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Externalities of extreme natural disasters on local tax capacity*

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Abstract

This paper studies the impact of extreme weather events on the local tax revenue across Colombian municipalities. We follow a two-step approach to evaluate to what extent a municipality's tax revenue depends on natural disasters taking place both locally and in its trade partners. In the first step, we estimate a gravity model of bilateral trade and construct a trade flow matrix allowing us to measure the strength of the economic relationships between cities. To do so, we build a novel dataset describing the inter-city trade flows for road transported goods in Colombia for the period 2015–2019. In the second step, we use spatial models to estimate the externalities of extreme weather events. Our results reveal that natural disasters in the destination cities increase the tax revenue in the origin city. We provide evidence of the capacity of trade to mitigate the negative effects of natural disasters.

Keywords: tax revenue, natural disasters, gravity, externalities.

JEL classification: H0, H71, Q54.

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Externalidades de los desastres naturales extremos sobre la capacidad fiscal[†]

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Resumen

Este artículo estudia el impacto de los eventos climáticos extremos en los ingresos fiscales locales en los municipios colombianos. Seguimos un enfoque de dos pasos para evaluar en qué medida los ingresos fiscales de un municipio dependen de los desastres naturales que ocurren tanto a nivel local como en sus socios comerciales. En el primer paso, estimamos un modelo gravitacional de comercio bilateral y construimos una matriz de flujo comercial que nos permite medir la fuerza de las relaciones económicas entre ciudades. Para hacerlo, creamos una nueva base de datos que describe los flujos comerciales entre ciudades de bienes transportados por carretera en Colombia para el período 2015-2019. En el segundo paso, utilizamos modelos espaciales para estimar las externalidades de los fenómenos meteorológicos extremos. Nuestros resultados revelan que los desastres naturales en las ciudades de destino aumentan los ingresos fiscales en la ciudad de origen. Este documento aporta evidencia de la capacidad del comercio para mitigar los efectos negativos de los desastres naturales.

Palabras clave: ingresos fiscales, desastres naturales, modelo gravitacional, externalidades.

Clasificación JEL: H0, H71, Q54.

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1. Introduction

Climate change is expected to lead to more frequent and intense extreme weather events such as drought and floods (IPCC, 2014). Their direct consequences has been studied for a range of economic outcomes (Deschenes and Greenstone, 2007; Di Falco et al., 2012), education and health (Maccini and Yang, 2009), and conflicts (S. M. Hsiang et al., 2011). Still, there has been little attention for interregional externalities (Hsiang, 2016), although a growing evidence-based literature has already measured the direction and magnitude of the spillovers of such events (Dall'erba and Domínguez, 2016; Lippert et al., 2009). However, little is known about the role of weather conditions and their extremes on local tax revenue or fiscal capacity, and even less on the role of the spillover of weather shocks. For instance, Brückner (2012) studies the elasticity of tax revenue to gross domestic product (GDP) at the country level using rainfall and commodity price shocks as instruments. Another example is Sanoh (2015) who studies the impact of rainfall shocks on municipal tax revenue and intergovernmental transfers in Mali. When it comes to extreme weather events, past contributions have already highlighted their effect on local demand and output (Acevedo et al., 2020; Hallegatte, 2012; Jahn, 2015), but not on tax revenue. Yet, if such events affect trade partners and/or compromise the transportation infrastructure (Berariu et al., 2015), one can argue that they will impact the tax revenue in exporting localities. In order to correctly estimate the impact of weather shocks on tax revenue and draw any policy recommendation from these estimates, it is necessary to account for these indirect effects (Anselin, 1988; LeSage and Pace, 2009). However, the tax literature has ignored this issue so far.

This paper fills this gap by studying the impact of extreme natural disasters on the tax capacity across Colombian cities, measured the Industry and Commerce Tax revenue (ICA, in Spanish), which is a proxy of local production in Colombian cities. Extreme natural disasters impact both the supply and demand (Cavallo et al., 2014; Gassebner et al., 2010), which may ultimately affect the amount of tax revenue of local governments. On the supply side, natural disasters in exporting cities can reduce exports because it can affect the production process and the delivery of goods, as in the case of floods damaging crops, which may have a negative impact on local tax revenue. On the demand side, households can shift the demand towards recovery or provisionary spending, reducing sales of nonessential products, which may compensate the tax revenue affected by a natural disaster. In addition, a shock in the trading partners can also have mixed effects. It could reduce demand in trading partners which may reduce local exports and tax revenue, but exports could also increase in order to compensate the shortage on goods that will be present after a natural disaster in the importing cities (Cavallo et al., 2014), which may increase local tax revenue. We focus on the impact of floods and landslides because such events accounted for the majority of lives lost and houses destroyed by natural disasters in the country over the period 1971–2011 (The World Bank Colombia, 2012). Our contributions are twofold. First, we construct a novel dataset describing the inter-city trade flows goods and commodities carried by road over 2015–2019. This data is based on information of the Ministry of Transportation in combination with the International trade Database at the Product-Level (BACI, in French) data on prices. It is important to point out that interregional trade data is not commonly available in developing countries, especially at the city level, and even only a limited number of developed countries collect and report domestic trade data. Examples include the United States (Felbermayr and Gröschl, 2014; Wolf, 2000), France (Combes et al., 2005), Germany (Lameli et al., 2015) and Japan (Wrona, 2018). The case of Colombia offers a valuable opportunity for estimating intranational trade flows at a very disaggregated scale in a developing economy.

