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MEASURING THE FINANCIAL SHOCKS OF NATURAL DISASTERS: A PANEL STUDY OF U.S. STATES

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This paper employs panel vector autoregression to examine the dynamic fiscal response to natural disasters. With 50-state, 1970–2013 panel data on state government finance and disaster damage, we estimate disaster impacts on revenue, expenditure, debt issuance, and federal-state transfers. We find that following a disaster, states increase program expenditure and receive more federal transfers. Disasters have limited impact on total tax revenues but amplify fluctuations in sales, income, and property tax revenues. Our findings suggest that disaster-induced additional spending is largely financed through federal transfers, which include not only disaster relief funds but also non-disaster-related public welfare assistance.

Keywords: natural disaster, panel vector autoregression, intergovernmental transfer

JEL Codes: Q54, H7, H30, H12, H53

I. INTRODUCTION

Natural disasters can cause economic shocks by inflicting direct damage to homes, infrastructures, and assets as well as disrupting normal business activities. Disasters can also pose severe shocks to government operations and finance (Benson and Clay, 2004) because these events are widely viewed as a public problem requiring government interventions (Schneider, 1995). Costs are incurred when a government provides emergency response, disaster relief, and assistance for the recovery of affected communities, which increase public expenditure and require budgetary adjustments. The macroeconomic impact of disasters (e.g., on incomes and employment) may influence tax bases and government revenues. These potential impacts raise a series of questions

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on how we should assess the fiscal costs of natural disasters. Specifically, how is the disaster burden shared across levels of government? How are these costs distributed inter-temporally over multiple budget cycles? How does governmental aid redistribute resources between the disaster victims and other taxpayers who are not directly affected? How can we forecast a government's financial exposure to future natural disasters and appropriately budget for these shocks? All these questions become increasingly important to both policymakers and researchers, given that disaster damage keeps growing and climate change will likely increase the frequency and intensity of extreme weather events such as hurricanes and floods (Intergovernmental Panel on Climate Change, 2012).

This paper provides one of the first estimates of the fiscal costs of natural disasters at the U.S. state level. Using a panel vector autoregression (VAR) model, we empirically examine the dynamic impact of natural disasters on state government finances including their expenditures, tax revenues, intergovernmental transfers, and issuance of debt over four decades (1970–2013). The methodology allows us to compute the dynamic multiplier functions (DMFs) based on the panel VAR estimates to identify the duration and rate of decay of a disaster's fiscal impact. One major finding is that natural disasters significantly increase the total spending of state governments and also increase the intergovernmental revenues they receive from the federal government. The five-year cumulative response of a state's total spending (measured in percentage of its gross state product, or GSP) is estimated at 0.2 percentage points, following a 1 percentage point increase in its direct disaster damage (share of GSP) that occurs in year 0. The same shock would increase the cumulative federal transfers the state receives in the next five years by a factor of 0.27. Our findings are robust to alternative disaster severity measures.

Our study contributes to the public finance and disaster literature in several ways. First, while the public finance literature has a traditional interest in how governments respond to economic crisis and output fluctuations (e.g., Poterba, 1994; Sorensen, Wu, and Yosha, 2001), fewer studies have looked into the fiscal implication of other exogenous events (e.g., Burnside, Eichenbaum, and Fisher, 2004).[1] Less attention has been paid to the shocks triggered by natural disasters to government expenditures and revenues. Our research fills this gap by investigating how disasters affect different fiscal behaviors and allowing for the endogenous interdependency among these variables. Our finding provides empirical evidence on the countercyclical spending pattern following disasters, which not only sheds light on the fiscal cost of natural disasters but can also be used to assist governments in budgeting for future natural disasters.[2]

Second, while much research has been done to analyze the short- and long-run economic impacts of natural disasters (including total outputs, economic growth, incomes, and employment),[3] few studies have examined the fiscal implications, and almost all are cross-country analyses using aggregate national accounts to estimate the general

[1] Burnside, Eichenbaum, and Fisher (2004) examined the financial shocks triggered by the Korean War, the Vietnam War, and the Carter-Reagan military build-up as well as their subsequent macroeconomic impacts.

[2] For more discussion about public budgeting for natural disasters, see Phaup and Kirschner (2010).

[3] For a comprehensive review of the literature, see Cavallo and Noy (2011) and Kousky (2014).

equilibrium effects. For example, Melecky and Raddatz (2011, 2014) examine the impact of different types of disasters (geological, climatic, and others) on government expenditures, revenues, and deficits of high- and middle-income countries from 1975 to 2008. Using a panel VAR model, they find that natural disasters, particularly climate hazards, lead to significant increases in budget deficits, and this effect is larger in lower-middle-income countries. Lis and Nickel (2010) focus on large-scale extreme weather events and find that, compared to developed countries, developing countries experience much larger budgetary deficits after these disasters. Using quarterly data, Noy and Nualsri (2011) find that natural disasters lead to increased spending and decreased revenues in developed countries but cause the opposite pro-cyclical response in developing countries. Finally, Ouattara and Strobl (2013) examine the impact of hurricanes on a sample of 18 Caribbean countries and find that hurricane strikes increase their government spending but have no significant effects on public investment, tax revenues, or debt.[4]

Despite the aforementioned cross-country evidence, little is known about the fiscal cost of natural disasters at the subnational level and the intergovernmental dynamics in responding to these shocks.[5] Our study fills this gap and suggests that disaster-induced additional state government spending is largely financed through federal transfers. It also sheds light on post-disaster welfare redistribution, implying that a considerable proportion of local disaster costs are shifted to taxpayers across the nation.

Our findings on intergovernmental disaster financing should offer valuable insights into the ongoing discussion regarding the U.S. disaster policy and the role that federal government plays in providing disaster assistance. The Stafford Disaster Relief and Emergency Assistance Act of 1988 and its antecedents from the Disaster Relief Act of 1950 authorize the President to issue disaster declarations, which trigger federal grants provided through various programs to subnational governments as well as affected households.[6] The past few decades have seen a steady increase in the number of Presidential Disaster Declarations (PDDs) and growing federal disaster expenditures.[7]

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[4] In addition to the national government finances, another line of research has examined how natural disasters affect the flows of international aid and remittances, also in a cross-country setting (Yang, 2008; Cavallo and Noy, 2011; David, 2011; Hsiang and Jina, 2014).

[5] A recent working paper (Yang, Fidrmuc, and Ghosh, 2012) examines post-disaster fiscal dynamics also using state-level panel data. Our study improves their work by using better quality disaster data and a more rigorous estimation methodology. We further examine the disaster impacts on disaggregate fiscal outcomes (e.g., tax revenues by type, separating federal disaster-related aid from non-disaster-related transfers).

[6] When a natural disaster strikes and overwhelms the resources and capabilities of state and local governments, the state's governor may submit a request for federal assistance. After the Federal Emergency Management Agency (FEMA) performs the preliminary assessment of disaster damage, the President can either approve the request and issue PDD or deny the request. The federal government normally pays at least 75 percent of all eligible expenses once a PDD is made. FEMA's Disaster Relief Fund (DRF) is the primary funding source for disaster response and recovery. When a catastrophic incident threatens to deplete the DRF, the President typically submits a request to Congress for supplemental appropriations.

[7] According to the Office of Management and Budget (OMB), the federal government incurred more than $300 billion in direct costs associated with extreme weather and fire between 2004 and 2013. More than half of these expenditures were for direct disaster responses and relief, and the remainder was spent on flood and crop insurance, and wildland fire management.

Nonetheless, identifying the full scope of spending and transfer payments related to natural disasters involves at least two complications. First, the majority of federal grants for disaster response and relief are funded through supplemental appropriations in the aftermath of a large-scale disaster, and these *ad hoc* appropriation bills may likely involve non-disaster-related spending (Donahue and Joyce, 2001). Second, natural disasters not only increase government spending on disaster aid but may also increase other program expenditures such as healthcare and property management. While several studies have attempted to identify the amounts of federal disaster spending (e.g., Healy and Malhorta, 2009; Cummins, Suher, and Zanjani, 2010), our study is the first to estimate the disaster impact on federal-state transfers as another approach to gauging the size of federal disaster burden. We also use historical data on annualized disaster losses and federal disaster relief expenditures to estimate the direct damage-spending relationship.

In this study, we also decompose the disaster impact on a variety of state finance subcomponents to illuminate the mechanism behind the aggregate fiscal shocks. On the revenue side, although natural disasters appear to have little effect on states' total own-source revenues, we find that they cause fluctuation in revenues from different taxes (e.g., by causing negative shocks to property and income tax revenues). This finding could be useful for understanding the link between a government's tax structure and its financial resilience to disaster risks.

On the spending side, we show that natural disasters increase state capital spending, welfare payments, and most prominently, spending on local governments. We also find that natural disasters not only increase disaster-related transfers (e.g., disaster relief distributed by FEMA), but also increase federal transfers on non-disaster-related public welfare programs. This result is consistent with the findings in Deryugina (2017) and suggests that the actual fiscal cost of natural disasters could be much larger than the traditional estimates that only account for disaster-related spending.

The remainder of the paper proceeds as follows. In the next section, we discuss the mechanisms through which natural disasters affect pubic finance and outline our hypotheses. Section 3 describes our data sources. Sections 4 and 5 present the empirical methodology and main results, respectively. Section 6 discusses our results and concludes.

