Financial Mechanisms in a Disaster Aftermath
The Mexican Case

Alejandro Uriel Becerra-Ornelas

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In this dissertation, I explore the financial mechanisms available to individuals and governments after a disaster in developing countries, using Mexico as a case study. Specifically, I explore the role of fiscal federalism, remittances, migration, access to financial services, and catastrophe bonds. Across these dimensions, I focus on the effects of hurricanes and earthquakes, as these have been the costliest hazards for Mexico.

First, I estimate the effects of natural disasters on municipal revenues and expenditures. I find that the current fiscal rules disincentivize municipalities from collecting more taxes or reallocating funds to implement post-disaster policies. Additionally, state-level officials do not appear to follow federal criteria when distributing federal transfers to municipalities in the aftermath of a disaster. Second, I test whether remittances to the affected region are filling the gap left by the lack of government response. Overall, the findings reveal that remittance levels decrease after a municipality has been hit by an earthquake or both earthquakes and hurricanes. I further test whether this decline is driven by access to financial services or migration. My results suggest that the affected agents migrate after a disaster to smooth consumption. Third, I propose a comprehensive policy evaluation framework to evaluate risk-financing tools. Then, I illustrate this policy framework using the Mexican CAT bonds program as a case study. The results reveal that the Mexican CAT bonds program performs well against the criteria of the input evaluation stage. However, my results suggest that the program could be adjusted to improve its performance relative to the process/product evaluation criteria.

Based on this work, there are two potentially important future research areas. First, improve the understanding of the underlying mechanisms that explain changes in the spending priorities to identify leverage points for policy improvements in the fiscal federalism and disaster response systems. Second, identify damage drivers and use them to estimate both the marginal effects of disasters based on their intensity and to improve the triggering parameters of Mexican CAT bonds. Further exploring these research streams is particularly relevant in a future where the frequency and magnitude of natural hazards are expected to increase.
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Now, let me switch on the Spanish section.

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## Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>ATE</td>
<td>Average Treatment Effect</td>
</tr>
<tr>
<td>ACE</td>
<td>Average Cumulative Effect</td>
</tr>
<tr>
<td>Banxico</td>
<td>Mexican Central Bank / Banco de México</td>
</tr>
<tr>
<td>CAT bonds</td>
<td>Catastrophe bonds</td>
</tr>
<tr>
<td>CENAPRED</td>
<td>National Center for Prevention of Disasters / Centro Nacional para la Prevención de Desastres</td>
</tr>
<tr>
<td>CNBV</td>
<td>National Banking and Securities Commission / Comisión Nacional Bancaria y de Valores</td>
</tr>
<tr>
<td>CONAGUA</td>
<td>National Water Commission / Comisión Nacional del Agua</td>
</tr>
<tr>
<td>CONAPO</td>
<td>National Population Council / Consejo Nacional de Población</td>
</tr>
<tr>
<td>DiD</td>
<td>Difference-in-Differences</td>
</tr>
<tr>
<td>DOF</td>
<td>Official Journal of the Federation / Diario Oficial de la Federación</td>
</tr>
<tr>
<td>FCL</td>
<td>Fiscal Coordination Law / Ley General de Coordinación Fiscal</td>
</tr>
<tr>
<td>FTPS</td>
<td>Final Terms and Pricing Supplements</td>
</tr>
<tr>
<td>FONDEN</td>
<td>Fund for Natural Disasters / Fondo de Desastres Naturales</td>
</tr>
<tr>
<td>ILS</td>
<td>Insurance-Linked Securities</td>
</tr>
<tr>
<td>INEGI</td>
<td>National Institute of Statistics and Geography / Instituto Nacional de Estadística, Geografía e Informática</td>
</tr>
<tr>
<td>JPT</td>
<td>Joint Placebo Test</td>
</tr>
<tr>
<td>MIA</td>
<td>Mexican Information Act / Solicitud de transparencia</td>
</tr>
<tr>
<td>MII</td>
<td>Migration Intensity Index</td>
</tr>
<tr>
<td>ML</td>
<td>Richter scale</td>
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<tr>
<td>MMS</td>
<td>Modified Mercalli Scale</td>
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<tr>
<td>MXN</td>
<td>Mexican Peso</td>
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<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
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<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>--------------</td>
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<tr>
<td>NSFC</td>
<td>National System of Fiscal Coordination / Sistema Nacional de Coordinación Fiscal</td>
</tr>
<tr>
<td>SEGOB</td>
<td>Ministry of the Interior / Secretaría de Gobernación</td>
</tr>
<tr>
<td>SINAPROC</td>
<td>National Civilian Protection System / Sistema Nacional de Protección Civil</td>
</tr>
<tr>
<td>SPV</td>
<td>Special purpose vehicle</td>
</tr>
<tr>
<td>SSN</td>
<td>Mexican National Seismological Agency / Servicio Sismológico Nacional</td>
</tr>
<tr>
<td>TWFE</td>
<td>Two-way fixed-effects</td>
</tr>
<tr>
<td>UNAM</td>
<td>National Autonomous University of Mexico / Universidad Nacional Autónoma de México</td>
</tr>
<tr>
<td>USA</td>
<td>United States of America</td>
</tr>
<tr>
<td>USD</td>
<td>United States Dollar</td>
</tr>
<tr>
<td>USGS</td>
<td>United States Geological Survey</td>
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I. General Introduction

Mexico is exposed to several natural hazards, including earthquakes, hurricanes, wildfires, heavy rainfall, floods, heat and cold waves, droughts, and volcanic eruptions. To mitigate the impacts of these risks, officials created a system that coordinates policy efforts across levels of government. For instance, if a hazard strikes and local governments see their own emergency management capacities exceeded, local officials can request assistance from federal officials by requesting the issuance of a disaster declaration. Disaster declarations were introduced in 2000 as a legal mechanism to receive federal funding for reconstruction operations.

To cover these operations, disaster declarations are funded with a combination of a federally managed reserve fund called the Fund for Natural Disasters\(^1\) (FONDEN) and three layers of risk-transfer instruments. The risk-transfer instruments are composed by two layers of insurance\(^2\) and one layer of catastrophe bonds\(^3\) (CAT bonds), which are used to insure and strengthen FONDEN resources. However, FONDEN only covers up to 50 percent of local assets in the first event. This share could diminish to 25 percent in the second event and zero percent in the third and subsequent reconstruction efforts if local assets are not insured. By conditioning federal aid on insurance take up, the current system is designed to decentralize financing and improve access to insurance markets for local bureaucracies. The underlying idea of this setup is that stronger local bureaucracies are better able to address the negative impacts of natural disasters, which are a local phenomenon.

While previous research has estimated the economic effects of federal aid (Del Valle, De Janvry, & Sadoulet, 2020), there remains a need for analysis of the policy problems that arise from covering the remaining response and reconstruction costs. These remaining costs have to be covered by already overwhelmed local governments, individuals living in affected municipalities,

\(^1\) In October 2020, the Mexican Congress approved a bill to eliminate the program because federal officials viewed FONDEN resources as “sitting” money during the Covid-19 pandemic. However, this policy change does not affect the estimations of the empirical Chapters as the last analysis period is 2019.

\(^2\) The first layer consists of the insurance of federal (mandated) and state-level (incentivized) agencies and the insurance of low-income households (encouraged). The second layer is composed of parametric or indemnity-based excess-of-loss insurance.

\(^3\) The bonds are used to hedge catastrophic risk coming from hurricanes and earthquakes.
and their safety nets. The overarching aim of this dissertation is to understand these problems by exploring the available financial mechanisms in a disaster aftermath. This dissertation focuses on three specific research questions within this overarching issue. (1) What are the effects of being hit by one or multiple natural disasters on government revenues and expenditures at the municipal level? (2) What is the behavior of economic agents and their safety nets after being hit by one or multiple natural disasters? (3) How can we better evaluate risk-financing tools? To answer these questions, I divide this dissertation into six additional chapters as follows.