These trade flow data are then used to estimate a gravity model of bilateral trade and assess the strength of the economic relationships between cities. To our knowledge, this is the first paper that uses inter-city trade to study spatial interdependence in a developing country setting. Some studies have used the weight of transported goods to measure spatial relationships at the state level (Cortázar-Gómez and Pineda-Guarín, 2019; Pérez-Valbuena, 2005; Perobelli et al., 2010), while others have used standard physical distance weighting matrices to measure spatial interdependence (Galvis-Aponte and Hahn-De-Castro, 2016). However, geographical distance is not appropriate given that trade is the main mechanism for the existence of spillover effects, trade partners are not constant over time, and the composition of trade partners is correlated with extreme weather shocks. On the other hand, the trade weight of transported goods does not necessarily reflect the economic linkages between cities because weight is not indicative of economic value across different goods. Second, we use the value of the trade relationships estimated in the first stage to assess how local tax revenue depend on local and trade partners' natural disasters shocks. We find that extreme natural disasters reduce sales from exporting cities, which can increase sales from local businesses and tax revenue in importing cities. As such, we find that extreme weather events in partner cities have a positive impact on local tax revenue.

The remainder of the paper is organized as follows. Section 2 briefly reviews the literature on the determinants of tax revenue. Section 3 describes our data and methodology while section 4 presents and discusses the results. Finally, section 5 offers concluding remarks and describes avenues for future research.

2. Literature review

This paper can be linked to the literature that studies the determinants of tax revenue. Tax capacity is closely related to economic development (Besley and Persson, 2014) because local entities with a higher fiscal revenue can make productive investment that creates a virtuous cycle of economic growth. In general, variables such as the level of development, exposure to trade, education, income distribution, corruption, institutional quality, and natural resource endowments have been analyzed as determinants of tax revenue (Baunsgaard and Keen, 2010; Bornhorst et al., 2009; Crivelli and Gupta, 2014; Fenochietto and Pessino, 2013; Gupta, 2007; Leuthold, 1991; Pessino and Fenochietto, 2010). Extreme weather events have also been shown to have a significant impact on tax capacity, although the evidence studying the impact of weather shocks on tax revenue is limited, especially at the subnational level. For example, Brückner (2012) finds that declines in rainfall levels of 10% decrease GDP by 0.6% on average in Sub-Saharan African countries, and a one percent decrease in GDP decreases tax revenue by up to 2.5%. Sanoh (2015) investigates the impact of rainfall shocks on municipal tax revenue and intergovernmental transfers in Mali. The findings indicate that a decrease in annual rainfall of one standard deviation can reduce annual tax revenue by 8% in farming municipalities. Lis and Nickel (2010) study the impact of extreme weather events on public budget balances. Their results show that the budgetary impact of extreme weather shocks ranges between 0.23% and 1.4% of GDP, and developing countries suffer from a larger impact than industrialized economies. Finally, Rasmussen (2004) discovers that natural disasters have a significant and negative effect on fiscal and external balances and that the impact is larger in developing countries than in developed ones. These results offer strong evidence that tax revenue can be significantly affected by extreme weather events both at the national and local levels.

However, to our knowledge, there is no evidence regarding the potential spillover effects that weather shocks can have on tax revenue. Natural disasters can impact supply and demand sides

(Cavallo et al., 2014) and their effects can be large enough to impact trade. As a result, their economic impact goes beyond the geographical location of the natural event. A shock in an exporting city is expected to reduce its exports, but the demand from the importing cities will not change, which induces an increase in exports from the rest of the exporting locations. Cross-country evidence can be found in Gassebner et al. (2010), who find that a natural disaster can reduce imports by 0.1% and exports by 0.2%. Their findings are in line with the results of Lis and Nickel (2010) and Rasmussen (2004), who find that natural disasters create budget imbalances in developing countries, which are closely related with trade balances. In addition, evidence has been found reflecting spatial interdependence in local tax capacity. For example, Yoshino and Abidhadjaev (2017) find that the construction of the Kyushu high-speed rail line had significant positive spillover effects on the tax revenue in neighboring prefectures, and Yoshino and Pontines (2015) find that infrastructure investment in the Philippines generated positive spillover effects on the tax revenue of the neighboring cities. It is expected that extreme weather events change the economic links between cities as determined by trade relationships, and as a result, local tax revenue will be affected. To our knowledge, ours is the first paper to address the spillover effects of extreme weather events on local tax revenue.