II. THE IMPACT OF NATURAL DISASTERS ON PUBLIC FINANCE

Conceptually, the fiscal implications of natural disasters are influenced by their direct impacts on economic activities as well as the disaster policy, fiscal institutions, and other behavioral responses of a government following these shocks. Concerning government revenues, the influence of disasters on tax bases is contingent on their macroeconomic impacts, which in theory could be either negative or positive. On the one hand, natural disasters could lower output by destroying physical capital and causing business interruption (Hallegatte, 2015); on the other hand, some scholars argue that disasters provide the opportunity to update productive assets and adopt new technologies, thereby yielding positive economic impact in the recovery phase (Skidmore and

Toya, 2002; Cuaresma, Hlouskova, and Obersteiner, 2008). The empirical evidence on disaster-induced macroeconomic effects is mixed: many studies (e.g., Raddatz, 2007; Noy, 2009; Hochrainer, 2009; Strobl, 2011; Hornbeck, 2012) find a negative disaster influence on output growth, whereas some others show a positive effect (Skidmore and Toya, 2002).[8] If natural disasters exert a negative net economic impact, we would expect them to reduce tax bases and lower government revenues. In the meantime, the revenue response also depends on the structure and rate of taxation (Noy and Nualsri, 2011) and whether a government adjusts its tax policy following disasters. Such adjustments can be either providing tax reductions to disaster victims or increase taxes to cover the disaster-related costs (Benson and Clay, 2004). These complications lead to an ambiguous effect of disasters on government revenues and make it an empirical question to test.

On the expenditure side, disasters often result in additional government spending on emergency responses and debris cleanup, reconstruction of damaged public infrastructures, and assistance to the disaster-affected populations.[9] These expenditures highlight an important role government plays in providing social insurance against natural disasters as well as stabilizing the economy and social order after these shocks. As discussed earlier, the "public" nature of disasters requires government actions and provision of assistance, and sometimes, politics drives the allocation of disaster aid to please the voters (Downton and Pielke, 2001; Garett and Sobel, 2003; Husted and Nickerson, 2014).

When a government incurs additional spending to cope with a disaster, it may also reallocate its budgetary resources, such as postponement or abandonment of other planned projects and investments, to accommodate its disaster spending (Benson and Clay, 2004). Such adjustment of expenditures could lower the disaster burden on aggregate government finance, but may cause welfare losses (Kousky, 2014). On the other hand, natural disasters might increase other types of government spending and transfer payments that are intended to reduce the economic impact caused by the shocks. For example, Deryugina (2017) finds that hurricanes lead to substantial increases in non-disaster government transfer through social safety net programs such as unemployment insurance and public medical payments, of which the present values even exceed that of direct disaster aid. Overall, in the U.S. federalism context, we expect large-scale disasters to increase state government expenditure as well as the intergovernmental transfers they receive from the federal government. States' post-disaster spending pattern can be affected by the amount of federal aid they obtain as well as their financial resources and managerial capacity.

[8] These empirical studies vary substantially on their time horizons (short term versus long term), types of natural hazards, the sample of countries or regions (e.g., developed nations versus developing nations), and the sectors affected by disasters (Loayza et al., 2012).

[9] It should be noted that the disaster-related expenditure should enter the calculation of the economic costs of disasters differently. While emergency response and reconstruction could be considered the direct cost of a disaster, government aid to disaster victims to reimburse their losses is essentially a transfer from the perspective of the society.

III. DATA

In this paper, we compiled a balanced panel which combines state government financial variables with statewide disaster severity measures during each fiscal year (FY). Our sample includes all 50 states from 1970 through 2013. Table 1 summarizes our main variables and the descriptive statistics.

A. State Government Finance

Our fiscal variables are from the U.S. Census Bureau's *State Government Finances Survey*, which provides annual statistics on government revenues by source, expenditures by object and function, indebtedness by term, and assets by purpose. At the aggregate level, we include each state government's total own-source revenues (including taxes, current charges, and other types of revenue), total expenditures (including intergovernmental and direct expenditures), total intergovernmental revenue from the federal government, and long-term debt issued in a given FY (flow of the newly-issued debt). We also divide these aggregate accounts into their main components to measure the disaggregate fiscal outcomes: tax revenues by source (general sales tax, individual income tax, corporate income tax, property tax); expenditures on current operations, capital outlays, intergovernmental expenditures at the local level, and social welfare payments;[10] and federal transfers by function (housing and community development, natural resources and agriculture, and public welfare). To measure the amount of federal disaster aid, we also collect data on FEMA's disaster relief from the Census Bureau's *Federal Aid to State Reports*, which documented federal government aid to state and local governments by agency and program.[11] The FEMA data are only available from FY 1981 to FY 2010. All the fiscal variables are deflated using the Bureau of Labor Statistics' consumer price index for urban consumers (year 2000 = 100). We follow the approach used in Noy and Nualsri (2011) by normalizing the fiscal accounts as percentage of the state's real GSP in the previous year, with the data retrieved from the U.S. Bureau of Economic Analysis.

B. Natural Disaster Severity

Given that public finance statistics are reported on a FY annual basis, we collect monthly disaster damage data from the *Spatial Hazard Events and Losses Database for the United States* (SHELDUS)[12] to match state-specific FYs.[13] SHELDUS reports

[10] These include insurance benefits and repayments, and assistance and subsidies.

[11] FEMA's reported disaster relief aid is comprised of primarily Disaster Relief Funding, disaster assistance direct loan financing account, and flood mitigation assistance. It should be noted that FEMA's disaster relief represents a large proportion of federal disaster relief, although there are other federal agencies, including U.S. Department of Agriculture (USDA) and Department of Housing and Urban Development (HUD), which also provide assistance and direct relief to disaster-stricken states and localities.

[12] The database is maintained by the Hazards and Vulnerability Research Institute at the University of South Carolina. SHELDUS data are assembled from public sources such as the National Climatic Data Center's monthly publications.

[13] According to the Census Bureau, most state government fiscal years end on June 30 except for four states with other ending dates: Alabama and Michigan (September 30), New York (March 31), and Texas (August 31).

Table 1

Summary Statistics of Main Variables (1970–2013)

Variables	N	Mean	SD	Min	Max
Natural Disaster Severity					
Total disaster damage (percent of GSP)	2200	0.19	1.20	0.00	32.55
PDD-affected counties (percent of all counties in a state)	2200	20.64	35.62	0.00	346.27
Count of large PDD incidents	2200	0.25	0.53	0.00	4.00
Aggregate Fiscal Variables (percent of GSP)					
Total own-source revenues	2200	3.07	1.22	–0.12	40.95
Total revenues from federal transfers	2200	2.83	1.21	0.95	10.12
Total spending	2200	11.08	3.28	4.84	32.80
Long-term debt issued	2200	1.01	0.81	0.00	6.34
Disaggregate Fiscal Variables (percent of GSP)					
Sales tax revenues	2200	1.58	0.79	0.00	4.15
Personal income tax revenues	2200	1.44	0.90	0.00	3.66
Corporate income tax revenues	2200	0.33	0.26	0.00	4.73
Property tax revenues	2200	0.13	0.34	0.00	4.22
Current operational spending	2200	5.48	2.18	1.71	23.10
Capital outlays	2200	1.01	0.48	0.26	5.81
Intergovernmental spending on local governments	2200	2.77	0.96	0.09	6.20
Welfare spending (insurance, subsidies, assistance)	2200	1.45	0.64	0.17	4.57
FEMA's disaster relief (1981–2010)	1500	0.03	0.10	–0.04	1.70
Federal transfers — housing and community development	2200	0.04	0.08	0.00	2.01
Federal transfers — agriculture and natural resources	2200	0.06	0.06	0.00	0.80
Federal transfers — public welfares	2200	1.33	0.78	0.16	5.12

disaster losses at the county level from 18 different types of natural hazards.[14] To measure the severity of natural disasters, we calculate statewide total monetary damage (direct property and crop losses) including all hazard types recorded in SHELDUS. Consistent

[14] The 18 types of hazards recorded in SHELDUS include hurricanes, flooding, earthquakes, droughts, tornadoes, winter weather, severe storm/ thunderstorms, hail, wind, wildfires, landslide, volcano, heat, lightning, coastal events (e.g., storm surges, coastal erosions), tsunami, fog, and avalanche, as seen in Table 2, Panel A.

with our treatment of the fiscal variables, a state's disaster damage is adjusted for inflation and then normalized as the ratio of its previous year's GSP. We expect that higher levels of disaster damage occurring in a state would induce larger fiscal repercussions, holding everything constant.

Two things are important to note here. First, direct disaster losses reflect the cost of damage sustained by properties, public infrastructures, and crops. The loss data of SHELDUS are primarily drawn from the Storm Events Database, which uses the estimates made by the National Weather Service based on a variety of sources. These direct losses include both insured and uninsured damage in both private and public sectors.[15] Second, although using the sum of losses may mask the heterogeneity in disaster-specific impacts, it can capture the overall severity of extreme events hitting a state within a time period, and also minimizes the possible omitted variable bias resulting from other excluded disaster damage.

Table 2, Panel A reports the average disaster damage by hazard type. The summary statistics show that hurricanes and tropical storms have caused the most damage ($81 million per year) in the United States during the 1970–2013 period; nearly 70 percent higher than the average costs of flooding, which represents the second most damaging event type. Damage is more or less similar among earthquakes, droughts, tornados, winter weather, and severe storms.

Panel B reports each state's average annual disaster damage over the sample period. It shows that the Gulf Coast (e.g., Florida, Louisiana, Texas, and Mississippi) states generally experienced the highest disaster damage (in a range of 0.8–1.7 billion U.S. dollars); this is presumably because they are at higher risk of hurricanes, the costliest natural hazard in the United States as seen in Panel A. These statistics also hint that larger states are more likely to be hit by natural disasters and incur greater disaster losses. However, when we take into account a state's size of economy (disaster damage as the ratio of GSP), the relative disaster impact becomes less significant for larger and wealthier states. Among all, Mississippi, North Dakota, Louisiana, and Iowa stand out as the four states with the highest proportion (over 0.8 percent of GSP) of their statewide wealth destroyed by natural disasters.

We compose Figure 1 using a longer time series, from 1960 through 2013, to show the increasing trend in annual natural disaster damage in the United States. The Figure highlights 2005 as the worst year because of Hurricane Katrina, which is the most expensive disaster event in U.S. history.