In Chapter II, I introduce a landscape on the costs and risk-financing strategies to cope with disasters in Mexico. In doing so, I provide an empirical justification to limit the analysis of this dissertation to hurricanes and earthquakes. In Chapter III, I present the Difference-in-Differences (DiD) estimator used to conduct the empirical analysis of Chapters IV and V. I start by introducing the problems with traditional two-way fixed-effects (TWFE) approaches to DiD estimation then introduce improved DiD estimators that overcome these problems. The identifying assumptions of the new estimators and the treatment indicator used in the estimations are also discussed.

In Chapter IV, I aim to answer research question (1) What are the effects of being hit by one or more natural disasters on government revenues and expenditures at the municipal level? To answer this question, I estimate the treatment effects of having been hit by one or more hurricanes, earthquakes, or both on the levels and composition of government revenues and expenditures at the municipal level. When estimating the treatment effects of natural disasters, I am indirectly able to assess whether local policy decisions deviate from federal criteria when distributing federal transfers to municipalities in the aftermath of a disaster.

In Chapter V, I aim to answer research question (2) What is the behavior of economic agents and their safety nets after being hit by one or more natural disasters? To answer this question, I estimate the treatment effects of having been hit by one or multiple earthquakes, hurricanes, or both on remittance levels. Likewise, when testing the underlying causal mechanisms, I also test the role of access to financial infrastructure and migration as post-disaster coping alternatives to smooth consumption. Specifically, I examine whether remittances to affected municipalities decline with higher migration indexes or lower access to financial services.

In Chapter VI, I aim to answer research question (3) How can we better evaluate risk-financing tools? To answer this question, I propose a comprehensive policy evaluation framework based on the fiscal resilience to disasters literature and framed using the context, input, process, product
(CIPP) evaluation model proposed by Stufflebeam (1983). Then, I illustrate this policy framework using the Mexican CAT bonds program as a case study. Mexico’s exposure to hazards and its leading use of CAT bonds makes it a good case study for highly exposed countries considering similar instruments. Finally, in Chapter VII, I present the overall conclusions and lay out next steps for future research.
II. Disaster Landscape in Mexico

For most of the twentieth century, Mexico lacked national or local policies to address any type of hazards. However, after a combination of natural and technological disasters in the late 70s and mid-80s, the need for a policy response towards hazards became self-evident. The outcome was the creation of the National Civilian Protection System (SINAPROC) in 1986. SINAPROC coordinates institutions and creates relationships and programs that aim to achieve a system of integrated risk management across public, private, and social sectors (OECD 2013). At the federal level, the System is coordinated by the SEGOB. At the local level, each state has developed their own civil protection legislation.

SINAPROC was designed to coordinate government across different levels following the principle of subsidiarity. This means that, if hazard strikes and local governments see their own emergency management capacities exceeded, municipalities can request assistance from states, and states can do the same with the federal government. One way to call for support of federal officials is requesting the issuance of a disaster declaration. Disaster declarations were introduced in 2000 as a legal mechanism to receive federal funding for reconstruction operations. Declarations are issued by SEGOB upon the request of the affected state and the approval of a technical committee, which verifies the occurrence of the event and measures the intensity of the hazard to a predefined threshold.

Since the introduction of disaster declarations, SEGOB has issued 804 declarations. Though most of these declarations are not related to hurricanes or earthquakes, these two hazards have been the costliest for the country. According to Mexico's National Center for Prevention of Disasters (CENAPRED), from 2000 to 2019, the average observed cost for disasters associated with earthquakes and hurricanes was 24.1 MXN billion. This figure means that these two hazards alone have represented 61.7 percent of the average of the total expenses related to catastrophic...
events\textsuperscript{6} (see Figure 1). These expenditures include costs associated with the reconstruction of federal and local infrastructure, and low-income housing.

**Figure 1 – Observed Costs of Hurricanes and Earthquakes**

Source: Author's calculations based on CENAPRED’s annual reports for 2018 and 2019.

To cover these costs, Mexican officials designed a risk-financing strategy composed of three layers of risk-transfer instruments based on the hazard related risk, where layer one covers minor events, layer two intermediate events, and layer three covers catastrophic events. The first layer consists of a mandate to insure federal assets. By law, federal agencies are mandated to take up insurance to cover their assets. The second layer is composed of parametric or indemnity-based excess-of-loss insurance. Insurance setups in this layer are meant to cover additional losses not covered by the first layer, which is usually the case after intermediate-impact events.

Finally, the third layer is covered by the CAT bonds. This layer focuses on high-impact events. In the Mexican case, CAT bonds cover associated costs coming from large earthquakes and hurricanes. The insurance premiums, the bond's coupons, and the excess losses of the first two layers were covered by and directed to a reserve fund called the FONDEN. FONDEN\textsuperscript{7} received a fixed share of the federal budget every year and was designed as a trust to carry forward unspent money. However, Mexican Congress approved a bill to eliminate the program in October 2020.\textsuperscript{8}

\textsuperscript{6} The list of catastrophic events analyzed by CENAPRED includes hydrometeorological, geological, wildfires, explosions, epidemics and technological.

\textsuperscript{7} FONDEN was created in 1996, but its trust was established in 1999.

\textsuperscript{8} Federal officials viewed FONDEN resources as “sitting” money during the Covid-19 pandemic.
Now, it is expected that officials substitute this fund with a budget program. This change would constrain the availability of resources to the fiscal year cycle. Figure 2 summarizes the federal government risk-financing strategy.

**Figure 2 – Federal Government Risk-financing Mechanisms**

Regardless of the risk-financing tool, when SEGOB issues a disaster declaration, federal officials must provide recovery and reconstruction assistance for low-income households and public infrastructure. At the local level, municipal officials organize bidding processes for reconstruction, and communicate the results to federal officials, who then transfer the funds directly to the companies. This way, FONDEN transfers are not registered in the municipal books. Instead, these transfers are registered in the FONDEN trust, which is managed by federal officials.

However, at the local level, FONDEN only covers 50 percent of the reconstruction costs of local assets in the first event. This share could diminish to 25 percent in the second event and zero percent in the third and subsequent reconstruction efforts if local assets are not insured (The World Bank, 2012). By conditioning federal aid on insurance take up, the current system is designed to decentralize financing and improve access to insurance markets for local bureaucracies. The underlying idea of this setup is that stronger local bureaucracies are better in addressing the negative impacts of natural disasters, which are a local phenomenon.
While previous research has estimated the economic effects of federal aid (Del Valle et al., 2020), there remains a need for analysis of the policy problems that arise from covering the remaining response and reconstruction costs. These remaining costs have to be covered by already overwhelmed local governments, agents living in affected municipalities, and their safety nets. In this dissertation, I estimate the impacts of covering the remaining costs coming from hurricanes and earthquakes. I argue that focusing on these two hazards is informative for policy and economic purposes as they are the two costliest hazards for the country (see Figure 1). Also, by nature, these two hazards can strike any given municipality one or multiple times, which could diminish the availability of federal aid given FONDEN rules.
III. Difference-in-Differences Estimators

Recent research on DiD estimators have shown that the two-way fixed-effects (TWFE) specifications lead to biased results in designs when the homogeneous treatment effect assumption is relaxed (Borusyak & Jaravel, 2018; de Chaisemartin & D’Haultfoeuille, 2020; Goodman-Bacon, 2021). This problem extends to event studies (Sun & Abraham, 2021) and increases in cases where the unit of analysis receives multiple treatments (de Chaisemartin & D’Haultfoeuille, 2021a). Addressing this problem is relevant for my research because hurricanes and earthquakes can strike any given municipality one or more times, and the effects of been treated may vary over time and across municipalities (heterogenous effects). In this Chapter, I follow this new DiD literature and introduce the mechanics of the DiD estimator used to conduct the empirical analysis of Chapters VI and V.

I. Problems of TWFE as DiD Estimator

Before introducing the actual DiD estimator, I introduce the underlying problems of TWFE estimators following three steps of increasing complexity. First, I discuss the basic 2x2 DiD setup with two periods (pre- and post-treatment) and two groups (treated and controls). Then, I expand to a setup holding constant the number of groups but increasing the number of periods. Finally, I consider an additional treatment group to have multiple time periods and variation in treatment timing. In building these steps, I closely follow the Bacon decomposition proposed by Goodman-Bacon (2021).