3. Methodology

In order to estimate the spillover effects of extreme natural disasters on tax revenue, we need to create a spatial weighting matrix, $\boldsymbol{W}$, that allows us to capture the strength of the inter-city relationships. Given the evidence that extreme natural disasters affect imports and exports at the country level (Gassebner et al., 2010) and at the subnational level (Dall'erba et al., 2021), we argue that trade is the main mechanism through which the spillovers of natural disasters affect tax revenue. Consequently, this paper uses inter-city trade data as a measure of the economic linkages between Colombian cities. Every element w_{ijt} of the $\boldsymbol{W}$ matrix represents the share of city $j \neq i$ in the total exports of city i at time t, i.e., $\boldsymbol{W}$ is row-standardized such that $\sum_j w_{ijt} = 1 \ \forall t$. The higher is the value of element w_{ijt}, the larger is the degree of economic interdependence between cities i and j, hence the greater the impact of a natural disaster taking place in j on tax revenue in i.

However, using observed trade might induce an endogeneity problem by reverse causality, given that the tax rates can affect production, sales, and exports. In order to address this issue, we rely on a gravity model to obtain the expected trade flows that will allow us to construct an exogenous weighting matrix of trade partners, $\widehat{\boldsymbol{W}}$. The estimated matrix of trading partners will depend only on observable characteristics of importing and exporting cities. Gravity is used in the trade literature to model bilateral trade flows as a function of origin and destination economic size, as well as multilateral barriers to trade such as distance, and it has become one of the main tools with which to model trade flows (Head and Mayer, 2014). In general, GDP is more traditionally used to capture the economic size of the exporter and importer that underpin the gravity model, but other variables such as population size can also be used. We follow the Poisson pseudo-maximum-likelihood (PPML) method proposed by Santos Silva and Tenreyro (2006, 2011) which has the advantages over traditional log-linearized specifications of gravity to generate consistent estimates in the presence of heteroskedasticity and the inclusion of zero-trade flows. The equation we estimate in the first stage is the following:

$$T_{ijt} = \exp\{\beta_1 + \beta_2 Shock_{it} + \beta_3 Shock_{jt} + \mathbf{X'}_{\mathbf{it}}\boldsymbol{\gamma} + \mathbf{X'}_{\mathbf{jt}}\boldsymbol{\eta} + \omega_{ij} + \tau_t + \mu_{ijt}\}. \qquad (1)$$

T_{ijt} represents the value of total exports in dollars from city *i* to city *j* in year *t*, $Shock_{it}$ is the exogenous shock in exporting city and $Shock_{jt}$ is the exogenous shock in importing location. $\boldsymbol{X_{it}}$ is a matrix of supply characteristics of the exporter, and $\boldsymbol{X_{jt}}$ is a matrix of demand factors of the importer, ω_{ij} is a set of dyadic fixed effects controlling for time-invariant *ij*-specific characteristics such as sharing a border or geographical distance, τ_t are time fixed effects and μ_{ijt} is the idiosyncratic error term. The exogenous shock is defined as a dummy variable equal to one if, in a specific month *m* in year *t*, the city experienced a natural disaster (flood or landslide) that led to a total population affected (PA) larger than the 90th percentile of the historic monthly values. That is, for cities *i* and *j*:

$$Shock_t = I(\text{Max}_t(PA_{tm}) > 90th \text{ percentile of } PA_{tm} \text{ for } 1998 < t < 2009). \qquad (2)$$

We obtain the predicted trade $\hat{T}_{ijt}$ from Eq.(1) and use it to construct an exogenous row-standardized $\widehat{W}$ weighting matrix of trading partners. The $\widehat{w}_{ijt}$ elements of $\widehat{W}$ represent the relative importance of city *j* in the total exports of city *i* and are defined by:

$$\widehat{w}_{ijt} = \frac{\widehat{T}_{ijt}}{\sum_j \widehat{T}_{ijt}}. \tag{3}$$

We then use the exogenous $\widehat{W}$ to evaluate the spillover effects of extreme natural disasters on local tax revenue or fiscal capacity. We do so by estimating a model of the form:

$$y_{it} = \alpha_1 + \alpha_2 Shock_{i(t-1)} + \alpha_3 \widehat{W} \cdot Shock_{j(t-1)} + \boldsymbol{\lambda X_{it}} + \rho_i + \delta_t + \epsilon_{it}, \tag{4}$$

where y_{it} is the logarithmic transformation of the Industry and Commerce Tax revenue (ICA, in Spanish) for city *i,* which is levied on the value of total sales of corporate entities and is collected at the municipality level. We assume that a natural disaster shock will affect current sales and future tax revenue, with a time lag. ICA and property taxes are the main sources of revenue for Colombian cities (Ayala and Dall'erba, 2020; Bonet and Ayala, 2020), but property taxes are not expected to show any spillover effect from weather shocks and therefore they are not included on our dependent variable. In addition, our dependent variable does not consider income tax and value added tax because these are collected at the national level. Note that the ICA collection is based on sales from local businesses, hence our choice of trade as the mechanism through which natural disasters can affect tax revenue. $\boldsymbol{X_{it}}$ is a matrix of control variables, ρ_i are city-level fixed effects, δ_t are time fixed effects, and ϵ_{it} is the error term. Since extreme weather events in trading partners are exogenous to local ICA revenue, we can consistently estimate the parameters α_2 and α_3 that represent the direct and indirect (spillover) effects of extreme natural disasters on ICA collection.