While direct damage is arguably an ideal measure of severity because it reflects the destruction caused by disasters, it can be endogenously influenced by socio-economic

[15] It should be noted that SHELDUS' loss data have a number of limitations (Gall, Borden, and Cutter, 2009), for example, using the lower bound of the range of the estimated losses and only include events causing at least $50,000 in property damage or causing at least one fatality may underreport losses for low-damage events. The dataset also equally distributes loss information across counties when multiple counties are involved in an event. But the latter is less worrisome for our study because we aggregate disaster damage at the state level.

Table 2

Statistics on Natural Disaster Damage in the United States

Panel A. Total Annual Damage by Disaster Type 1970–2013

Rank	Natural Hazard	Total Annual Disaster Damage ($Thousand)	Rank	Natural Hazard	Total Annual Disaster Damage ($Thousand)
1	Hurricane/Tropical Storm	81,469	10	Wildfire	6,808
2	Flooding	49,109	11	Landslide	2,832
3	Earthquake	18,383	12	Volcano	2,165
4	Drought	17,185	13	Heat	1,308
5	Tornado	16,042	14	Lightning	850
6	Winter Weather	14,142	15	Coastal events	805
7	Severe Storm/Thunder Storm	13,652	16	Tsunami	48
8	Hail	11,955	17	Fog	16
9	Wind	11,437	18	Avalanche	6

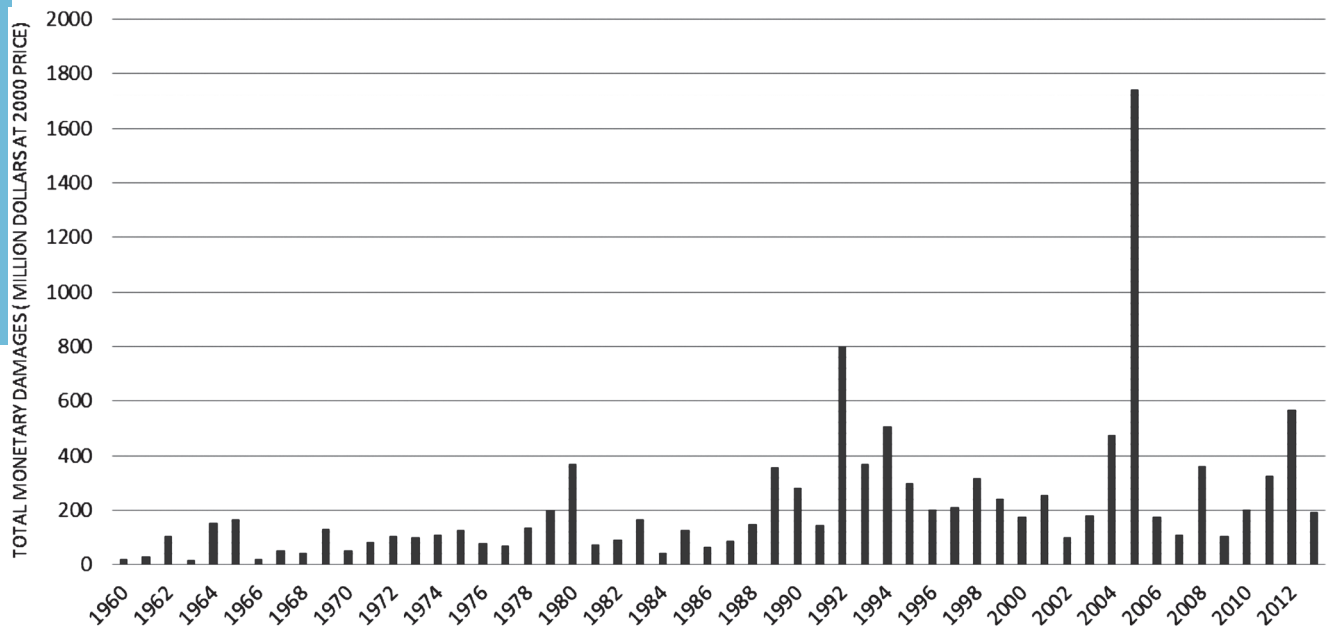
Panel B. Total Annual Damage by State 1970–2013

State	Damage (Percent of GSP)	Total Annual Disaster Damage ($Thousand)	State	Damage (Percent of GSP)	Total Annual Disaster Damage ($Thousand)
Florida	0.42	1,727,744	Kansas	0.18	134,632
California	0.16	1,536,719	Tennessee	0.08	131,221
Louisiana	0.89	1,353,967	Michigan	0.04	116,878
Texas	0.18	1,084,391	Georgia	0.05	91,432
Mississippi	1.26	798,956	Arizona	0.07	90,206
Iowa	0.81	702,304	Kentucky	0.09	86,275
New Jersey	0.14	501,475	Hawaii	0.16	64,158
Washington	0.28	352,474	Massachusetts	0.03	54,170
Alabama	0.29	322,022	New Mexico	0.10	50,102
North Carolina	0.12	273,979	West Virginia	0.12	49,393
New York	0.04	256,168	Vermont	0.27	41,693
Missouri	0.15	237,460	Utah	0.10	41,599
Illinois	0.06	222,229	South Dakota	0.24	38,071
Oklahoma	0.23	215,593	Maine	0.12	35,105
Wisconsin	0.15	211,421	Maryland	0.03	34,514
South Carolina	0.25	207,111	Idaho	0.13	33,759
Pennsylvania	0.06	195,738	Oregon	0.03	24,357
North Dakota	1.06	185,841	Nevada	0.04	23,653
Ohio	0.05	175,044	Connecticut	0.02	20,422
Nebraska	0.32	157,995	Alaska	0.07	19,532
Minnesota	0.12	155,317	Montana	0.06	12,471
Arkansas	0.25	147,294	Wyoming	0.06	11,614
Colorado	0.10	136,708	Rhode Island	0.03	8,587
Virginia	0.09	136,644	New Hampshire	0.02	6,815
Indiana	0.09	136,224	Delaware	0.02	5,955

Note: All the monetary amounts are converted into year 2000 dollars using the Consumer Price Index.

Figure 1

Trend in Annual Natural Disaster Damage in the United States (1960–2013)



Note: All the monetary amounts are converted into year 2000 dollars using the Consumer Price Index.

factors (Kahn, 2005). As robustness checks, we construct another two measures of disaster severity using the PDD data retrieved from FEMA.[16] Since a PDD is normally made at the county level, we use the information on the count of PDDs and the number of counties involved in a PDD to capture the frequency and scope of those particularly large disasters. Our first measure is the percentage of counties in a state that receive PDDs in a given FY. For a disaster that is declared "statewide," we include all the counties in this state.[17] Our second measure is the count of PDDs that affect at least one-third of a state's counties in a given FY. This procedure has reduced the total number of nationwide PDDs from 1,763 to 564 incidents over our study period.

IV. EMPIRICAL MODEL

We use a panel VAR model to estimate the dynamic impacts of statewide natural disasters on its government finances. This methodology combines the traditional VAR model, which allows a system of endogenous variables to be explained by its own lagged values, lagged values of other endogenous variables, and exogenous variables, with the panel data structure.[18] The panel VAR method has been applied extensively in the macroeconomics and development finance literature (e.g., Neusser and Kugler, 1998; Love and Zicchino, 2006; Mora and Logan, 2012), and this method has been used recently to analyze the impact of natural disasters (e.g., David, 2011; Noy and Nualsri, 2011; Cunado and Ferreira, 2014). In this section, we describe our specification, identifying assumptions, and discuss the main advantages of using this technique.

The conceptual argument that motivates our choice of model is that natural disasters pose an exogenous shock to a government and affect its different fiscal behaviors simultaneously. These responses, such as public expenditures and tax revenues, are inter-related and could pass over to each other through their dynamic interactions in the following years. Based on this notion, we specify a first-order reduced-form panel VAR model with a distributed lag of natural disaster variables as follows.[19]

$$(1) \quad Y_{it} = A_0 + A_1 Y_{it-1} + \sum_{j=0}^{5} B_j D_{it-j} + \theta_i + \gamma_t + e_{it},\ i \in \{1,2,...,50\}, t \in \{1,2,...,43\},$$

where Y_{it} is a vector of k fiscal variables of interest for state i in FY t,[20] which is determined by their one-year lagged values; D_{it-j} denotes the contemporaneous and lagged natural disaster severity measures ($j = 0, 1, \ldots, 5$), allowing for the delayed effect of

[16] FEMA categorizes the disaster declarations into four types: major disaster declarations, emergency declarations, fire management assistance declarations, and fire suppression authorizations. We confine our focus only to major disaster declarations.

[17] This variable can exceed 100 percent when a state has multiple statewide PDDs within a year.

[18] For a more comprehensive review of the panel VAR methodology, see Holtz-Eakin, Newey, and Rosen (1988), Love and Zicchino (2006), and Canova and Ciccarelli (2013).

[19] This specification is also referred to as the panel VARX model (Canova and Ciccarelli, 2013), which includes exogenous explanatory variables in the system of dynamic equations.

[20] $Y_{it} = \{revenue_{it}, spending_{it}, transfer_{it}, debt_{it}\}$ in the aggregate fiscal response model.

disaster shocks on government finances; θ_i is a vector of state fixed effects, which controls for the time-invariant unobserved heterogeneity across states (e.g., their baseline risk of natural hazards); γ_t is a vector of FY fixed effects, which controls for the national shocks common to all state government finances in the same year.[21] Finally, e_{it} is a vector of independently and identically distributed disturbance terms, and $\boldsymbol{A_0}$, $\boldsymbol{A_1}$, and $\boldsymbol{B_j}$ are estimated coefficient matrices. The lag lengths for the fiscal and the disaster variables are chosen based on the model selection criteria proposed by Andrews and Lu (2001). The panel VAR model is estimated using the package of programs provided in Abrigo and Love (2016). We cluster standard errors at the state level to address possible heteroscedasticity and autocorrelation in the data.