First, let us start with the basic 2x2 DiD setup with two periods (pre- and post-treatment) and two groups (treated and controls) as described in Figure 3. This figure summarizes the outcome evolution of two groups: one treated (dark blue) and one never-treated (red), over two time periods: period one when both groups are untreated, and period two when the treated group has been treated. In other words, the treatment group is treated between periods one and two. The DiD estimator would calculate the treatment effect by looking at the difference in the outcome evolution of treatment and control groups after factoring out any changes not attributable to receiving the
treatment, also known as pre-trends (dotted line in light blue). Mathematically, this estimator can be expressed as in equation (1).

**Figure 3 – 2x2 DiD**

![Graph showing the difference between post- and pre-treatment outcomes for treated and control groups.](image)


\[
\hat{\beta}^{DD} = (\gamma_{post}^{treated} - \gamma_{pre}^{treated}) - (\gamma_{post}^{control} - \gamma_{pre}^{control})
\]  

Equation (1) expresses the DiD estimator \( \hat{\beta}^{DD} \) as the difference between post- and pre-treatment outcomes \( \gamma \) in the treatment and control groups individually, and then calculates the difference of those differences. In doing this last step, the DiD estimator factors out any changes in the outcome evolution not associated with the treatment. So, the estimator assumes that, in the absence of the treatment, the treatment and control groups would have followed similar trajectories, and that any deviations are equivalent to the treatment effect. This assumption is the main identifying assumption for causal inference, and it is known as the parallel trends assumption.

In Figure 3, this means that, in the absence of the treatment, the treated group would have followed the same trend as the dotted line, which follows the same trend as the never-treated group. Therefore, the treatment effect is the difference between the observed outcome of the treated group (dark blue) and its counterfactual evolution in the absence of the treatment (dotted line). Numerically, we can get \( \hat{\beta}^{DD} \) by substituting observed values into equation (1) as follows
(4 - 2) - (2 - 1) = (2) - (1) = 1. Hence, the treatment effect captured by the DiD estimator in this example equals \( \hat{\beta}_{DD} = 1 \).

We can expand this initial 2x2 setup, to a setup holding constant the number of groups but increase the number of periods, as described in Figure 4. Like in Figure 3, Figure 4 shows the outcome evolution of one treated (dark blue) and one never-treated (red). However, unlike the previous setting, this figure shows the outcome evolution over multiple periods of time (e.g., 10 periods). In this particular example, the treatment group gets treated between periods 2 and 3 denoted by the vertical black dotted line. In other words, there are two pre-treatment periods (1 and 2), and eight post-treatment periods (3 to 10). Mathematically, this estimator can be expressed as in equation (2).

Equation (2) is equivalent to equation (1) except that, given the multiple time periods, the treatment effect now calculates the difference on the average outcomes \( \bar{y} \) in pre- and post-treatment periods. Applying equation (2) to Figure 4, the first part of the equation is expressed by the difference between the average outcome in post-treatment periods \( \bar{y}_{post}^{treated} \) (upper dotted line in light blue) and pre-treatment periods \( \bar{y}_{pre}^{treated} \) (lower dotted line in light blue) of the treated group. The second part of the equation is expressed by the difference between the average outcome in post-treatment periods \( \bar{y}_{post}^{control} \) (upper dotted line in light green) and pre-treatment periods \( \bar{y}_{pre}^{control} \) (lower dotted line in light green) of the never-treated group. Assuming that treatment and control groups meet the parallel trends assumption, \( \hat{\beta}_{DD} \) equals the difference in those two differences.

\[
\hat{\beta}_{DD} = (\bar{y}_{post}^{treated} - \bar{y}_{pre}^{treated}) - (\bar{y}_{post}^{control} - \bar{y}_{pre}^{control})
\]  

(2)
Finally, this setup could be expanded with an additional treatment group to have multiple time periods and variation in treatment timing, as presented in Figure 5. This figure shows the outcome evolution of three groups: one never-treated group (red), one early treated group (blue), and one late treated group (grey) over ten time periods. In this particular example, the early treated group gets treated between periods 2 and 3, and the late treated group gets treated between periods 7 and 8, as denoted by the vertical dotted lines.

**Figure 5 – DiD with Variation in Treatment Timing**

\[ y_{gt} = \alpha_g + \gamma_t + \beta_{DD, TWFE}^{DD} D_{gt} + \varepsilon_{gt} \]  

(3)

To estimate the treatment effect in this setup, previous empirical research argued that the TWFE specification would be a valid generalization of a simple 2x2 DiD estimator, as summarized in equation (3). This specification includes time and group specific fixed-effects, and an additional indicator to capture the treatment effect (e.g., 1 if the group gets treated and 0 otherwise). However, recent research has challenged the internal validity of this generalization as an unbiased DiD estimator. To introduce the new literature, I follow Goodman-Bacon (2021), who decompose TWFE $\beta_{DD, TWFE}^{DD}$ in a setting with multiple time periods and variation in treatment timing. In this Chapter, I also make some complementary references to Borusyak and Jaravel (2018), de Chaisemartin and D’Haultfoeuille (2020), and Sun and Abraham (2021).

Goodman-Bacon (2021) decompose the $\beta_{DD, TWFE}^{DD}$ coefficient of equation (3) in a setting with multiple treatments in different time periods. The article finds that the TWFE coefficient could be decomposed into four parts as presented in equation (4) and graphically represented in Figures 6 to 9. The first $\beta_{early,never}^{2x2}$ represents the treatment effect of the comparison between an early treated group (blue) and a never-treated one (red). The second $\beta_{late,never}^{2x2}$ captures the treatment effect of the comparison between a late treated group (grey) and a never-treated one. The third $\beta_{early,late}^{2x2,early}$ represents the comparison between an early treated group and a late treated group for the periods before the late treated group receives its first treatment (e.g., not-yet-treated). Finally, the fourth $\beta_{late,early}^{2x2,late}$ captures the comparison between an early treated group and a late treated group for all periods after the early treatment group was first treated.

\[
\hat{\beta}_{DD, TWFE}^{DD} = s_{early,never} \hat{\beta}_{early,never}^{2x2} + s_{late,never} \hat{\beta}_{late,never}^{2x2} + s_{early,late} \hat{\beta}_{early,late}^{2x2,early} + s_{late,early} \hat{\beta}_{late,early}^{2x2,late}
\]  

(4)
Each of the four components of $\hat{\beta}_{DD,TWFE}^{T}$ is weighted by $s$. This weighting factor is composed by the sample size and the variance coming from the number of pre- and post-treatment periods needed by each comparison. So, $\hat{\beta}_{DD,TWFE}^{T}$ is a weighted average of those four components. Given this decomposition, it is possible to see that the coefficient could be biased because of two main reasons. First, $s$ could differ to the proportion of units in that specific comparison account for the entire population.

Second, when analyzing the components, it is possible to see that there is a problem with the selection of control groups. The first two components use the never-treated group as controls, the third component uses the not-yet-treated as controls, but the fourth component uses early treated units as control for late treated units. In the presence of heterogeneous treatment effects, this fourth

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Footnote 9: For instance, groups treated in the middle of the panel have an equal number of pre- and post-treatment periods. Otherwise, there is an asymmetry in the number of pre- or post-treatment periods.
component bias $\beta_{DD,TWFE}$ by imposing negative weights to the coefficient (Borusyak & Jaravel, 2018; de Chaisemartin & D’Haultfoeuille, 2020; Goodman-Bacon, 2021). This problem persists in setups estimating dynamic TWFE over a time window, also called event studies (Sun & Abraham, 2021).