4. Data

The inter-city trade data is constructed by using the inter-city transportation records from the *Registro Nacional Despacho de Carga* (RNDC) from the Ministry of Transportation. It is available from 2015 onwards. This database contains the weight (in kilograms) of all road-transported goods, which is the main mode of inter-city transportation of goods in Colombia. For example, in 2018, 81% of all cargo was transported by road. If we exclude coal, that is traditionally transported by rail, this share rises to 96% (Ministry of Transportation, 2018). The database classifies goods by a 4-digit Harmonized System code (HS) that can be matched with information from the BACI trade data (Gaulier and Zignago, 2010), an international trade database that contains information at the product level. From the BACI trade data, we can obtain the average price of every exported good and use it to convert the local quantities from the RNDC database into a monetary value.

Once aggregated across commodities, one ends up with inter-city trade flow values, as usual in the gravity model literature.

Table 1 shows the summary of the main traded goods registered in the RNDC database for the period 2015-2019 for animal products, crops, and manufacturing sectors. This sample of products represents 66% of the total value of road transported goods in Colombia for 2015. It shows the level of disaggregation of the information contained in this database, which makes it a valuable source for estimating the value of inter-city trade flows in a country where this information is not readily available. Poultry, milk and its derivatives, and poultry eggs represented 86% of total trade in the animal product sector, while coffee, corn, and rice represented 73% of total trade of crops. Finally, platinum, radioactive chemical elements, and isotope represented 65% of total trade in manufacturing in 2015. The estimated total trade increased from US$620 billion in 2015 to US$1,208 billion in 2019.

Table 1. Inter-city trade in Colombia, main products by sector, 2015 – 2019.

	2015	2016	2017	2018	2019
Animal products (share on total trade %)	**5.8**	**7.5**	**7.3**	**6.3**	**4.5**
Poultry (% on total sector)	82.4	75.1	88.8	89.9	89.9
Trade (US million $)	29,883	24,327	60,593	68,860	49,242
# importing cities	51	40	44	64	63
# exporting cities	69	60	69	78	82
Milk and milk derivatives (% on total sector)	1.9	2.7	2.1	2.1	1.8
Trade (US million $)	691.0	858.9	1,403.2	1,642.0	973.0
# importing cities	149	173	204	208	207
# exporting cities	82	89	97	108	116
Poultry eggs (% on total sector)	1.8	2.2	1.6	1.5	1.4
Trade (US million $)	668	715	1,122	1,144	768
# importing cities	123	136	133	142	139
# exporting cities	69	69	69	60	70
Crops (share on total trade %)	**1.3**	**2.0**	**1.1**	**0.8**	**0.5**
Coffee (% on total sector)	52.2	55.0	52.4	50.3	49.6
Trade (US million $)	4,239	4,672	5,236	4,646	3,234
# importing cities	140	151	160	156	155
# exporting cities	217	228	232	271	242
Corn (% on total sector)	11.1	10.0	9.4	11.3	11.0
Trade (US million $)	903	852	937	1,043	719
# importing cities	273	286	288	292	290
# exporting cities	144	159	162	163	137
Rice (% on total sector)	9.8	9.9	11.2	9.3	10.0

Trade (US million $)	800	838	1,117	863	654
# importing cities	580	619	627	636	602
# exporting cities	154	157	178	156	148
Manufacturing (share on total trade %)	**92.8**	**90.5**	**91.6**	**93.0**	**94.9**
Platinum (% on total sector)	51.1	2.3	7.5	15.9	10.1
Trade (US million $)	294,102	8,801	63,657	179,838	115,778
# importing cities	28	9	39	40	40
# exporting cities	3	3	3	3	4
Radioactive chemical elements (% on total sector)	11.6	29.8	8.0	8.9	5.5
Trade (US million $)	66,782	115,901	68,708	100,825	63,515
# importing cities	194	212	226	218	200
# exporting cities	82	81	95	100	80
Isotope (% on total sector)	2.0	21.1	1.7	5.3	4.0
Trade (US million $)	11,566	81,867	14,916	59,997	45,908
# importing cities	81	103	88	85	103
# exporting cities	35	38	33	39	40
Total trade	**620,142**	**429,518**	**931,908**	**1,218,793**	**1,208,459**

From the BACI trade data, we estimate a price index dividing the Free on Board (FOB) value of total Colombian exports by the total exported quantity for every four-digit good k. That is, for every year t, the price index for commodity k, p_t^k, will be defined as:

$$p_t^k = \frac{FOB_t^k}{Q_t^k}. \tag{5}$$

Q is the weight of the total exports. This export price index is then used with the RNDC data to obtain the total value of inter-city trade in Colombia. For every year *t*, we obtain the total trade between city *i* and city *j* as follows:

$$T_{ijt} = \sum_k p_t^k q_{ijt}^k, \tag{6}$$

where q_{ijt}^k is the weight of the total trade from *i* to *j* at year *t*. Figure 1 shows the flow of exports from the capital city, Bogotá, to the rest of the cities in 2015. Our approach makes it possible to isolate the potential confounding price effects since, by construction, the quantities of goods in all cities are transformed into value using the same average price. We can do so because the shocks are defined at the city level, making it unlikely to affect national equilibrium prices. Furthermore, there is evidence that prices are not affected after a natural disaster in a specific location (Cavallo et al., 2014) because the latter are localized events and there is no single commodity, even a specialized one like coffee plants, that is produced exclusively in one municipality. As a result, any impact or spillover effect can be understood in real terms.