One major advantage of using panel VAR is that it allows multiple fiscal variables to be endogenous and inter-related within the same system. This is consistent with the stylized observation that fiscal decisions are often highly interdependent (Poterba, 1994). One of the reasons is that most states have a balanced budget requirement, which leads to joint decisions on government revenues and spending. Moreover, a state's receipts of federal transfers may also influence its spending behaviors. Therefore, our model allows the impact of exogenous disaster variables on one endogenous variable to spillover on other endogenous variables in succeeding periods. For example, if natural disasters cause a change in federal transfers, which later affect state government spending, the panel VAR model can pick up the indirect effect of disasters on spending. Another advantage, to be discussed later, is to allow the disasters' impact to vary over time which enables us to identify the duration and rate of decay of a disaster shock.

Our key identifying assumption is that natural disasters are exogenous, wherein past or present fiscal conditions are irrelevant in explaining the timing and severity of natural disasters after controlling for the state fixed effects.[22] However, one might worry that a state's disaster losses may correlate with its socioeconomic characteristics (for example, property losses directly depend on the values of properties; therefore, wealthy states may suffer larger monetary damage from natural disasters because they have more assets to lose). We address this concern by normalizing disaster losses by GSP. We also conduct Granger-causality tests on the normalized disaster variables and show that a state's pre-existing fiscal conditions are overall insignificant in predicting (i.e., do not Granger-cause) its later disaster damage (see Online Appendix A).[23]

Several things are important to note regarding the estimation of our empirical model. First, we follow Holtz-Eakin, Newey, and Rosen (1988) by removing state fixed effects using first-differencing, and estimate the differenced model using generalized method

[21] We removed the time fixed effects before estimation by subtracting the cross-sectional mean from each variable in the model.

[22] In other words, we use the within-state variation in annual disaster damage to identify its impact on fiscal behaviors. It is likely that some states are at higher risks of certain natural hazards (e.g., the south Atlantic states are particularly prone to hurricanes and coastal flooding) and better adapted to these shocks, and such baseline hazard profile is controlled for by the state fixed effects.

[23] A variable x Granger-causes another variable y when, given past values of y, past values of x are useful in predicting values of y (Granger, 1969).

of moments (GMM). It is well-known that first-differencing introduces correlation between the differenced lagged dependent variable and the disturbance process that could lead to biased estimates (Nickell, 1981). We address this issue by instrumenting the differenced lagged dependent variables with lags of ***Y*** and ***D*** in levels, following Holtz-Eakin, Newey, and Rosen (1988). We test our instrumental variables for over-identifying restrictions using Hansen's J-statistic, and check the eigenvalue stability condition for our panel VAR specifications and estimates.[24]

Second, we quantify the dynamic impact of exogenous disaster shocks on fiscal variables by calculating the DMFs based on the estimated panel VAR coefficients and the error variance-covariance matrix. The DMF shows the isolated impact of a shock in an exogenous variable on the dependent variables in the system one period at a time, while holding other shocks equal to zero. By taking this approach, we are able to portray the effect of a unit increase in the disaster severity measure on the temporal trajectory of state fiscal variables, and we could also identify the duration through which a disaster shock persists. More specifically, we compute the DMF point estimates ψ_t at period t by using the estimated coefficients $\mathbf{A_1}$ and $\boldsymbol{B_j}$ in the following equation,

$$(2) \quad \psi_t = \sum_{j=0}^{5} A_1^{t-j} MB_j,$$

where the kxk M matrix having elements $M[r, c]$ equals one if $r = c$ and $j \geq t$, and zero if otherwise. We perform Monte Carlo simulations with 500 iterations to generate the 95 percent confidence interval for the DMFs.

Finally, as a prerequisite for estimating panel VAR, we test all our variables for the presence of panel unit root, which may have a bearing on the relevance of the instruments. In Table 3, we show that each series is stationary based on the test proposed by Im, Pesaran, and Shin (2003) for heterogeneous panels.[25]

V. RESULTS

In this section, we begin by modeling disasters' impact on aggregate-level state government finances, including total spending, total own-source revenues, intergovernmental revenues from the federal government, and long-term debt issuance. We also undertake several robustness checks using alternative disaster severity measures. We then break the revenue and spending totals into subcategories and analyze how natural disasters affect different tax revenue sources (e.g., sales and income taxes), major spending categories (e.g., current operations, capital outlays), and various types of federal transfer by functions (e.g., disaster relief, public welfare, housing and community development),

[24] For the Hansen J test, we do not reject the null hypothesis that instruments are uncorrelated with the error terms. As for the stability test (Lütkepohl, 2005), we checked the modulus of each eigenvalue of the estimated model to ensure that all moduli of the companion matrix are strictly less than one.

[25] We use the IPS test in this case because we have moderate T and moderate N. Note that we cannot reject the unit root hypothesis with the federal welfare transfer variables when we exclude the time trend. However, this should not be a big concern because our model includes FY fixed effects.

Table 3

Unit Root Tests (Im, Pesaran, and Shin, 2003)

	Without Time Trend		With Time Trend	
Variable	W_{tbar} – Stat	p-value	W_{tbar} – Stat	p-value
Total disaster damage	–27.8431	0.0000	–28.4296	0.0000
Total own-source revenues	–3.7618	0.0035	–4.5039	0.0000
Total spending	–3.5797	0.0002	–8.6177	0.0000
Revenues from federal transfers	–2.5075	0.0061	–8.7491	0.0000
Long-term debt issued	–20.9415	0.0000	–22.7882	0.0000
Sale tax revenues	–3.2719	0.0005	–5.4534	0.0000
Personal income tax revenues	–4.7447	0.0000	–7.7299	0.0000
Corporate income tax revenues	–8.9559	0.0000	–11.6544	0.0000
Property tax revenues	–1.3850	0.0830	–10.0456	0.0000
Current operational spending	–1.7288	0.0419	–7.5887	0.0000
Capital outlays	–11.5351	0.0000	–13.4006	0.0000
Intergovernmental local spending	–4.1567	0.0000	–4.7050	0.0000
Welfare spending	–4.1708	0.0000	–7.4843	0.0000
FEMA disaster relief	–9.1548	0.0000	–12.8031	0.0000
Federal transfers (housing and community)	–3.1532	0.0008	–7.1634	0.0000
Federal transfers (natural resource and agriculture)	–5.8601	0.0000	–6.8780	0.0000
Federal transfers (public welfares)	0.3758	0.6465	–7.9114	0.0000

Note: All unit root tests have subtracted the cross-sectional means for consistency with the specification of our PVAR model.

respectively. We also use the data on FEMA's Disaster Relief Fund (DRF) to estimate the federal government's financial exposure to nationwide disaster damage.

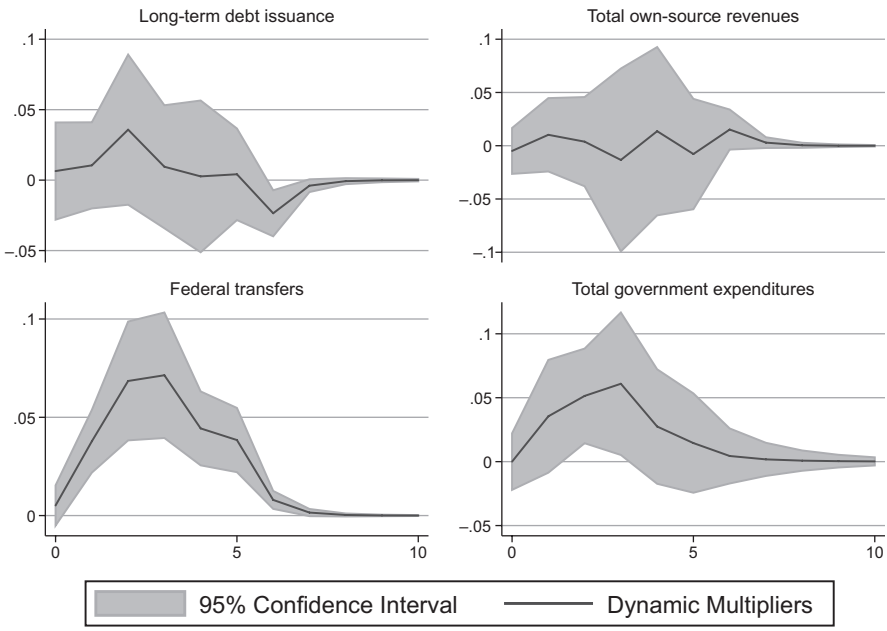
A. Aggregate Fiscal Responses

Figure 2 presents our estimated DMFs of natural disaster shocks to aggregate government finances from FY t through FY $t + 10$.

Table 4, Panel A presents the point estimates of the DMFs, which can be interpreted as changes in a state's fiscal outcomes from a one-unit increase in its natural disaster damage in each FY as well as the cumulative effects through FY $t + 5$. Overall, we find that disasters exert a significant and positive impact on total state governmental spending and intergovernmental revenues from the federal government. The effect on spending

Figure 2

Dynamic Multiplier Functions: Aggregate Fiscal Responses to Natural Disasters



Notes: Both disaster damage and the fiscal variables are normalized as percentage of a state's total GSP in the previous year. The x-axis presents the fiscal years 0–10. The y-axis indicates the changes in the state fiscal outcomes from a one-unit increase in its natural disaster damage (i.e., ratio of total disaster damage in GSP goes up by 1 percent) in year 0. Shaded area indicates the 95 percent confidence interval for the relevant dynamic multiplier function.

becomes statistically significant in year $t + 2$ and peaks in year $t + 3$ (0.06 percent of GSP with respect to 1 percentage point increase in disaster damage as share of GSP in year t), and declines thereafter. The five-year cumulative effect is roughly 0.2 percent of GSP.[26] The federal-to-state transfer ratio increases more than state total spending in each period; it remains statistically significant through year $t + 5$ and totals to 0.27 percent of GSP over the five-year post-shock period. In tandem, the observed changes in the two variables suggest that disaster-induced increased state expenditures are largely covered by federal transfers. This implies that the fiscal burden of the disaster-affected states is shifted to the rest of the nation, and the federal government plays a leading role in reallocating resources to address states' post-disaster needs.