II. Treatment Dynamics

To overcome potential biases from the TWFE specification, a set of new DiD estimators have been recently developed (Callaway & Sant’Anna, 2021; de Chaisemartin & D’Haultfoeuille, 2020, 2021a, 2021b; Sun & Abraham, 2021; Wooldridge, 2021). I use the DiD estimator proposed by de Chaisemartin and D’Haultfoeuille (2021a). The power of this estimator is that it allows us to identify both average treatment effect (ATE) and the average cumulative effect (ACE), while overcoming the shortcomings of traditional TWFE specifications. Calculating both treatment effects is economically relevant because of the dual nature of natural disasters.

On the one hand, the ATE is the treatment effect coming from a staggered design. In staggered designs, once a municipality has been treated, it will remain treated for the rest of the panel. So, the ATE captures the effect of "having ever been treated." Calculating the ATE becomes relevant as disaster declarations signal the occurrence of an event where federal aid is needed as the damages go beyond the budgetary capacities of the treated municipality. This could translate to long-lasting effects and could be used to argue in favor of a staggered design even if the event itself was transient.

On the other hand, the ACE is the treatment effect coming from a non-staggered design. In non-staggered designs, municipalities can be treated multiple times over the panel. So, the cumulative effect becomes a well-defined intention-to-treat estimator which has to be divided by the average number of actual treatments. This way, the ACE captures the change in the outcome created by a one-unit change in the treatment. Allowing for multiple treatments is relevant, not only because their effects can accumulate over time but also because municipalities could be receiving less FONDEN money in subsequent events if they did not insure their assets after the first event.

Researchers need to be aware of the implications of the treatment design when using DiD estimators. Estimating the ACE is better suited for non-staggered designs or multiple treatments, while estimating the ATE is better for staggered designs. However, there are also cases where
estimating both treatment effects could be economically interesting. I argue that this could be the case for estimating the impacts of natural disasters. On the one hand, the treatment itself is transient and can be coded as a non-staggered design allowing to estimate the effect of multiple events. On the other hand, the effects of having had a disaster may not be transient, leading the researcher to specify a staggered design (de Chaisemartin & D’Haultfoeuille, 2021; Deryugina, 2017; Sun & Abraham, 2021).

To capture both treatment effects, I define treatment as a binary variable that indicates the issuance of a disaster declaration related to an earthquake or hurricane. By definition, disaster declarations are signaling the occurrence of costly events. So, the effects of events that triggered declarations could be modeled as long-lasting, making the case for the ATE. In this case, the treatment variable equals zero in all pre-treatment periods and one at and after the initial treatment. However, Mexican municipalities have experienced multiple treatments and federal aid changes after the first treatment. So, treatment could be modeled as in the ATE case to then be divided by the average number of actual treatments, making the case for the ACE. In this case, the treatment variable equals one in the period of the event, and zero otherwise.

In Chapters IV and V, I focus on the ACE estimands in all settings where municipalities experienced more than one treatment during the analysis period. I focus on this estimator because of the following reasons. First, federal aid diminishes in the second and subsequent events if local public assets are not insured. Receiving less federal aid has a direct impact on municipal public finance (e.g., Chapter IV), but also has an indirect impact on individuals living in affected municipalities (e.g., Chapter V) as they may receive less post-disaster assistance in subsequent events. Individuals may not remit more after their relatives have experienced one disaster but may decide to do it if conditions in their municipalities deteriorate after subsequent events. The same dynamic could be expanded to migration. Some individuals may migrate after the first event and some others may decide to stay. However, if conditions worsen after multiple events, individuals that had decided to stay may migrate as well.

Second, previous research has shown the natural disasters are associated with negative shocks to economic activities (Felbermayr & Groschl, 2014; Noy, 2009; Strobl, 2011, 2012). So, experiencing multiple treatments may magnify the negative consequences of disasters, making economically interesting to estimate the average cumulative effects. Third, I argue that the ACE estimator is a more relevant estimator in cases where there are not strong priors on the underlying
treatment dynamics and multiple treatments per unit of analysis. In this case, some municipalities could experience long-lasting effects, but some others could recover relatively fast. However, in Chapters IV and V, I present both treatment effects in all settings where municipalities experienced more than one treatment in case policymakers have more nuanced information on the treatment dynamics or future researchers want to study these dynamics further.

III. DiD Estimator

de Chaisemartin and D’Haultfoeuille (2021a) propose an estimator in the form of a ratio. In terms of my research design, the numerator indicates the average of the dynamic effects of revenues and expenditures (Chapter IV) or remittances (Chapter V) arising at and after the initial treatment. The denominator indicates the average number of treatments, which in this case is equivalent to the average number of disaster declarations. In staggered designs, the numerator is equivalent to the treatment effect with a denominator equal to one as these designs only capture the effect of the first event. In non-staggered designs, the numerator becomes a well-defined intention-to-treat estimator which has to be divided by the average number of actual treatments, which is less than one.

To build the numerator, de Chaisemartin and D’Haultfoeuille (2021a) start by estimating individual 2x2 DiD estimands as described in equation (5). In this equation, groups are indexed by \( g \in \{1, \ldots, G\} \), time periods are indexed by \( t \in \{1, \ldots, T\} \), and the number of periods after the first treatment are indexed by \( \ell \in \{0, \ldots, L\} \). In terms of the research design of the following empirical Chapters, the estimator compares the evolution of revenues, expenditures, or remittances \( y_{g,t} \) received at municipality \( g \) at quarter \( t \) after being hit by an event for the first time \( \ell \) periods ago. The treatment \( D_{g,t} \) denotes experiencing one or multiple earthquakes, hurricanes, or both for all \( d \in \{0,1\}^T \). The first treatment \( F_{g,1} = \min \{ t: D_{g,t} = 1 \} \) is experienced at \( t - \ell \) and \( F_{g,1} > t \) denotes if group \( g \) is never-treated. Finally, \( N_{g,t} \) denotes the number of observations in group \( g \) at period \( t \). So, \( N_{t,\ell}^1 = \sum_{g:F_{g,1}=t-\ell} N_{g,t} \) is the number of observations treated for the first time \( \ell \geq 0 \) periods ago at time \( t \), and \( N_{t}^u = \sum_{g:F_{g,1}>t} N_{g,t} \) denotes the number of observations in untreated groups \( u \) from period 1 to \( t \).
\[
\text{DiD}_{+,t,\ell} = \sum_{g: F_{g,1}=t-\ell} \frac{N_{g,t}}{N_{t,\ell}} (y_{g,t} - y_{g,t-\ell-1}) - \sum_{g: F_{g,1}>t} \frac{N_{g,t}}{N_{t,\ell}} (y_{g,t} - y_{g,t-\ell-1})
\] (5)

Mechanically, equation (5) is composed by two parts. The first part estimates the difference in outcome levels from period \(t - \ell - 1\) to \(t\) for every \(t\) and \(\ell\) in municipalities treated for the first time in \(t - \ell\). This difference is weighted by the share of treated municipalities that were used in the calculation \(\frac{N_{g,t}}{N_{t,\ell}}\). The second part estimates the same difference, but for never-treated municipalities \(F_{g,1} > t\), using as weights the share of untreated municipalities used in this calculation \(\frac{N_{g,t}}{N_{t,\ell}}\). For both calculations, this estimator uses period \(t - \ell - 1\) as the baseline and calculates 2x2 DiD estimands comparing the baseline period against every period after the first treatment. Finally, after separately calculating the difference in outcome levels for both treatment and control groups, equation (5) takes the differences of those differences to get \(\text{DiD}_{+,t,\ell}\).

For instance, if there are ten periods at and after the initial treatment (e.g., \(0 \leq \ell \leq 9\)), equation (5) first returns ten estimands for treated groups and ten estimands for control groups, comparing each of those post-treatment periods against the baseline period. Then, after separately calculating the differences for treatment and control groups, this equation takes the difference of those differences to calculate a total of ten DiD estimands. Estimands coming from the first 2x2 DiD (e.g., \(t - \ell - 1\) to \(t\) when \(\ell = 0\)) are known as instantaneous effects. While estimands from the following post-treatment comparisons at \(1 \leq \ell \leq 9\) are known as dynamic effects.