Our data represents a panel of 1,101 Colombian municipalities for the period 2015–2019. The estimated total exports of Colombian cities were US$ 620 billion in 2015 and increased to US$ 1,208 billion in 2019. Although it is not possible to know the degree of sensitivity of ICA collection to local sales with the available information, it can be seen in figure 2 that there is a positive correlation between exports and tax capacity at the city level. It is important to point out that because we use tradeable goods transported by road, non-tradable goods as well as trade in services are not included in our estimations because of data availability, a common limitation in studies of interregional trade (Alexandre et al., 2021). Since trade data is used only to construct the matrix of trade partners, we do not expect that this limitation threaten our identification and methodology.

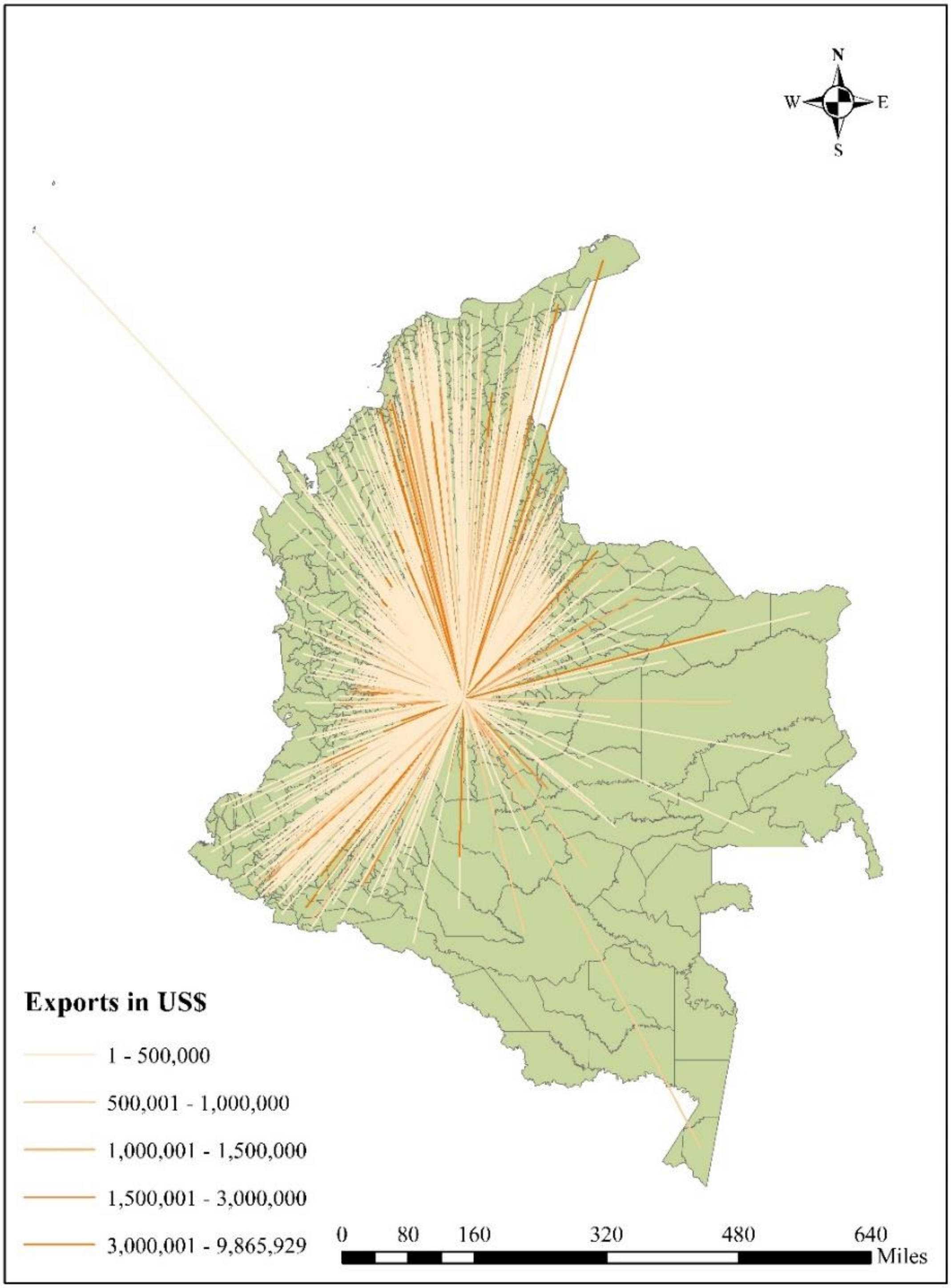

Figure 1. Exports from Bogota to other Colombian cities, 2015.