[26] The significant increase in government spending following disasters is consistent with the findings of previous cross-country studies (e.g., Melecky and Raddatz, 2011; Ouattara and Strobl, 2013).

Table 4

Dynamic Multiplier Functions: Aggregate Fiscal Responses to One Unit Increase in Disaster Severity Measure

	t	$t+1$	$t+2$	$t+3$	$t+4$	$t+5$	Cumulative through $t+5$
Panel A. Disaster Severity: Total Damage (Percent of GSP)							
Total own-source revenues	–0.005	0.010	0.004	–0.013	0.014	–0.008	0.002
Total governmental spending	0.000	0.035	0.051***	0.061**	0.027	0.015	0.190***
Total revenues from federal transfers	0.005	0.038***	0.068***	0.071**	0.044***	0.038***	0.266***
Long-term debt issued	0.006	0.010	0.036	0.009	0.003	0.004	0.069
Panel B. Disaster Severity: PDD-Affected Counties (Percent of All Counties)							
Total own-source revenues	0.0002	0.0005	0.0007	–0.0004	–0.0006	0.0005	0.0009
Total governmental spending	0.0008*	0.0012*	0.0013	0.0005	0.0002	0.0004	0.0045*
Total revenues from federal transfers	0.0004*	0.0008*	0.0006	0.0005	0.0005	0.0003	0.0031**
Long-term debt issued	0.0002	0.0008	0.0010	0.0006	0.0007	0.0004	0.0037
Panel C. Disaster Severity: Large PDD Incidents							
Total own-source revenues	–0.0345	–0.0058	0.0063	–0.0516	–0.0409	0.0062	–0.1203
Total governmental spending	0.0256	0.0662*	0.00774	0.0402	0.0220	0.0239	0.2544*
Total revenues from federal transfers	0.0262*	0.0542*	0.0475	0.0579	0.0527	0.0481	0.2866***
Long-term debt issued	–0.0140	0.0187	0.0190	–0.0035	–0.0061	–0.0572	–0.0429

Notes: Asterisks denote significance at the 1% (***), 5% (**), and 10% (*) levels. For Monte Carlo simulations, 500 replications were used in the computation of error bands.

In comparison, the effect of natural disasters on state issuance of long-term debt is statistically insignificant — though positive — through the t to $t + 5$ window. This may suggest that states could rely on federal assistance for the post-shock outlays and therefore, have no need for additional borrowing. On the revenue side, the impact of natural disasters on state governments' own-source revenues is statistically insignificant. While similar results are also reported in the prior cross-country research (e.g., Ouattara and Strobl, 2013), this finding could be linked to the post-disaster aid that lessens the economic shock and contributes to restoring the tax bases. It could also be linked to a state's tax structure and composition, which necessitates a more detailed investigation of disaster impacts on different types of tax revenue sources as we discuss next.

Figures 3A and 3B present the dynamic fiscal impacts of natural disasters, measured by the two alternative severity variables using the data on state-level PDDs and affected counties. Table 4, Panels B and C report the corresponding DMF estimates. Overall, these results are similar to our baseline findings: a major disaster shock increases state government spending and their receipt of federal transfers, while exerting little effect on states' own-source revenues as well as new debt. Specifically, panel B indicates that a state's aggregate spending and received federal transfers would increase by 0.004 and 0.003 percent of GSP, respectively, over the five-year post-disaster period, when the ratio of its PDD-affected counties rises by 1 percentage point in year t. In Panel C, we show that a large PDD incident (affecting at least one-third of a state's counties) would cumulatively increase a state's total spending by 0.25 percent of GSP and received federal transfers by 0.29 percent of GSP in the next five years.[27] Since the estimated changes in total expenditures and federal transfers are similar in magnitude when we use alternative disaster measures, it confirms our baseline finding of a shift of disaster-financing burden to the federal government.[28]

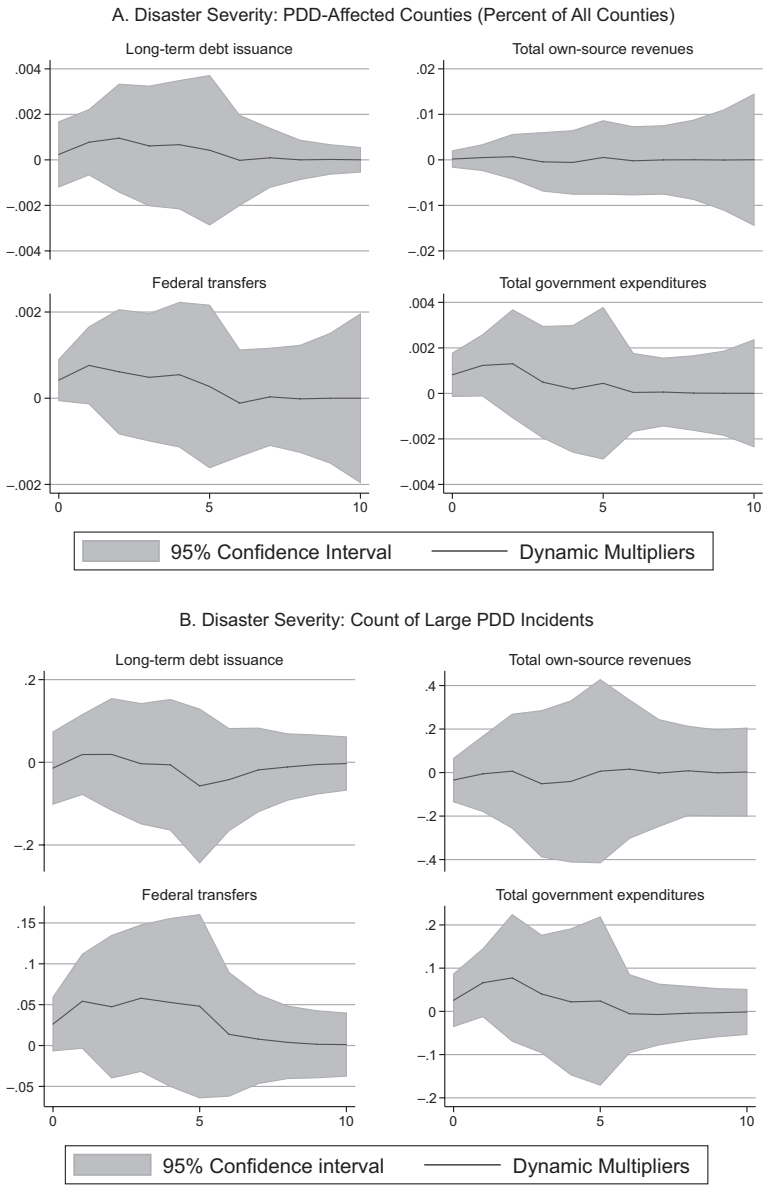
We also use the disaster damage measure to perform additional robustness checks (with more details provided in the Online Appendix). First, we replace the total disaster damage with direct damage from PDDs only, and obtain similar estimates of state fiscal responses. In another test, we exclude the Hurricane Katrina-affected state-year observations, and find that the results are quantitatively similar except that state governments are more likely to engage in borrowing following a major disaster event (i.e., natural disasters have a significant and positive effect on states' long-term debt issuance). To further investigate the heterogeneity across states in their fiscal responses to natural disasters, we divide our sample into higher- and lower-income groups depending on

[27] We also use other criteria for defining significant PDDs such as those affecting at least half of a state's counties and find similar results.

[28] One caveat with our estimates is that in the current model we do not account for the possible spatial correlation or interdependency of the fiscal outcomes (Baicker, 2005). It is possible that a natural disaster that occurs in one state may also affect the fiscal behaviors of the neighboring states through different channels such as migration. In the presence of positive spatial spillover across states, we would expect our estimates to likely suffer from attenuation bias.

Figure 3

Aggregate Fiscal Responses to Natural Disaster Shocks
(Alternative Measures of Disaster Severity)



Notes: The x-axis presents the fiscal years 0–10. The y-axis indicates the changes in the state fiscal outcomes from a one-unit increase in the two disaster severity measures in year 0. Shaded area indicates the 95 percent confidence interval for the relevant dynamic multiplier function.

whether a state's GSP per capita (mean value over the study period) is above or below the median. As shown in Online Appendix D, we find that both state groups increase their total expenditures after natural disasters and also receive more federal transfers. Moreover, richer states spend slightly more during the post-disaster period compared to lower-income states and they also borrow more to finance disaster responses and recovery.

B. Disaggregate Fiscal Responses

To better understand the mechanisms through which natural disasters affect states' fiscal stances, we look into the major components of state expenditures, own-source revenues, and federal transfers, and estimate separate sets of panel VARs for each category. Regarding tax revenues, we consider general sales tax, personal income tax, corporate income tax, and property taxes. On the expenditure side, we distinguish among current operational spending, capital outlays, state-to-local transfers, and welfare spending (the sum of a state government's spending on insurance benefits and repayments, assistance, and subsidies).[29] Regarding federal-to-state transfers, we consider the direct disaster relief distributed by FEMA, housing and community development aid, natural resources and agriculture-related aid, and transfers through public welfare programs.[30] It is important to note that although FEMA is responsible for the bulk of the federal disaster relief expenditures, other federal agencies (e.g., USDA, HUD, Small Business Administration, Department of Commerce, and the Department of Health and Human Services) also operate various programs providing disaster relief and assistance (Healy and Malhotra, 2009). Therefore, we examine the disaster impact on multiple categories of federal-to-state transfers. We present the DMFs portraying the dynamic response of disaggregate fiscal variables in Figure 4. Table 5 Panels A through C report the DMF estimates in individual years and the five-year cumulative effect.