Equation (6) estimates the average of all estimands coming from equation (5) in all post-treatment periods at and after the initial 2x2 estimation (e.g., \(t = \ell + 2\)) until the last period of analysis \(T\).10 This average is weighted by \(\frac{N_{t,\ell}}{N_{1,\ell}}\), where \(N_{1,\ell} = \sum_{t=\ell+2}^{T} N_{t,\ell}\) denotes the number of units reaching \(\ell\) periods after their first treatment at or before \(T\). This equation is the core of the numerator in de Chaisemartin and D’Haultfoeuille (2021a) ratio.

\[
\text{DiD}_{+,\ell} = \frac{1}{N_{1,\ell}} \sum_{t=\ell+2}^{T} N_{t,\ell} \text{DiD}_{+,t,\ell}
\] (6)

---

10 This is the case when there is a never-treated group throughout the panel. In cases without a never-treated group, the analysis is truncated to the last period with a not-yet-treated group.
To estimate the denominator, de Chaisemartin and D’Haultfoeuille (2021a) use the same setup as equations (5) and (6). However, instead of estimating the evolution of the outcome (e.g., revenues, expenditures, or remittances $y_{g,t}$), the denominator estimates the evolution of the treatment $D_{g,t}$ (e.g., earthquakes, hurricanes, or both). In staggered designs the evolution of the treatment becomes trivial as it is set equal to one. But in non-staggered designs the evolution of the treatment is important to divide the treatment effect over the number of actual treatments. Thus, equation (7) follows equation (5) and estimates all 2x2 DiD for every $t$ and $\ell$ for treatment $D_{g,t}$.

$$\text{DiD}_{+,t,\ell} = \sum_{g:\tilde{g}_{g,1}=t-\ell} \frac{N_{gt}}{N_{t,\ell}} (D_{g,t} - D_{g,t-\ell-1}) - \sum_{g:\tilde{g}_{g,1}>t} \frac{N_{gt}}{N_{t,\ell}} (D_{g,t} - D_{g,t-\ell-1})$$  \hspace{1cm} (7)$$

Equation (8) estimates the average of all estimands coming from equation (7) in all post-treatment periods at and after the initial 2x2 estimation such as equation (6) does with the estimands coming from in equation (5). This equation is the core of the denominator de Chaisemartin and D’Haultfoeuille (2021a) ratio.

$$\text{DiD}_{+,t,\ell} = \frac{1}{N_{t,\ell}} \sum_{t=\ell+2}^{T} N_{t,\ell} \text{DiD}_{+,t,\ell}$$  \hspace{1cm} (8)$$

Therefore, when we bring equations (6) and (8) together, we get de Chaisemartin and D’Haultfoeuille (2021a) ratio as presented in equation (9). The numerator estimates the average effect of first switchers on the outcome, while its denominator estimates the same effect on the treatment. In other words, the ratio calculates the average of all the dynamic effects arising at the date of and after the first event and divides it over the average number of events at the date of and after the first event. As in the previous steps, the numerator and denominator are weighted by the share of units $w_{+,t,\ell} = \frac{N_{t,\ell}}{\sum_{\ell=0}^{L} N_{t,\ell}}$ used in that calculation over the $L$ periods of analysis.

$$\delta_+ = \frac{\sum_{\ell=0}^{L} w_{+,t,\ell} \text{DiD}_{+,t,\ell}}{\sum_{\ell=0}^{L} w_{+,t,\ell} \text{DiD}_{+,t,\ell}}$$  \hspace{1cm} (9)$$

In staggered designs (ATE), $\text{DiD}_{+,t,\ell} = 1$ as these designs only capture the effect of the first event. So, $\delta_+$ is a weighted average of $\text{DiD}_{+,t,\ell}$ estimators and can be interpreted as the effect of "having ever been treated" as presented in equation (10).
\[ ATE = \sum_{\ell=0}^{L} w_{+,\ell} DiD_{+,\ell} \]  \hspace{1cm} (10)

In non-staggered designs (ACE), the numerator becomes a well-defined intention-to-treat estimator which has to be divided by the average number of actual treatments, which is lower than one \((DiD_{+,\ell} < 1)\) as presented in equation (11). Therefore, \(\delta_+\) is interpreted as the change in the outcome created by a one-unit change in the treatment.

\[ ACE = \frac{\sum_{\ell=0}^{L} w_{+,\ell} DiD_{+,\ell}}{\sum_{\ell=0}^{L} w_{+,\ell} DiD_{+,\ell}^D} \]  \hspace{1cm} (11)

IV. Identifying Assumptions

To establish a causal relationship from equation (9), two identifying assumptions must hold. The first one is called the "no anticipation" assumption. No anticipation imposes that neither hurricanes nor earthquakes can be predicted. In de Chaisemartin and D’Haultfoeuille (2021a) estimator, the assumption can be relaxed by allowing anticipation effects to start arising after a municipality has experienced a first treatment switch. This allows for the possibility that municipality’s outcome at time \(t\) be affected by their past and future treatments.

The second identifying assumption is called “parallel trends” condition. The parallel trends condition requires that outcomes of treated municipalities would have followed a similar path to the never-treated ones if they had not been hit by a hazard. de Chaisemartin and D’Haultfoeuille (2021a) propose placebo estimators to test these assumptions. There is no need to test the no anticipation assumption as it is not possible to predict the location (or path) and severity of an earthquake or hurricane a quarter or year in advance (e.g., to be captured by the evolution of my outcomes of interest). However, it tests the parallel trends condition using the proposed placebo estimators.

de Chaisemartin and D’Haultfoeuille (2021a) propose long-difference placebos to test the parallel trends assumption underlying \(\delta_+\), as presented in equation (12). These placebos mimic the actual estimators previously introduced in equation (5). However, instead of comparing the outcome evolution in post-treatment periods, placebos compare the outcome evolution of groups before treatment groups receive their first treatment (e.g., pre-treatment periods). Specifically,
long-difference placebos compare the outcome evolution between periods \( t - 2\ell - 2 \) and \( t - \ell - 1 \) instead of \( t - \ell - 1 \) to \( t \), where \( \ell \in \{0, \ldots, (T - 3)/2\} \) and \( t \in \{2\ell + 3, \ldots, T\} \).

\[
\text{DiD}_{+,t,\ell}^{pl} = \sum_{g:F_{g,1} = t-\ell} \frac{N_{g,t} N_{1t,\ell}}{N_{t,\ell}} (y_{g,t-2\ell-2} - r_{g,t-\ell-1}) - \sum_{g:F_{g,1} > t} \frac{N_{g,t} N_{nt}}{N_{nt}} (y_{g,t-2\ell-2} - r_{g,t-\ell-1})
\] (12)

Mechanically, this means that, unlike in equation (5), there is not baseline period used as the comparison period. In this case, the \( D_{+,t,\ell}^{pl} \) estimator tests if common trends hold for \( \ell + 1 \) periods.

For instance, let us assume a setting where \( T = 9 \), so \( 0 \leq \ell \leq 3 \). When \( \ell = 0 \), the placebo estimator compares the evolution of remittance levels from period \( t - 2 \) to \( t - 1 \). Likewise, when \( \ell = 1 \), the placebo estimator compares the evolution of remittance levels from period \( t - 4 \) to \( t - 2 \), and so forth until \( \ell = 3 \). Finally, as equation (6) does with estimands coming from equation (5), equation (13) averages long-difference placebos coming from equation (12), where \( \text{DiD}_{+,\ell}^{pl} \) is a placebo estimator mimicking \( \text{DiD}_{+,\ell}^{pl} \).

\[
\text{DiD}_{+,\ell}^{pl} = \frac{\sum_{t=2\ell+3}^{T} N_{1t,\ell} \text{DiD}_{+,t,\ell}^{pl}}{\sum_{t=2\ell+3}^{T} N_{1t,\ell}^{2}}
\] (13)

According to the authors, there are two main advantages of mimicking the actual estimators. First, this allows to test whether \( E[DID_{+,\ell}^{pl} | D] = 0 \) using a F-test, where the null hypothesis states that placebos are not different than zero (e.g., parallel trends hold). If we reject the null, the value of the placebo could be used to sign the bias coming from the estimand. Second, mimicking placebos is lined up with the partial identification approach proposed by Rambachan and Roth (2019). Their approach assumes that parallel trends do not need to hold exactly, and the magnitude of the placebos could be informative of the bias generated by existing pre-trends.
IV. The Fiscal Impacts of Natural Disasters

Introduction

Natural disasters disrupt economic activities by damaging infrastructure, human capital, and production facilities (Lis & Nickel, 2009). These disruptions are almost always local\textsuperscript{11} and are typically addressed by governments with post-disaster spending. However, the successful implementation of post-disaster projects is bounded by the budgetary capacity of local and national governments. This capacity is particularly constrained in developing countries, where limited resources could be a major obstacle to recovery (Clarke & Dercon, 2016).