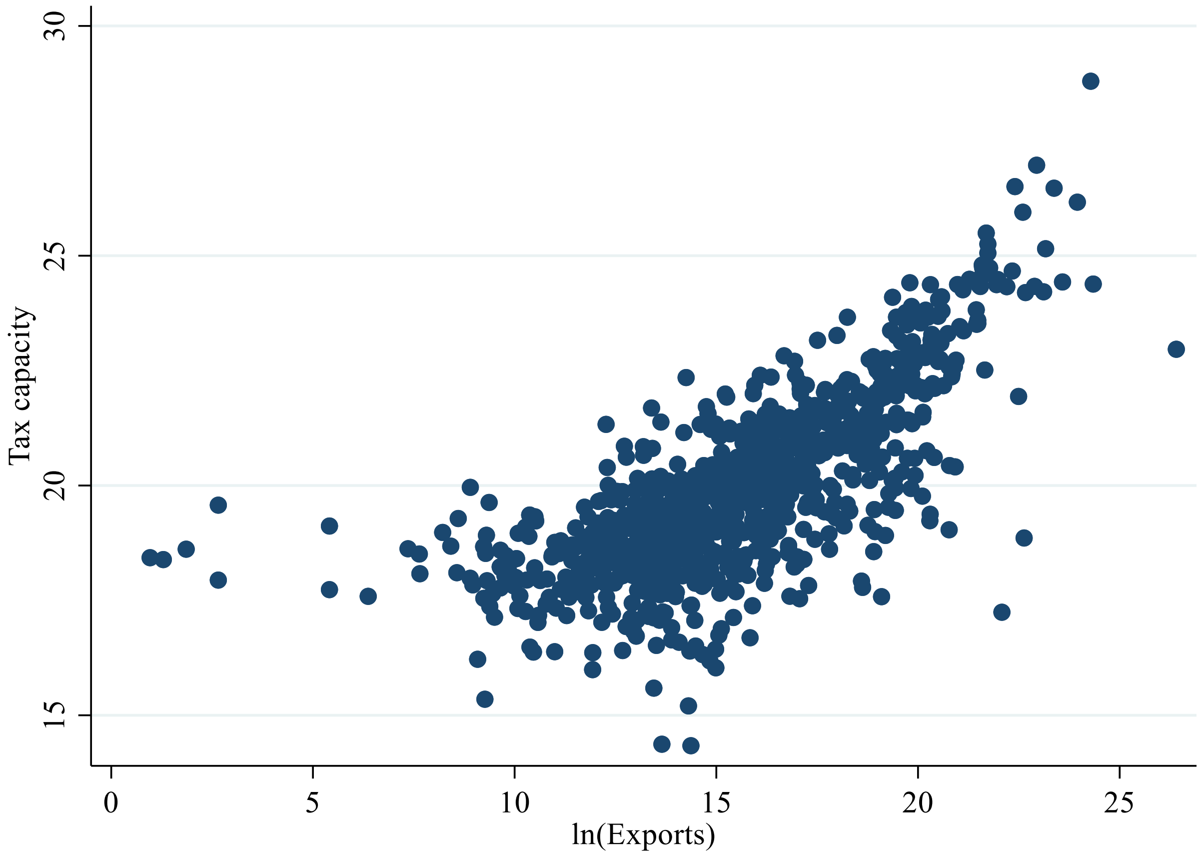

Figure 2. Tax capacity and local exports, 2015.

5. Results

5.1 Gravity estimation

We estimate equation (1) by PPML and report the estimates in table 2. We consider two different specifications. In model (I), we include the population size (in logs) in *i* and *j* while model (II) relies on GDP (in logs). Both models use dyadic and year fixed effects. The results show that a natural disaster shock in exporting cities decreases the value of exports, but the same shock in the importing cities does not significantly affect local exports once all the other control factors are considered. The results are consistent across the two specifications. The population size in the exporting and importing city are not statistically significant, whereas the GDP shows that wealthier cities export and import more as expected. This result may be explained by a similar trend in population growth rates between importing and exporting cities, which does not happen with GDP growth. Although gravity is usually estimated using GDP, we decide to use model (I) to predict the exogenous trade flows that will allow us to construct our matrix of trade partners, $\widehat{W}$. We do so because of the reverse causality condition between GDP and exports, which could create endogeneity problem in our two-step estimation. In addition, the results in both specifications are consistent even though model (I) is based on a larger sample as we can access one additional year of information. In our case, the most relevant part is to obtain an exogenous matrix of trade partners, for which the measure of the size of the economy is not restricted to the GDP. With the results of model (I), extreme natural disasters (floods and landslides) in exporting cities reduce exports by 36% on average.