1. Tax Revenue Components

The results of disaster impact on tax revenues are presented in Table 5, Panel A and Figure 4A. We find that general sales tax revenues increase after natural disasters and peak (0.01 percent of GSP, statistically significant at the 5 percent level) one year later. This temporary increase can be attributed to the post-disaster purchases for replacing damaged properties and assets.[31] However, this effect declines and turns negative

[29] These spending categories, mainly involving direct payments to individuals, are listed as stand-alone items under state government direct expenditure. Specifically, insurance benefits and repayments include social insurance payments to beneficiaries, employee-retirement annuities and other benefits, and withdrawals of insurance or employee retirement contributions. Assistance and subsidies comprise direct cash assistance payments to public welfare recipients as well as veteran's bonuses, direct cash grants for tuition, and scholarships.

[30] The reason for collecting FEMA disaster aid data from another source is because the Census data do not specifically identify disaster assistance but rather categorize it under "all other" federal transfers.

[31] This result seems to resonate with the finding in Baade, Baumann, and Matheson (2007) that taxable sales increased in Miami, Florida, after Hurricane Andrew.

Figure 4

Dynamic Multiplier Functions: Disaggregate Fiscal Responses to Natural Disaster Damage

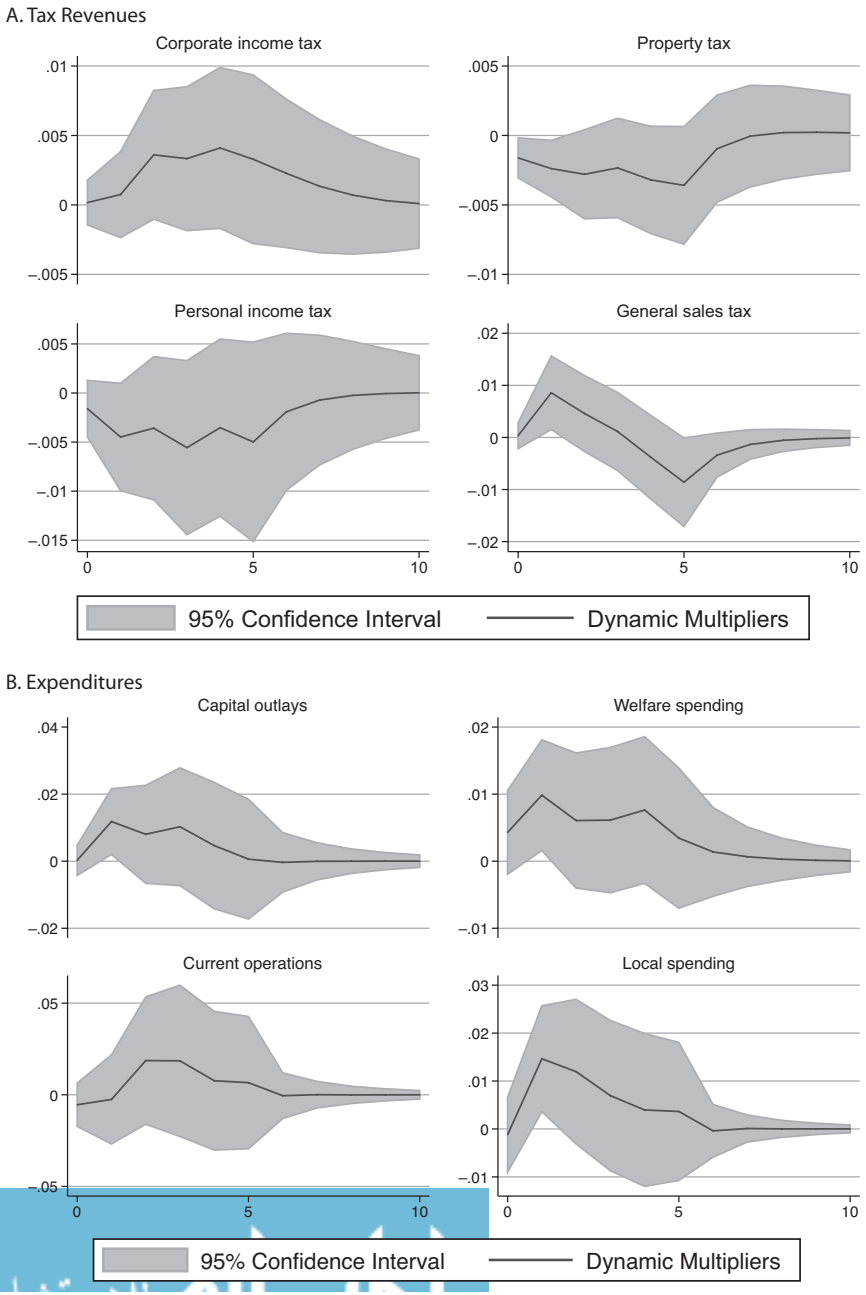
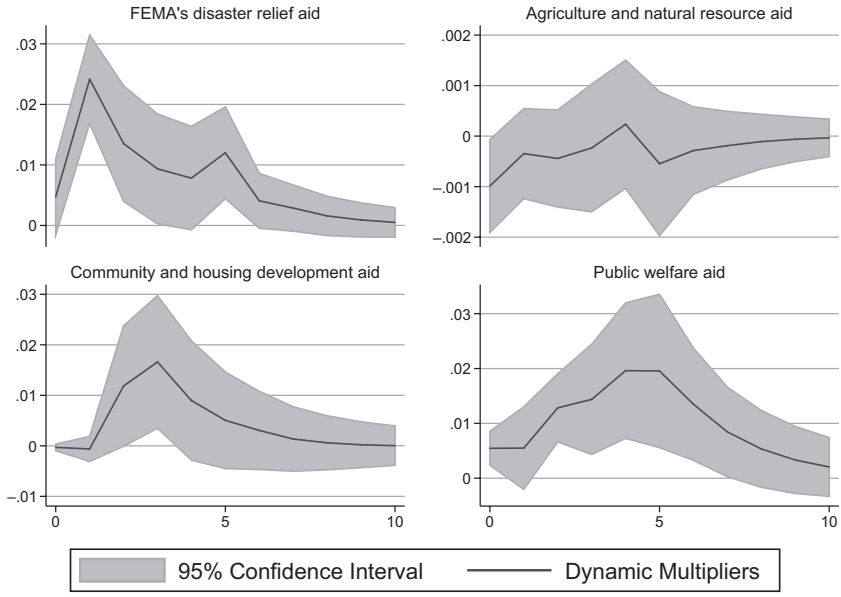


Figure 4 (Continued) Dynamic Multiplier Functions: Disaggregate Fiscal Responses to Natural Disaster Damage

C. Federal Transfers



Notes: Both disaster damage and the fiscal variables are normalized as percentage of a state's total GSP in the previous year. The x-axis presents the fiscal years 0–10. The y-axis indicates the changes in the state fiscal outcomes from a one-unit increase in its natural disaster damage (i.e., ratio of total disaster damage in GSP goes up by 1 percent) in year 0. Shaded area indicates the 95 percent confidence interval for the relevant dynamic multiplier function.

(–0.01 percent of GSP) in year $t + 5$, which might be associated with the negative impacts caused by disasters on incomes and consumption. The negative response offsets the initial increase and results in an insignificant cumulative effect on sales tax revenues over the five-year period.

We also show that natural disasters cause an immediate decline in property tax collections, which totals to –0.016 percent of GSP in the next five years following a 1 percent increase in total disaster damage as percent of GSP in year t. The negative disaster impact is expected because natural disasters cause property damage and thus diminish the tax base. It could also be driven by policies on disaster relief for properties. For example, some California counties allow immediate reappraisal of property values to reflect the damaged conditions and also allow property owners to postpone their property tax installment. The reduced tax revenue may also result from the decline in housing values in the affected regions. Some studies have shown that natural disasters like floods and earthquakes raise public awareness of local risks and cause a negative effect on property values in the hazardous areas (e.g., Kousky, 2010; Atreya, Ferreira, and Kriesel, 2013).

Table 5

Dynamic Multiplier Functions: Disaggregate Fiscal Responses to One Unit Increase in Disaster Damage

	t	$t+1$	$t+2$	$t+3$	$t+4$	$t+5$	Cumulative through $t+5$
Panel A. Disaggregate Tax Revenues							
General sales tax	0.000	0.009**	0.005	0.001	–0.004	–0.0099*	0.002
Personal income tax	–0.002	–0.004	–0.004	–0.006	–0.004	–0.005	–0.024**
Corporate income tax	0.000	0.001	0.004	0.003	0.004	0.003	0.015***
Property tax	–0.002**	–0.002**	–0.003*	–0.002	–0.003	–0.004*	–0.016***
Panel B. Disaggregate Spending Categories							
Capital outlays	0.000	0.012***	0.008*	0.010*	0.005	0.001	0.036***
Current operational spending	–0.005	–0.003	0.019*	0.019	0.008	0.007	0.043
Welfare (assistance, subsidies, insurance benefits)	0.004*	0.010***	0.006*	0.006*	0.008*	0.003	0.037***
Intergovernmental spending (on local governments)	–0.001	0.015***	0.012***	0.007	0.004	0.004	0.040***
Panel C. Disaggregate Federal Transfers							
FEMA's disaster relief aid	0.005	0.024***	0.014***	0.009**	0.008*	0.012***	0.072***
Housing and community development aid	0.000	–0.0001	0.012**	0.017**	0.009	0.005	0.042***
Agriculture and natural resources program transfers	–0.001**	–0.0003	–0.0004	–0.0002	0.0002	–0.0005	–0.0023*
Public welfare aid	0.005***	0.005	0.013**	0.014***	0.020***	0.020***	0.077***

Notes: Asterisks denote significance at the 1% (***), 5% (**), and 10% (*) levels. For Monte Carlo simulations, 500 replications were used in the computation of error bands.