In Mexico, municipal revenues are mainly composed of self-collected taxes and federal transfers. Municipal expenditures are defined by the Constitution of Mexico, which states that municipalities must oversee the provision of public services and local police as further described in Section II. In the case of external shocks such as natural disasters, local governments can call for financial support from federal officials via disaster declarations. As previously introduced in Chapter II, when SEGOB issues a declaration, federal officials cover up to 50 percent of the local reconstruction costs of public assets. While previous research has estimated the economic effects of federal aid (Del Valle et al., 2020), it has ignored the local fiscal consequences of the remaining response and reconstruction costs, which local governments completely cover.

In this Chapter, I aim to fill this research gap by asking the question (1) What are the effects of being hit by one or more natural disasters on government revenues and expenditures at the municipal level? To answer this question, I estimate the treatment effects of having been hit by one or more hurricanes, earthquakes, or both on the levels and composition of government revenues and expenditures at the municipal level. When estimating the treatment effects of natural disasters, I am indirectly able to assess whether local policy decisions deviate from federal criteria when distributing federal transfers to municipalities in the aftermath of a disaster.

In the estimations, I employ modern DiD estimators as previously introduced in Chapter III. The treatment indicator is denoted by the disaster declarations issued by SEGOB. While the

\textsuperscript{11} This is the case specially in geographically disperse economies as proposed by Horwich (2000).
outcome of interest is denoted by municipal public finance data published by the National Institute of Statistics and Geography (INEGI). On the revenues side, data on the overall revenues, local taxes, and federal transfers (earmarked and nonearmarked) is included. On the expenditures side, data on overall expenditures, services, infrastructure, social assistance, payroll, and debt is included. The analysis starts in 1999 with the beginning of the issuance of disaster declarations and it is truncated in 2019 to avoid noise in the treatment effect coming from the Covid-19 pandemic.

This work contributes to two main strands of literature. First, it contributes to the literature on the fiscal impacts of disasters, which has typically focused on developed economies by adding an analysis in a developing country. I introduce Mexico as a case study, where limited resources could be a major obstacle to recovery deriving in different findings than in developed economies. Moreover, the effects of having been exposed to multiple events are estimated, which responds to a slightly different question than previously studied. Previous research has estimated the effect of natural disasters by setting up staggered treatment designs (Deryugina, 2017). While economically interesting, I show that calculating the average cumulative effects is also relevant. Especially, to understand the effects on municipalities that have been hit multiple times.

The second strand focuses on the incentives created by fiscal federalism rules. In this Chapter, I set the null hypotheses for the estimations based on the observed fiscal federalism framework, that is, the fiscal responsibilities of each level of government and the federal criteria for the use of federal transfers. So, when estimating the ATE and ACE of natural disasters on the composition of local revenues and expenditures, I contribute to the literature by indirectly assessing whether local policy decisions deviate from federal criteria when distributing federal transfers to municipalities in the aftermath of a disaster. This is relevant in terms of policy as previous research for the Mexican case have found evidence that state level officials often do not follow federal criteria when distributing federal transfers to municipalities (Hernández Rodríguez, 2008; Hernández Trillo & Jarillo-Rabling, 2008; Timmons & Broid, 2013) and that subnational officials have little political incentives in increasing tax collection (CEEY, 2013; Cibils & Ter-Minassian, 2015; The World Bank, 2013).

Overall, the findings suggest that natural disasters change the composition of revenues and the spending priorities of municipal governments. On the revenues side, natural disasters have a statistically significant change in the composition of federal transfers. Municipalities hit by
hurricanes receive less earmarked transfers, but this change is offset by an increase in nonearmarked revenues. So, municipalities do not get more transfers, but they get more discretionary money. Municipalities hit by both hazards follow the same pattern, but these changes are not statistically significant. In the case of the 2017 earthquakes, municipalities received less earmarked transfers, but this decrease was not compensated by nonearmarked revenues driving a decline in total revenues.

These findings run counter to the hypothesis that federal expenditures rise in response to local disasters. But they are lined up with Timmons and Broid (2013), who found that state-level officials reallocate federal funds so municipalities can address different policies, including disasters. So, this finding contributes to the preexisting literature on the strategic behavior of state officials driven by the current fiscal federalism rules (Hernández Rodríguez, 2008; Hernández Trillo & Jarillo-Rabling, 2008).

On the expenditures side, municipalities hit by hurricanes decrease their services and assistance spending. This decline in public spending is offset by a statistically significant increase in the municipal payroll. Likewise, municipalities hit by the 2017 earthquakes decreased their services spending. Lastly, municipalities hit by both hurricanes and earthquakes increased their total expenditures driven by higher indebtedness levels. These findings suggest that the current fiscal rules also disincentivize municipalities to reallocate funds to implement post-disaster policies. However, it is unclear why municipal officials do not reallocate money to traditionally post-disaster priorities such as infrastructure and public assistance.

Finally, as Mexico lacks economic stabilization policies such as unemployment insurance or public medical payments, these changes in the spending priorities suggest that natural disasters could be having a large negative effect on the lives of the affected populations. This finding is the opposite of was has been found by Deryugina (2017), who concludes that victims in the US and developed countries are better insured against natural disasters than previously thought. Thus, the results contribute to the broader literature on disparities between developing and developed countries, as well as the one on regional disparities, income inequality, and poverty inside each country.

The rest of the Chapter is organized as follows. Section I introduces the literature on the economic and fiscal implications of natural hazards. Section II introduces the Mexican fiscal
federalism system. Section III describes the data, while Section IV presents the results. Finally, Section V discuss the policy implications.

I. Literature Review

The fiscal impacts of natural hazards have been relatively understudied compared to their economic consequences (Bazoumana & Strobl, 2013). In the economic impacts literature, there are mixed results on the effects of natural disasters. Noy (2009), Strobl (2011), Strobl (2012), and Felbermayr and Groschl (2014) have found negative consequences on the economy, which would be expected as the strike of a hazard could be disruptive for economic activities. In contrast, Albala-Bertrand (1993), Skidmore and Toya (2002), Noy and Bang Vu (2010), and Loayza, Olaberría, Rigolini, and Christiaensen (2012) have found positive effects arguing that disasters could lead to update the capital stock and adopt new technologies that would increase the economic output. However, there is some consensus that impacts tend to be local rather than national (Horwich, 2000; Klomp, 2016; Strobl, 2011, 2012), more negative in developing settings (Felbermayr & Groschl, 2014; Klomp, 2016; Noy, 2009), and that more research needs to be done in this area as local governments in developing settings are under-investigated due to the lack of data (Klomp, 2016; Strobl, 2012).

In this Chapter, I follow these last findings of the economic impacts literature and extends them to the fiscal impacts. To the best of my knowledge, the previous literature has not focused on a developing economy at the local level. Previous research have studied developing settings (Bazoumana & Strobl, 2013), or a combination of developed and developing (Lis & Nickel, 2009; Melecky & Raddatz, 2011; Noy & Nualsri, 2011) only at the national level. Meanwhile, others have focused on the local level (Chen, 2019; Deryugina, 2017; Miao, Hou, & Abrigo, 2018b), but all of them analyzed the USA.