Table 2. Gravity results (by PPML)

Dep. Var.: Total Exports	(I)	(II)
Shock_{it}	**-0.445***	**-0.390****
	(0.246)	(0.176)
Shock_{jt}	0.068	0.068
	(0.119)	(0.141)
$\ln(\text{Population}_{it})$	0.279	
	(2.074)	
$\ln(\text{Population}_{jt})$	0.143	
	(3.118)	
$\ln(\text{GDP}_{it})$		2.180
		(1.576)
$\ln(\text{GDP}_{jt})$		**1.053****
		(0.449)
Constant	15.081***	-80.926
	(0.988)	(53.707)
Year Fixed Effects	YES	YES
Dyadic Fixed Effects	YES	YES
Pseudo R^2	0.908	0.916
Observations	401,390	291,116

Standard errors two-way clustered by exporter and importer. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

5.2 Spillover effects of natural disaster shocks on tax revenue

Table 3 shows the results of our second stage, represented by equation (4). We find that last year's local extreme natural disasters do not affect current year's tax revenue, but the same shock averaged across trading partners increases ICA collection. Using the coefficients of model (2) in table 3, we find that a shock in all trading partners in the previous year (t–1) will increase local tax revenue by approximately 4.5% (exp(0.044)–1). Consequently, if the shock occurs only in 25% of the trading partners, ICA revenue would be increased by 1.1% (exp(0.044*0.25)–1). These results are consistent with the findings of the gravity estimation in the first stage: cities that experience a shock export less, which means that their trading partners import less from them. When cities reduce their exports because of an extreme natural disaster, then their market portion can be taken by local business in the destination cities or by businesses from other cities. This situation may give local businesses in the cities of destination the opportunity to increase their sales, which increases the local tax revenue. This hypothesis is supported by the heterogeneous effects found on the spillover effects by the population size shown in table 4. We divided the cities in three groups: i) cities with less than 30,000 inhabitants (Group 1), ii) cities with population between 30,000-100,000 inhabitants (Group 2), and iii) cities with more than 100,000 people (Group 3). The results indicate that larger cities show a larger spillover effects, which may suggest that local businesses in larger cities have a higher capacity to take the market portion that is not supplied by cities affected by extreme natural disasters. An extreme natural disaster in trading partners increases local tax revenue by 2.9% for the Group 1 of cities, 13% in Group 2, and 22.6% in Group 3.

Table 3. Spillover effects of extreme natural disasters on tax revenue

Dep. Var.: Tax capacity	(1)	(2)
$\text{Shock}_{i,(t-1)}$	-0.009	-0.007
	(0.008)	(0.008)
$\widehat{W} * \text{Shock}_{j,(t-1)}$	**0.045*****	**0.044*****
	(0.014)	(0.013)
$\ln(\text{GDP}_{i,t-1})$		**0.050*****
		(0.018)
$\ln(\text{Population}_{i,t-1})$		**0.784*****
		(0.136)
Constant	0.571***	-7.203***
	(0.004)	(1.319)
City Fixed Effects	YES	YES
Year Fixed Effects	YES	YES
Observations	5,505	5,505
Adjusted R^2	0.147	0.164

Standard errors clustered at city level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
City and year fixed effects included.

Table 4. Extreme natural disasters and tax revenue: Heterogeneous effects

Dep.Var.: Tax capacity	(1)	(2)
$\text{Shock}_{i,(t-1)}$		
Group 1	-0.007	-0.004

	(0.007)	(0.007)
Group 2	-0.038	-0.038
	(0.032)	(0.031)
Group 3	0.056	0.058
	(0.038)	(0.037)
$\widehat{W} * \text{Shock}_{j,(t-1)}$		
Group 1	**0.029****	**0.029****
	(0.013)	(0.013)
Group 2	**0.129****	**0.122****
	(0.058)	(0.058)
Group 3	**0.227*****	**0.204*****
	(0.084)	(0.076)
$\ln(\text{GDP}_{i,t-1})$		**0.049*****
		(0.018)
$\ln(\text{Population}_{i,t-1})$		**0.777*****
		(0.136)
Constant	0.571***	-7.137***
	(0.004)	(1.316)
Observations	5,505	5,505
Adjusted R^2	0.150	0.167

Standard errors clustered at city level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
City and year fixed effects included.

The elasticity of our measure of local tax revenue with respect to GDP is estimated at 0.05, which means that a 10% percent increase in GDP is associated with a 0.5% increase in local sales tax revenue. In addition, larger cities have higher tax collection. Our findings are consistent with different definitions of the natural disaster shock. Table 5 shows the results for different thresholds. Models (1) and (2) show the results defining the shock as a dummy variable equal to one if the natural disaster exceeds the 80th percentile threshold, while models (3) and (4) show the results when the threshold is the 85th percentile. The results show that a shock in the trading partners has a positive and significant effect on local tax revenue, although the results are smaller than those obtained with a 90th percentile threshold. This implies that larger shocks will have larger impacts on trade and on local tax revenue.

