSVDM model suggests.

Our review has three important findings. First, to date, the factors to measure vulnerability have been viewed in relative isolation, including individual, community, and system–institutional forms of social vulnerability. While the sociological, economic, and environmental studies highlight distinct, disciplinary forms of social vulnerability, if taken

⁴ See more information about the social vulnerability indicators of the CDC/ATSDR https://www.atsdr.cdc.gov/placeandhealth/svi/data_documentation_download.html, and the HVRI https://www.sc.edu/study/colleges_schools/artsandsciences/centers_and_institutes/hvri/data_and_resources/sovi/index.php.

⁵ For example, FEMA (2015)’s “State Mitigation Plan Review Guide” states that “risk assessment evaluates where populations, infrastructure, and critical facilities are vulnerable to hazards, and to what extent injuries or damage may occur” and that “vulnerability and potential losses are [...] the summary of the potential impacts to those assets from the identified hazards. Factors affecting vulnerability may include asset use and function as well as construction type, age, or intended use.”(p. 15).

⁶ For instance, Albany, New York, uses the USC’s index to identify areas with a high proportion of vulnerable populations as part of risk assessment efforts, following the FEMA guidelines on Hazard Mitigation Plan (HMP), <https://mitigationy.availabs.org/risk/vulnerablepopulations>. Also, government agencies in Austin, Texas, and Takoma Park, Maryland, adopt the CDC’s indicator in their practice to manage natural and human-induced disasters. See more information about the Austin case, <https://data.austintexas.gov/Health-and-Community-Services/Minority-Status-and-Language-dataset-of-CDC-Social/x89r-5ts4/data>, and the Takoma Park case, <https://takomaparkmd.gov/government/housing-and-community-development/planning-and-community-development/data-driven-approach-to-disaster-pandemic-response/>.

together, they could provide a complementary view of social vulnerability factors that account for the limitations of each individual disciplinary perspective. There have been no studies to our knowledge integrating measures that capture these three critical and inter-related risk factors in the literature on financial and natural hazards management—particularly those concerned with the financial impact of natural disasters. Thus, our framework developed in this study offers an integrative perspective that reflects a variety of interacting social vulnerability factors that influence the vulnerability of a local population overall, showing also how they interact with system–institutional factors. This framework has the potential to improve the validity of the measurement of social vulnerability overall.

Second, extant studies on the financial impact of natural hazards overlook the concept of social vulnerability of communities, which could create a gap between the estimated demands for fiscal policy and the actual demands in the real world. Despite the possible link between the cost of disaster and social vulnerability, little attention has been paid to assessing the moderating effect of social vulnerability between natural hazards and their financial impact, in either the public finance or natural hazards studies. Given that the share of vulnerable populations would differently shape an increase in transaction volume leading to a rise in short-term government revenue after a disaster, an analysis without considering vulnerable groups may produce biased and inconsistent estimates of the fiscal impact of natural disasters.

Third, the previous discussion indicates the possibility that policy interventions can interact with other vulnerability factors at the individual and community level, which is also shown in our framework and model. That is, policy interventions, on the one hand, may determine the vulnerability of individuals and communities, and on the other, their vulnerability influences the level of such interventions. Regardless of whether policy intervention occurs prior to or after the occurrence of a disaster, the government typically will bear the costs. As a result, the cost of social vulnerability is not limited to the losses suffered by individuals and communities but also includes the cost of the policy interventions too.

Through the literature review, we suggest that considering social vulnerability not only has normative values for disaster management—it suggests providing resources to the most vulnerable in society—but also can be useful in deriving more precise cost estimate of disasters in practice to ensure that local governments can effectively recover from disasters more generally.

On a practical level, this study can help policymakers put more effort into developing an indicator system to measure social vulnerability, although measuring social vulnerability remains challenging. Our estimation model can assist government offices in refining the estimation of financial costs of natural disasters so that they can develop more effective disaster management strategies. Taken together, this study enables governments to differentiate the vulnerability factors that affect their populations and the likely costs of disaster recovery, and in turn, the financial efforts governments will need to undertake to prepare and recover from a variety of disruptive events. The COVID-19 pandemic is a case in point. The pandemic has created financial instability, as many governments at different levels experienced budget shortfalls (NCSL 2020). The pandemic also disproportionately affected vulnerable groups: Groups with high social vulnerability have a higher likelihood of infection and death and the economic losses (Karaye and Horney 2020; Gaynor and Wilson 2020; CDC 2020; Anderson et al., 2021; Rifat and Liu 2021). The factors presented in this study (e.g., socioeconomic variables, social relations, and government aid programs) can be useful to predicting vulnerability to cope with unexpected pandemics and other disasters. This study also indicates certain policies that help to reduce social vulnerability to

disasters, and thus future financial risk. As such, it may improve the relevance of policies aimed at financial stability to account better for social vulnerability.

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Conflict of interest The authors declare that there is no conflict of interest.

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