At the national level, Lis and Nickel (2009) analyzed a sample of 138 countries to estimate the effect of weather related hazards on the change in the budget balance as percentage of GDP. Authors found that developing countries face a much larger effect on budget balances than advanced economies. This finding is consistent with Melecky and Raddatz (2011), who estimated the effect of damages related to natural hazards on government expenditures, revenues, and GDP using a sample of 81 countries. They found that on average budget, deficits increase only after
climatic disasters, but for lower-middle-income countries, the increase in deficits is widespread across all events.

Furthermore, Noy and Nualsri (2011) estimated and quantified the effect of damages associated with natural hazards on government consumption, revenues, payments, surplus, and debt using a sample of 42 countries. They found that, contrary to developed countries, developing ones decreased spending. Authors argued that this behavior is likely to worsen the adverse consequences of natural hazards on middle- and low-income countries. Finally, Bazoumana and Strobl (2013) traced the impacts of hurricanes on government spending, public investment, taxes, and debt in Caribbean countries. Contrary to Noy and Nualsri (2011) findings, authors found a positive and significant response of government spending. They also found that governments respond by engaging in short term deficit financing, which is consistent with the rest of the literature.

At the local level, Deryugina (2017) set up a staggered treatment design to estimate the impact of hurricanes on non-disaster government transfers to counties in the USA. The author found that hurricanes lead to increases in unemployment insurance and public medical payments, whose present value exceeds that of direct disaster aid. This implies that the fiscal costs of disasters have been underestimated, and that affected populations in countries with stabilization channels are better insured than previously thought. Likewise, Miao et al. (2018b) used the effect of damages related to natural hazards to estimate their impact on revenues, expenditures, debt issuance, and federal-state transfers in the USA. They found states increase expenditures and receive more federal transfers. Moreover, lined up with Deryugina (2017), authors pointed out that the increase in spending is largely financed by federal transfers, including non-disaster public welfare assistance.

Finally, Chen (2019) estimated the impact of damages associated with natural hazards on four indicators of financial condition\(^\text{12}\) of counties and cities of the state of New York. She found that damages coming from natural hazards are not significant when controlling fiscal institution variables. In other words, she found that the presence of fiscal institutions such as disaster reserves moderate the financial consequences of natural hazards. Overall, though the findings at the national

\[^{12}\text{The indicators were cash over total liabilities, assets over liabilities, fund balance over total revenues, and debt balance over total revenues.}\]
level suggest that fiscal consequences of natural disasters are different in developed and developing countries, to the best of my knowledge all research at the local level has focused on the USA. Hence, this work aims to contribute to the literature on developing countries by using Mexican municipalities as a case study.

II. Mexican Fiscal Federalism

A. Revenues

Mexico is a federation composed of 31 states and 2,454 municipalities. Its fiscal intergovernmental relations are regulated through the National System of Fiscal Coordination (NSFC). The NSFC was created in 1980 aiming to achieve fiscal coordination agreements to avoid double taxation. In the agreements, states gave up most of their tax powers to the federal government, in exchange for a share in federal tax revenues (Serna de la Garza, 2004). Specifically, states gave up their power to collect income, value added, and corporate taxes to get part of those revenues via federal transfers.

Federal transfers are split up into earmarked and non-earmarked. Non-earmarked transfers were created in 1980 as one of the outcomes of the NSFC. These transfers are distributed unconditionally among all states following guidelines established in the Fiscal Coordination Law (FCL). According to the FCL, states are incentivized to increase their economic activity and tax collection to receive more nonearmarked transfers (Peña Ahumada, 2011). Likewise, states must distribute, at least, 20 percent of their non-earmarked transfers to their municipalities.

Earmarked transfers were created in 1998 as part of a decentralization process driven by the transition to democracy (CEEY, 2013; Chiapa & Velázquez, 2011). As indicated by their name, earmarked transfers can only be spent as defined by federal officials. The spending guidelines are also established by the FCL. To tighten the restrictions of these transfers, the FCL divides them into policy specific funds (such as education, health, infrastructure, or public security) and local governments must send quarterly spending reports to federal officials. Some of the policy funds are targeted for states and others for municipalities, but as with nonearmarked transfers, all transfers must go through the states to reach the municipalities.

The condition that all funds must go through the states has encouraged opportunistic behavior of state officials, who often do not follow federal criteria when using, distributing, and monitoring
federal transfers (Hernández Rodríguez, 2008; Hernández Trillo & Jarillo-Rabling, 2008; Timmons & Broid, 2013). Hernández Trillo and Jarillo-Rabling (2008) found evidence that governors redistribute funds from an infrastructure fund to areas with more voters. While Timmons and Broid (2013) found evidence on the reallocation of all transfers to address different policies, including disasters.

Besides federal transfers, local governments can generate their own revenues collecting some taxes and fees. Most notably, municipalities can collect property taxes and some especial fees for the use of public infrastructure or the provision of specific public services. However, as federal transfers have increased, subnational officials have shown little interest in collecting their own revenues (CEEY, 2013; Cibils & Ter-Minassian, 2015; The World Bank, 2013). As a result, federal transfers represent the majority of their revenues. Figure 10 presents the evolution of the three main component of municipal revenues as reported by INEGI.

Figure 10 – Municipal Revenues

![Figure 10 – Municipal Revenues](image)

Source: Author's calculations based on INEGI.

B. Expenditures

On the expenditures side, municipal responsibilities are regulated by Article 115 of the Federal Constitution. This Article states that municipalities must “oversee the provision of water, sewage, public lighting, landfill management, local markets, graveyards, slaughterhouses, street paving, parks, local police, and the ones determined by state legislatures.” In practice, municipalities often take responsibility of additional functions such as the provision of public assistance (e.g., social
policy) or policies aiming economic development within their jurisdictions (Cabrero Mendoza, 2003).

Figure 11 summarizes the evolution of the main components of municipal expenditures as reported by INEGI. Most notably, payroll is the biggest component and represents around a third of their total expenditures. This could be driven not only by the size of local bureaucracies or police corporations, but also by pensions of retired bureaucrats. The second biggest component is the public infrastructure spending (e.g., street paving or public lighting), while services and assistance spending are the third and fourth biggest components. It is worth highlighting that, though public assistance is not part of municipal core spending responsibilities, it is the fourth most important spending component.

![Figure 11 – Municipal Expenditures](image)

Source: Author's calculations based on INEGI.

Finally, municipalities can also acquire debt in case their expected expenditures are higher than their expected revenues. Guidelines on municipal debt are established by both federal and state laws. However, debt acquisition requires some level of technical expertise that not all municipal bureaucracies have. As a result, municipal debt has remained at relatively low levels and concentrated in a small share of municipalities (IMCO, 2020; CEFP, 2021). Figure 12 summarizes the evolution debt levels as reported by INEGI.
C. External Shocks

As previously explained in Chapter II, local governments can call for financial support of federal officials following disasters. If the shock is a natural hazard, municipalities can request the issuance of a disaster declaration through their states. Disaster declarations are funded with a combination of a federally managed reserve fund called FONDEN and three layers of risk-transfer instruments. FONDEN\textsuperscript{13} receives a fixed share of the federal budget every year and was designed as a trust to carry forward unspent money. While the risk-transfer tools are composed by two layers of insurance and one layer of catastrophe bonds.

When SEGOB issues a disaster declaration, federal officials must provide recovery and reconstruction assistance for low-income households and public infrastructure. However, FONDEN only covers 50 percent of the reconstruction costs of local assets in the first event. This share could diminish to 25 percent in the second event and zero percent in the third and subsequent reconstruction efforts if local assets are not insured (The World Bank, 2012). By conditioning federal aid on insurance take up, the current system is designed to decentralize financing and improve access to insurance markets for local bureaucracies. The underlying idea of this setup is that stronger local bureaucracies are better in addressing the negative impacts of natural disasters, which are a local phenomenon. Regardless of the amount, municipal governments are only

\textsuperscript{13} FONDEN was created in 1996, but its trust was established in 1999.
responsible of organizing the bidding process and communicating the results to federal officials, who then transfer the funds directly to the companies. Hence, FONDEN transfers are not registered in the municipal books and the additional resources coming after the strike of natural hazards should not modify the regular flow of federal transfers.