While natural disasters appear to exert little impact on personal and corporate income tax revenues in individual years, the cumulative responses of the two variables are both statistically significant, which merits attention. Specifically, the negative shock to personal income tax revenues over the five-year horizon could be explained by multiple reasons: (1) disasters impose negative impacts on individual and household incomes (e.g., lost jobs and reduced wages); (2) out-migration from the disaster-affected regions could lower the local tax bases (Strobl, 2011); and (3) states might provide income tax relief for the disaster victims. In contrast, the cumulative disaster effect on corporate income tax revenues is positive (0.015 percent of GSP). One possible explanation is that disasters lead to additional market transactions and investments to replace the destroyed assets, which are sufficiently large to offset the negative macroeconomic effects of natural disasters. Meanwhile, the increase in corporate income tax revenues, as opposed to the later decline in sales tax revenues, may suggest that natural disasters pose larger negative shocks to local consumption rather than to production in the affected regions.

Overall, we find that although natural disasters have little impact on state total own-source revenues, they cause different patterns of fluctuations to various tax revenue sources. Our findings are useful for policymakers to understand how states' tax structures may influence their fiscal vulnerability to natural disaster shocks.

2. Expenditure Components

Regarding disaggregate state expenditure variables (Table 5, Panel B; Figure 4B), we find that natural disasters increase major spending components in the short term, although the impact on current operational spending is insignificant overall (except the positive response of 0.019 percent in year $t + 2$). Given that disaster destruction induces the need for reconstruction, as expected, states increase their capital spending immediately following a shock (0.012 percent of GSP) in year $t + 1$, and experience a cumulative increase of 0.036 percent of GSP through year $t + 5$.

After a disaster shock, states also increase their intergovernmental spending on local governments,[32] which peaks (0.015 percent of GSP) in year $t + 1$ and totals to 0.04 percent of GSP. Given that PDDs are approved at the county level which allow counties to receive federal aid, we presume a large proportion of increased state-to-local transfers is financed with federal transfers. In other words, state governments redistribute the federal disaster aid to their lower-level governments.

We also show that natural disasters cause an immediate and persistent increase in state welfare spending, which peaks in year $t + 1$ (0.01 percent of GSP) and totals to 0.037 percent over the five-year post-disaster period. Note that the expenditures in this

[32] Local expenditures include amounts paid to local governments as fiscal aid in the form of shared revenues and grants-in-aid, as reimbursements for performance of general government activities and for specific services for the state government, or in lieu of taxes. It excludes amounts paid for purchase of commodities, property, or utility services, any tax imposed and paid as such, and employer contributions for social insurance.

category are primarily comprised of direct payments to individual beneficiaries, which contain both disaster-related direct relief and non-disaster-related welfare spending (e.g., unemployment insurance).[33]

3. *Federal Transfer Components*

Figure 4C along with Panel C of Table 5 present the dynamic disaster impact on various types of federal transfers to state governments. Consistent with our expectations, states see an immediate and significant increase in FEMA's disaster relief aid following a major disaster. This effect remains positive and significant from year $t + 1$ through $t + 5$, summing to 0.072 percent of GSP. The continued influence on relief funding is also expected because it usually takes a relatively long time for FEMA to evaluate disaster damage, approve claims and project applications, and distribute the relief funds.

In addition to FEMA's disaster aid, we also observe significant increases in federal transfers through public welfare programs as well as housing and community development aid after disasters. The housing and community development aid, primarily administered by HUD, has also been used to provide disaster relief and assistance for long-term recovery (Kousky and Shabman, 2012).[34] Therefore, it is not surprising to see disasters lead to increased transfers in this category (the five-year cumulative effect is 0.042 percent of GSP).

Public welfare transfers include cash assistance paid directly to the needy individuals and households under the categorical programs or under other social welfare and insurance programs. They are not specifically related to disaster aid, but natural disasters can indirectly influence these transfer payments because their negative impact on personal incomes, health, and employment status may make more people become eligible for social welfare. Our results show that natural disasters also increase the welfare transfers states receive from the federal government, and moreover, the magnitude of cumulative increase in public welfare transfers (0.077 percent of GSP) is slightly larger than the increase in FEMA disaster relief. This finding resonates with Deryugina (2017) and suggests that the actual fiscal costs of disasters should not be confined to disaster-related programs but also include governmental expenditure through traditional social safety net programs. The increased federal welfare transfers may also explain the increase in states' own welfare spending following disaster shocks.

Finally, we show that states receive fewer federal transfers in the natural resources and agriculture category (–0.001 in year t and –0.002 over five years after a disaster).

[33] Nonetheless, here we could not separate the disaster-related payments from the general social welfare payments because this information is unavailable in the Census data.

[34] For example, the Community Development Block Grant (CDBG) program operated by HUD is not a disaster relief program and has been historically used to provide disaster relief and recovery aid to the affected communities.

Despite the relatively small magnitude of our estimate, this finding may suggest that the increased federal transfers due to natural disasters might crowd out other types of federal transfers.

C. Federal Financial Exposure to Natural Disaster Risks

Since our baseline results suggest that natural disasters increase state government expenditures at the cost of federal transfers, we take an additional step to examine the relationship between nationwide disaster damage and federal disaster expenditures. Because we use normalized disaster damage and fiscal outcomes (both as percentage of GSP) in estimating the panel VAR model, it is difficult to put these figures into perspective. In this section, we provide more direct estimates in terms of dollar amounts so as to inform projection of the federal financial exposure to future natural disasters.

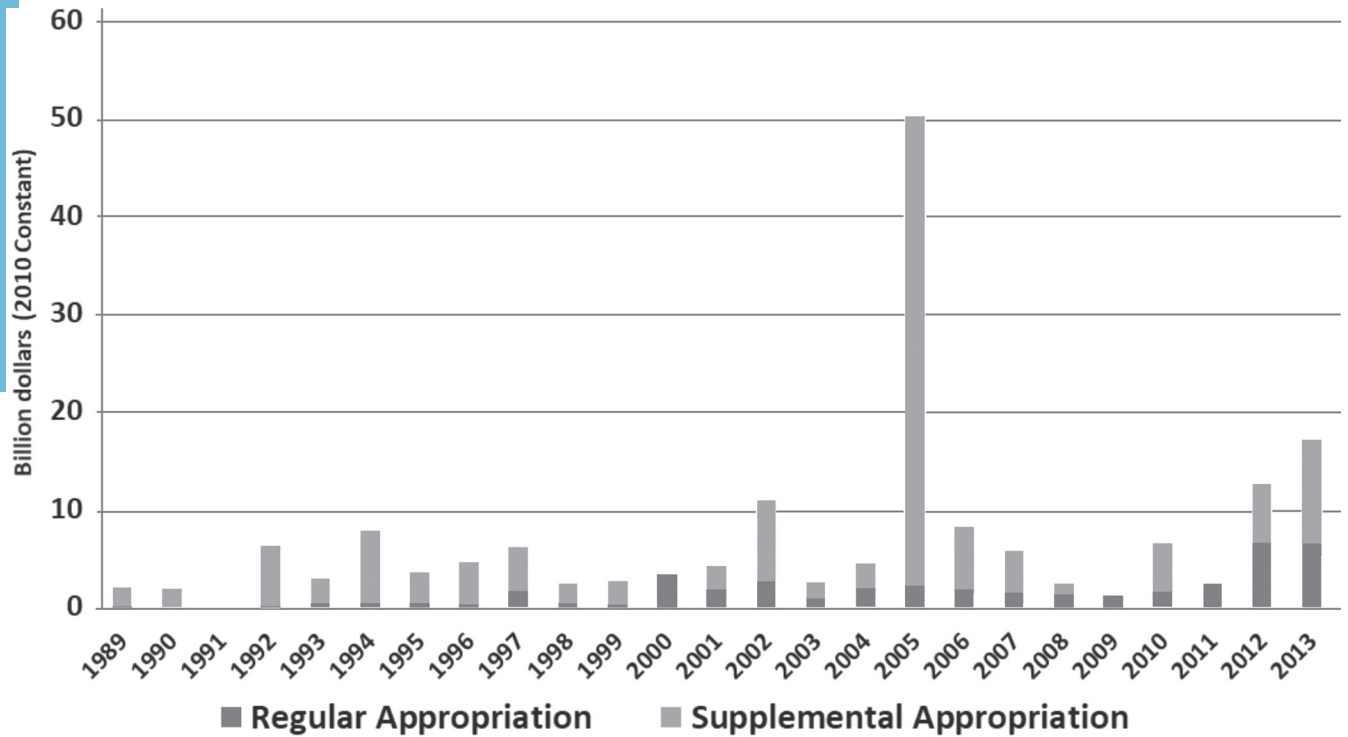
We first calculate the sum of regular appropriations and emergency supplemental appropriations for FEMA's DRF in each FY as a proxy for federal disaster funding. For these appropriations, we use the statistics compiled in Lindsay (2014) and Lindsay and Murray (2014), as shown in Figure 5. We merge the annual federal spending data with the PDD-related disaster damage incurred nationwide, and construct a time-series dataset from FY 1989 to FY 2013.[35]

Table 6 reports the ordinary least square (OLS) estimation results of the effect of direct disaster losses on federal disaster aid, both adjusted to the year 2000 constant dollars. We include both the contemporaneous and one-year lagged total damage to allow for delayed disaster effect on spending. We also include a linear time trend in Column 2. Our results suggest that each dollar of direct disaster losses is associated with 34–37 cents in immediate federal spending on post-disaster response and relief. However, one caveat is that the FEMA DRF flow data do not capture the full scope of federal disaster expenditures, which also include disaster supplemental appropriations to other agencies (e.g., HUD, Department of Defense, Department of Transportation), agriculture disaster assistance administered by USDA, and federal insurance programs such as the National Flood Insurance Program (NFIP) and Federal Crop Insurance Program. Also worth noting is that disasters also increase federal social welfare expenditures (as we show earlier), and these also should be incorporated as part of the federal financial exposure. Therefore, our estimates tend to underestimate the actual federal costs of large-scale natural disasters.

