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Vulnerability and adaptation to severe weather events in the American southwest

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A B S T R A C T

Climate change can induce changes in the frequency of severe weather events representing a threat to socio-economic development. It is thus of uttermost importance to understand how the vulnerability to the weather of local communities is determined and how adaptation public policies can be effectively put in place.

We focused our empirical analysis on the American Southwest. Results show that, consistently with the predictions of an investment model, economic characteristics signaling local economic growth in the near future decrease the level of vulnerability.

We also show that federal governments transfers and grants neither work to support recovery from and adaptation to weather events nor to distribute their costs over a broader tax base. Finally, we show that communities relying on municipal bonds to finance adaptation and recovery policies can benefit from local acknowledgment of the need for such policies and that they do not have to pay lenders a premium for the risk induced by weather events.

In conclusion, our findings suggest that determinants of economic growth support lower vulnerability to the weather and increase options for financing adaptation and recovery policies, but also that only some communities are likely to benefit from those processes.

1. Introduction

Climate change can induce an increase in the frequency and intensity of weather events at the global and regional scale (IPCC, 2012). To evaluate the sustainability of economic growth and welfare, it is crucial to have a deeper understanding of how regional economic development affects vulnerability of local communities, that is to say the propensity to be adversely affected by the weather (IPCC, 2012).

Vulnerability to climate change is the outcome of a complex interaction between climatic and socio-economic dynamics. The natural configuration of the world we live in and the ever-changing patterns of climate and weather surely influence vulnerability by posing heterogeneous and sometimes unforeseen challenges to socio-economic systems. Until humankind will learn to govern the climate and the weather, only two ways are at disposal to avoid the most harmful outcomes: mitigate the impact of human activities on the climate and reduce the vulnerability of human systems to weather events that is to say to adapt them.

In this work we focus on the second option and thus on the two economic dynamics that co-determine vulnerability. First, economic development is associated with local accumulation of economic assets (e.g., manufacturing plants, transportation and energy infrastructures, residential neighborhoods, etc.). The presence of economic assets creates the possibility of being harmed by exogenous events since those are the assets at stake, which can be damaged or lost. A hypothetical region without economic assets and human presence is not vulnerable at all just because nothing can be affected there. People, infrastructure, and economic and social assets present in a region are usually referred as the exposure of a region (IPCC, 2012).

Second, when there are resources at stake mitigation of natural hazards can be implemented. Hazard mitigation means to invest resources today in order to provide socio-economic systems with protections from potentially disruptive weather events, today and in the future (e.g., dams and reservoirs against floods and droughts, building codes and elevation of flood-prone properties, prescribed fires and mechanical treatments of hazardous fuels against wildfires, etc.).

Similarly to what said before for a region without anything exposed, even a region with several assets exposed to the weather could be completely not vulnerable, but that requires the highest level of hazard mitigation possible.

Frequent news in the media about both large-scale disasters and more common small-scale severe weather events demonstrate that

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unfortunately the example just described is theoretical only. Actual socio-economic systems invest in hazard mitigation only up to a point, and they thus remain significantly vulnerable.

Understanding vulnerability thus means to study how the level of hazard mitigation is determined in relationship with exposure. To be more specific, in this work we address two important research questions about vulnerability and adaptation to the weather. First, inspired by economic theories of investment, we investigate whether contemporary indicators of future economic development play a role in determining the contemporary amount of hazard mitigation and consequently on vulnerability. Second, we investigate the financial means policy makers have at disposal to contribute to adaptation.

So far the focus has been on disasters that affect large areas and require immediate emergency response and external support for recovery. Such studies are usually macroeconomic at the state level. When focused on impacts of weather events, they point out the differences in damage size, recovery time, and subsequent economic growth between countries at different stages of development and over time (Toya and Skidmore, 2007; Noy, 2009; Strömberg, 2007; Mirza, 2003; Loayza et al., 2012). When focused on vulnerability, they point out the positive role of socio-demographic variables such as education and access-to-sanitation levels (Brooks et al., 2005; Pacific Institute, 2010) and they acknowledge the non-linear relationship between vulnerability and exposure, often measuring this latter variable in terms of *GDP* (Kellenberg and Mobarak, 2008; Schumacher and Strobl, 2008, 2011).