Table 5. Spillover effects of extreme natural disasters on tax revenue, alternative thresholds

Dep. Var: Tax capacity	(1)	(2)	(3)	(4)
	80th percentile		85th percentile	
$Shock_{i,(t-1)}$	-0.009	-0.007	-0.005	-0.003
	(0.007)	(0.007)	(0.007)	(0.007)
$\widehat{W} * Shock_{j,(t-1)}$	**0.024****	**0.024****	**0.031*****	**0.032*****
	(0.010)	(0.010)	(0.011)	(0.011)

$\ln(GDP_{i,t-1})$		**0.051*** **		**0.051*** **
		(0.018)		(0.018)
$\ln(Population_{i,t-1})$		**0.783*** **		**0.788*** **
		(0.137)		(0.136)
Constant	0.574***	-7.194***	0.572***	-7.246***
	(0.004)	(1.322)	(0.004)	(1.319)
City Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES
Observations	5,505	5,505	5,505	5,505
Adjusted R-squared	0.146	0.163	0.146	0.163

Standard errors clustered at city level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

In addition, we explore the possibility that the results vary with the type of goods traded across cities. For instance, one might expect that agricultural commodities are much more sensitive to weather events than, say, manufactured goods of which production takes place indoor. Table 6 shows the results of the spillover effects using trade in crops and plants, animal products, and manufactured goods to build the matrix of trading partners. We use the 90th percentile threshold to define a natural disaster shock as in table 3. The results are consistent with the findings of table 3. Indeed, the results indicate that there are significant and positive spillover effects of extreme natural disasters, with a point estimate that is larger when the intensity and directionality of trade are defined using exports of predicted crops and plants rather than animal products or manufacturing.

Table 6. Spillover effects of extreme natural disasters on tax revenue, different W matrices

Dep.Var: Tax capacity	Crops	Animal Products	Manufacturing
$Shock_{i,(t-1)}$	-0.007	-0.007	-0.007
	(0.008)	(0.008)	(0.008)
$\widehat{W} * Shock_{j,(t-1)}$	**0.067*** **	0.031	**0.040*** **
	(0.018)	(0.021)	(0.012)
$\ln(GDP_{i,t-1})$	**0.050*** **	**0.050*** **	**0.050*** **
	(0.018)	(0.018)	(0.018)
$\ln(Population_{i,t-1})$	**0.780*** **	**0.781*** **	**0.785*** **
	(0.136)	(0.137)	(0.136)
Constant	-7.162***	-7.174***	-7.210***
	(1.317)	(1.325)	(1.319)
City Fixed Effects	YES	YES	YES
Year Fixed Effects	YES	YES	YES
Observations	5,505	5,505	5,505
Adjusted R^2	0.166	0.163	0.164

Standard errors clustered at city level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

6. Conclusion

Climate change has increased the frequency and intensity of extreme weather events and, naturally, the cost of the damages on the infrastructure and the people they affect has surged. Because cities are not isolated entities, the consequences of a natural disaster go beyond the physical location of the city in which it takes place. This paper has shed some light on this relationship by measuring the direction and magnitude of the spillover effects of weather shocks on local tax revenue across Colombian municipalities. In this country, local tax revenue is a driver of the local economic development and it can be a better representation of economic activity at the subnational level.

We use an approach based on economic connections between cities to estimate the externalities of natural disasters. Our measure of economic links is based on inter-city trade flows, for which we rely on a database of goods and commodities transported by road at the city level in Colombia. We convert its basic volume units into value and use it to estimate a gravity model of bilateral trade across Colombian cities. To our knowledge, this effort has never been implemented before. In addition, we did not find evidence of the study of economic links across cities using inter-city trade flows for a developing country. Inter-city trade flows at the commodity level are not usually available in developing countries, and only a limited number of developed economies collect some sort of subnational trade data. The gravity results show that a natural disasters shock in exporting cities reduces its exports, but no effect was found if the shock occurs in importing cities. This first step result allows us to obtain a predicted trade flow that is exogenous to the local sales tax revenue.

We use the predicted trade flows from the gravity model to construct an export-weighted matrix of extreme weather events. The constructed matrix allows us to assess the dependence of local sales tax revenue on weather events taking place both locally and in other cities. The results show that a natural disaster shock in the trading partners has a positive effect on local tax revenue. This result can be driven by a window of opportunity that local businesses increase production and sales when imports from trading partners are reduced as a consequence of extreme natural disasters. However, no impact of local natural disaster shock on local tax capacity. The results are robust to different specifications. Our findings can shed some light on understanding the determinants of tax capacity, and how the spatial interdependence between cities plays a significant role. In addition, we provide evidence of economic linkages being the mechanism through which shocks to production and productivity drive spatial spillovers between economic entities at the subnational level. Future research may focus on the impact of extreme weather events outside the country for specific commodities or regions, as well as different dependent variables such as household income of farmers. Government officials in higher levels of public administration can also find these results useful when deciding the amount of discretionary resources to be transferred for relief spending after natural disasters, considering that cities not affected by natural disasters may have a surge in local tax revenue.

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