[35] We confine our focus to PDDs because most federal disaster aid becomes available after a PDD is approved. We compute the PDD-related damage by matching the FEMA's PDD information with SHELDUS's disaster losses data based on hazard type. Because the raw SHELDUS data do not have a PDD identifier and only contain aggregate damage, we cannot match damage by events. Therefore, we include a state's damage for a specific disaster category (e.g., floods) into the national total if the state receives a PDD for this hazard type in a given year.

Figure 5

U.S. Congress Regular and Supplementary Appropriations for the Disaster Relief Fund (FY1989–FY2013)



Sources: Lindsay (2014) and Lindsay and Murray (2014).

Table 6

Response of Federal DRF Appropriations to PDD-related Disaster Losses (OLS, 1989–2013 Time Series)

	(1)	(2)
PDD disaster dollar losses(t)	0.340***	0.370***
	(0.0627)	(0.0493)
PDD disaster dollar losses(t – 1)	0.00651	0.0197
	(0.0626)	(0.0487)
Fiscal year time trend		0.4242***
		(0.1078)
Constant	1.522	–847.7818***
	(1.3047)	(215.9245)
Observations	25	25
R-squared	0.581	0.759

Notes: Standard errors in parentheses. Asterisks denote significance at the 1% (***), 5% (**), and 10% (*) levels. Unit of analysis is federal government.

VI. DISCUSSION AND CONCLUSION

In this paper, we employed panel VAR to empirically investigate the dynamic fiscal responses of U.S. state governments to natural disasters in the last three decades. Our goal is to identify the fiscal cost of natural disasters at the state level as well as to examine the distribution of such costs across levels of government. Overall, we have shown that natural disasters trigger fiscal repercussions by causing significant increases in state expenditures and federal-state intergovernmental transfers.[36] These effects tend to peak soon after a disaster strikes and decline thereafter. Our main results show that the disaster-induced increase in federal transfers slightly exceed that in state spending, suggesting that the subnational fiscal cost of disasters is largely borne by the federal government. This finding entails several policy implications. First, although federal transfers alleviate disaster shocks to the affected communities, they spread the

[36] Notably, the countercyclical fiscal responses to natural disasters we find in this paper is different from the pattern of states' response to unexpected financial shocks (tax increase and spending cuts) as suggested in Poterba (1994). But the increase in federal transfers after disasters is similar to the finding in Sorensen, Wu, and Yosha (2001) regarding the countercyclical federal grants in response to the state-level output fluctuations.

disaster's fiscal cost to taxpayers across the nation.[37] In particular, the majority of the federal disaster aid is funded through *ad hoc* supplemental appropriations following disaster shocks (Donahue and Joyce, 2001), which means these increased expenditures are likely to be covered by additional taxation (Kousky, 2014).

The substantial amount of federal disaster relief may cause a moral hazard problem (Coate, 1995) and lead state governments to underinvest in *ex ante* disaster mitigation because they would expect federal relief following a disaster (Wildasin, 2008a; Cohen and Werker, 2008; Donahue and Joyce, 2001). Federal disaster relief may also encourage subnational governments to continue development in hazard-prone areas, which in turn increases their risk for catastrophic losses (Burby, 2006). From the public budgeting perspective, the generosity of federal disaster aid may also explain the fact that almost no states maintain reserve funds dedicated for future disasters and most state governments rely on the federal government to cover most of their disaster expenditures (Government Accountability Office, 2015).[38] In this context, our study sheds light on the budgeting needs for natural disasters at both the federal and state levels. It should be of value to ongoing discussion regarding the creation of disaster contingency funds. Our empirical finding on disaster-induced fiscal costs could also inform the cost-benefit analysis of pre-disaster mitigation programs.

A fundamental question that arises from the previous discussion is how to best allocate the fiscal responsibilities for managing natural disasters between the central and subnational governments. Based on the fiscal federalism theory, disaster management should be devolved to the subnational governments because they have better knowledge about unique local circumstances including their risk profile and how to manage their local disaster risks (Escaleras and Register, 2012; Goodspeed, 2015). The central government can pool risks across subnational regions and provide disaster relief as a form of national insurance (Goodspeed, 2015). The federal grants are also justified to correct fiscal disparities across localities as well as the spillover effects of local disaster management activities (Donahue and Joyce, 2001). However, a common criticism of the U.S. disaster policy is that the federal government spends disproportionally more on post-disaster aid and underinvests in disaster mitigation and preparedness, although the latter can more effectively reduce future disaster losses (Healy and Malhotra, 2009).[39] From this perspective, our research points to new directions of designing federal grant programs for disaster management (Hou, 2013). It can be further extended by examining the allocation of federal disaster mitigation grants before and after disaster strikes in comparison with the disaster relief funding.

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[37] To provide additional context on the scale of federal transfers, the cost-sharing ratio for FEMA's Public Assistance program is that federal government pays 75 percent of all eligible expenses once a PDD is made and affected subnational governments pay the remaining 25 percent. Our research, by identifying the disaster effect on total governmental transfer, suggests that the federal share could be higher.

[38] To address this problem, Wildasin (2008b) proposed creating mandated disaster reserves at the state level which commensurate with the disaster risk faced by different states.

[39] Healy and Malhotra (2009) estimate that one dollar spent on federal disaster mitigation programs can reduce future disaster damage by $15, while the relief spending has little effect on risk reduction. They argue that the underinvestment in disaster mitigation can cause substantial social welfare losses.

Our investigation of disaggregate fiscal responses provides additional insights into post-disaster dynamics. We find that while natural disasters exert little impact on states' total own-source revenues, they result in different levels of fluctuations in sales, income and property tax revenues, which appear to offset each other, thus leaving states' tax-revenue neutral. Although we do not possess evidence to conclusively explain the reasons behind these changes, they could be closely associated with the macroeconomic effects of natural disasters, disaster-induced behavioral changes, as well as adjustment of tax policy.

Another finding of this study is that natural disasters not only increase disaster-related spending and transfers but also significantly increase non-disaster-related transfers including welfare payments. Our results suggest that the actual fiscal costs of natural disasters could be much larger than the current estimates, if we account for the increased welfare spending as an indirect result of natural disasters. It is critical for policymakers to account for this portion of expenditures in gauging a government's financial exposure to natural hazards. It is also important for more future research to examine whether and how different grant programs (disaster-related aid and non-disaster-related social insurance programs) mitigate the adverse economic shocks from disasters. For example, a recent study by Gallagher and Hartley (2017) suggests that Hurricane Katrina has significantly reduced the debt of the affected households because they use insurance payouts from the federally-funded NFIP to pay down their mortgages. It is also worth noting that federal transfers naturally bring up discussions of the flypaper effect (Hines and Thaler, 1995). Another possible extension of this paper, reserved for the future, is to explore the flypaper effect based on the envelope calculation of the disaster impact on personal incomes vis-à-vis their effect on state government expenditures.

Finally, it is important to point out that disaster aid and welfare transfers only offset part of disasters' direct damage. There are other mechanisms to mitigate the direct disaster losses, including private insurance payouts and nonprofit activities. For example, Pena et al. (2014) find that natural disasters increase the financial flows to nonprofit organizations located in disaster-stricken counties. Our study could be further extended by including the private and nonprofit sector expenditures to understand more fully the dynamics of financial activities in the post-disaster period. It is equally important to estimate the proportion of actual disaster losses borne by the affected individuals, after accounting for transfers through different channels in post-disaster dynamics.

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Summaries of Articles

MEASURING THE FINANCIAL SHOCKS OF NATURAL DISASTERS: A PANEL STUDY OF U.S. STATES

Qing Miao, Yilin Hou, and Michael Abrigo

Natural disasters pose shocks to government finance by disrupting local economies, eroding tax bases, and causing additional expenditures on disaster response, relief, and recovery assistance. The fiscal consequence of disasters has been a subject of limited research, with most empirical evidence coming from cross-country studies. This paper presents one of the first attempts to empirically estimate the financial impacts of natural disasters at the subnational level in the United States. With a particular focus on state governments, we are interested in understanding how disasters affect their expenditures, revenues, new debt issuance, and receipts of federal transfers. Our study, based on a 50-state, 1970–2013 panel dataset, sheds light on the fiscal costs of natural disasters and also the distribution of disaster costs between the federal and state governments.

In our analysis, we employ a panel vector autoregression model to trace the duration and decay of the financial shocks triggered by disasters. We find that following a major disaster, state governments increase their expenditures (in particular, capital outlays, transfers to local governments, and welfare payments) and receive more intergovernmental transfers from the federal government. These effects tend to peak soon after a disaster strikes and decline thereafter. Our finding suggests that the local fiscal costs of natural disasters is largely borne by the federal government. It also highlights an important role that federal government plays in redistributing resources in the aftermath of natural disasters. Although federal transfers alleviate the disaster shock to the affected communities, they shift a large proportion of local disaster costs to taxpayers across the nation. As pointed out in previous research, the generous federal post-disaster aid may cause a moral hazard problem. It also raises the question of how efficiently and effectively state governments spend the federal money on post-disaster relief and recovery. To further examine the federal financial exposure to disasters, we estimate that one dollar of direct disaster losses leads to an increase of $0.34–$0.37 in immediate federal disaster relief spending.

While we find that natural disasters have little impact on a state's total own-source revenues, they cause different levels of fluctuations in general sales, income, and property tax revenues. This finding is beneficial for policymakers to understand the link between fiscal sustainability and tax structure in the context of natural disasters. Finally,

we show that natural disasters also lead to significant increases in government spending and federal transfers on public welfare programs. This finding suggests that the actual fiscal costs of natural disasters could be much larger than the traditional estimates that only account for the disaster-related programs. Therefore, it is critical for policymakers to include this portion of expenditure in gauging their financial exposure and budgeting for future natural disasters.