In order to answer our research questions we thus need to use a novel analytic approach that relies on different kinds of information. We need regional level information because weather events and socio-economic systems are very much heterogeneous and excessive spatial aggregation can hide relevant explanatory dynamics. Furthermore, the local knowledge and context are needed to successfully develop and implement adaptation policies (Agrawal, 2009; Adger et al., 2005; Adger, 2001) and thus we have to refer to policy making at the local level. Second, we need to take into consideration shorter time horizons because economies and markets change fast and because most of weather events, albeit with lesser impacts than seen in disasters, are short and very frequent.

2. Materials and methods

2.1. Theory

From an economic viewpoint, the relationship between hazard mitigation and exposure can be framed as an investment. In fact, hazard mitigation requires an expensive investment today that will probabilistically provide “revenues” in the future. The amount of future revenues is equivalent to the losses avoided thanks to hazard mitigation and thus to the part of exposure that is protected.

Since the seminal contributions of Keynes and Fisher, the investment model predicts that investments are made until the present value of expected revenues equals the marginal cost of the investment. Formally, the level of hazard mitigation is simply determined as $L = c$, where L is the amount of avoided losses and c is the marginal cost of hazard mitigation.

Empirical analyses in the literature (e.g., Kellenberg and Mobarak, 2008; Schumacher and Strobl, 2011) have so far approximated the measurement of L with *GDP*, implicitly assuming an exogenous and idiosyncratic, and time-invariant c.

GDP, though measuring an economic flow, is a good approximation of the existing stock of economic assets in an area, and undoubtedly one of the most available and reliable economic measures.

The marginal cost of hazard mitigation has not been fully analyzed yet, but it is realistic assuming two features about it. First, c is non-linear because several mitigations have the capability of protecting large parts of exposed assets at once (e.g., a dam). Second, c is globally increasing over the amount of protection because hazard mitigation of assets dispersed in space is more expensive, and thus those are probably the assets last to be protected.

In this work, in studying the vulnerability to the weather, we investigate whether reducing L to *GDP* implies an analytic cost due to a too short-term viewpoint in comparison with hazard mitigation investments that have a longer life cycle (e.g., riverbanks, dams, etc.). In fact, we investigate whether other economic indicators, which signal economic growth in the near future, contribute to explain weather vulnerability.

We investigate an investment model with the same equilibrium $L = c$, but where the avoided losses do not consider only the contemporary value of *GDP* but instead the present value of future levels of *GDP* in the periods covered by the hazard mitigation investment. Formally, we consider $L = \sum_t \frac{GDP_t}{(1+r)^t}$, where r is a discount rate and $t = 1 \ldots T$ with T equal to the duration of the protection provided by the hazard mitigation investment.

Taking inspiration from some measures of local economies developed in the field of innovation studies and economic growth (Frenken et al., 2007; Los, 2000) and from the associated theoretical models, we consider four different types of economic dynamics signaling future economic growth.

First, we consider Jacobs externalities (Jacobs, 1969) that are external economies created by the presence in the same region of firms operating in different industries. Knowledge spillovers from different domains facilitate innovation and growth. Jacobs externalities are observable through measures of regional economic variety.

Second, we consider localization economies (i.e., Marshallian externalities – David and Rosenbloom, 1990) that are external economies created by the presence in a region of multiple firms operating in the same industry or in industries with a similar production process from the technological perspective. The presence of several similar firms at the edge of competition and collaboration can, again, facilitate innovation and growth. The presence of localization economies can be estimated through measures of technological homogeneity.

Third, we consider urbanization economies (Kawashima, 1975; Kanemoto, 1980) that are the external economies uniquely provided by the urban size and density of production factors. Indicators of population density can approximate urbanization economies.

Fourth, we consider increasing returns to scale (Krugman, 1991) that are internal economies in terms of cost efficiencies generated within a firm that serves large markets. Increasing returns to scale are measurable by means of the average establishment size in a region.

The model we propose aims at contributing to a deeper understanding of vulnerability by shedding light on the relationship between exposure and hazard mitigation. The model in particular predicts that, controlling for the current level of exposure, economic characteristics of a region signaling its future economic growth decrease vulnerability because they make hazard mitigation more convenient.

Then, we focus our attention on public finance and on how recovery policies and adaptation ones, that is to say policies aimed at reducing vulnerability, are financed at the local level.

Starting from the theoretical model introduced above, we acknowledge that there are hazard mitigation investments that are directly made by households and firms, and others that require the intervention of local governments due to needs of coordination or to the public nature of hazard mitigation. In the case of the latter kind of hazard mitigations, local governments need to raise funds in order to make the investment.

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