Finally, previous research has found a relationship between electoral years and the issuance of declarations (Beltrán Pulido, 2015; Núñez Aguilar, 2018). A discretionary issuance of disaster declarations could undermine their validity as a treatment indicator that signals the occurrence of an event where damages go beyond the budgetary capacities of the treated municipality. However, previous research did not break down the analysis by type of hazard. This is not the case for hurricanes and earthquakes and test whether the issuance of a declaration is associated with the occurrence of a large event. First, declarations of these hazards need to be approved by a technical committee, which verifies the occurrence of the event and measures the intensity of the hazard to a predefined threshold. In the case of earthquakes the technical agency is CENAPRED, while for hurricanes is the National Water Commission (CONAGUA). For instance, in the case of hurricanes, the committee relies on a heavy rainfall and sustained wind speed rules (Del Valle et al., 2020).

Second, to test whether the issuance of a declaration is associated with the occurrence of a large event, I construct a dataset with the path and intensity of all hurricanes and earthquakes that have triggered the issuance of a disaster declaration and plots the density distributions to visually assess the relationship. This dataset captures the highest registered magnitude of any given hurricane or earthquake at the state level and includes a binary variable which indicates whether that event triggered a disaster declaration. Given this construction, it is expected that events with larger intensities have a higher probability of triggering a declaration.

For hurricanes, I use information of the National Oceanic and Atmospheric Administration\textsuperscript{14} (NOAA). NOAA provides detailed information on the path and magnitude of each hurricane using the Saffir-Simpson Scale. For earthquakes, I use information of the United States Geological Survey\textsuperscript{15} (USGS). The USGS provides detailed information on the epicenter and seismic wave of each earthquake using the Modified Mercalli Scale (MMS). Though the actual technical

\textsuperscript{14} For more details, please follow this link: https://coast.noaa.gov/hurricanes/#map=4/32/-80
\textsuperscript{15} For more details, please follow this link: https://earthquake.usgs.gov/earthquakes/map/
assessment to determine the issuance of a disaster declaration includes additional parameters (e.g., rainfall or length) and it is done at the municipal level, I argue that this visual assessment could be a useful proxy to test the validity of using disaster declarations as treatment indicators.

Figures 13 and 14 summarize the distribution of hurricanes and earthquakes by disaster declaration, respectively. For hurricanes, Figure 13 shows that states without declaration (grey) experienced lower magnitude compared to states with declaration (blue). However, there is a significant overlap between states with and without declarations in hurricanes coded in categories zero and one. This could be explained because the declaration was triggered by rainfall, not wind speed. So, the declaration was triggered by an additional dimension\textsuperscript{16} not captured in Figure 13. An in-depth analysis using rainfall data is beyond the scope of this Chapter, but previous research has shown the validity of using disaster declarations using heavy rainfall data (see Del Valle et al. (2020)). For earthquakes, Figure 14 shows that states without declaration (grey) experienced lower magnitude compared to states with declaration (blue). Unlike hurricanes, the overlap in the distributions is smaller. So, there is a clearer distinction in magnitude between states with and without declarations.

\textbf{Figure 13 – Distribution of Hurricane Disaster Declarations in the Saffir-Simpson Scale} \hspace{1cm} \textbf{Figure 14 – Distribution of Earthquake Disaster Declarations in the MSS}

Source: Author's calculations based on CENAPRED and NOAA. \hspace{1cm} Source: Author's calculations based on CENAPRED and USGS.

\textsuperscript{16} In the specific case of hurricanes coded as category zero, hurricanes did not pass over any given state, but the tails of the hurricane triggered rainfall.
D. Hypotheses

In this Chapter, I propose a set of hypotheses for municipalities hit by earthquakes or hurricanes based on the observed fiscal federalism framework, that is the fiscal responsibilities of each level of government and the federal criteria for the use of federal transfers. These hypotheses are tested in Section IV and further discussed their implications in Section V. On the revenues side, local taxes should not change as municipalities can only collect property taxes. Unlike consumption or income taxes (Lis & Nickel, 2009; Miao, Hou, & Abrigo, 2018a), the collection of property taxes should not be disrupted by a natural disaster.\textsuperscript{17} Federal transfers (including nonearmarked and earmarked ones) should not change as there is no legal mechanism that triggers an increase in these transfers after a natural disaster (Peña Ahumada, 2011). So, the null hypothesis for both nonearmarked and earmarked transfers is not expected change.

On the expenditures side, infrastructure spending should increase as federal aid is conditional on local governments having a budget counterpart to fully cover the remaining post-disaster expenses (SEGOB, 2011). So, the null hypothesis for infrastructure spending is an expected increase. For the remaining components there is not underlying legal mechanism to support setting null hypotheses. I follow previous research to set the remaining hypotheses. Social policy spending should increase as these events could disrupt economic activities and governments could increase non-disaster related spending as shown by (Deryugina, 2017) in the USA case. So, the null hypothesis for public assistance spending is expected increase.

Services spending and the municipal payroll should not change in the case of a natural disaster. Municipalities provide services such as local markets, graveyards, or slaughterhouses. The provision of these services should not be affected after a disaster. So, the null hypothesis is not expected change. Likewise, municipal payroll should not change as local officials are not in charge are only responsible of organizing the bidding process and communicating the results to federal officials, who then transfer the funds directly to the companies in charge of reconstruction efforts. So, the null hypothesis is also no expected change. Finally, public debt should increase as there are not expected changes on the revenues side, but there are expected increases in the expenditures

\textsuperscript{17} Even if the property is affected by the event, the tax rate is set following a municipal cadaster, which is not updated on an annual basis.
side (e.g., infrastructure and public assistance). So, the null hypothesis for public debt is an expected increase in indebtedness levels.

Deviations from this set of null hypotheses could be explained by the political economy literature. As described above, previous research has found strategic behavior of local officials when using, distributing, and monitoring federal transfers (Hernández Rodríguez, 2008; Hernández Trillo & Jarillo-Rabling, 2008; Timmons & Broid, 2013). Testing the specific causal mechanisms is beyond the scope of this Chapter, but possible hypotheses for future research are discussed in Section V.

III. Data

There are two main data sources used to conduct the analysis. First, municipal public finance data comes from INEGI. INEGI collects and systematizes administrative resources coming from both state and municipal governments. The dataset is an annual panel that goes from 1989 to 2019 and includes all the components of revenues and expenditures. However, I limit this dataset in two ways. First, the panel starts in 1999 to line it up with the start date of the issuance of disaster declarations. Second, the analysis is constrained to the main components of revenues and expenditures, which is set as components greater or equal than 10 percent of the total. For revenues, taxes and federal transfers (earmarked and nonearmarked) are included. While for expenditures, expenditures, debt, infrastructure, assistance, services, and payroll are included.

Public finance data covers all states and, at least, 80 percent of municipalities. However, to calculate DiD estimators using the approach outlined in Chapter III, the estimators requires observing municipalities over consecutive years and throughout the entire panel. After removing the observations that do not meet these criteria, the final sample includes 978 municipalities. Given that the estimations are calculated using a sample of the total number of municipalities, tests for internal and external validity of this sample are considered. For internal validity, the correlation between overall reporting and not reporting when a hazard strikes a municipality in any given year

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18 For more details, please follow this link: https://www.inegi.org.mx/programas/finanzas/
19 This latter requirement could be relaxed as long as municipalities are observed over consecutive periods. However, relaxing it would imply not using the same sample of municipalities for all dynamic effects.
is $-0.06$. Thus, the missing municipalities should not bias the estimations as being struck by an event does not affect the likelihood of reporting public finances.

For external validity, T-tests for revenues and expenditures conditional on being in sample are calculated. Results coming from T-tests reject the null hypothesis that there are no differences between in sample and out of sample, indicating that there is a statistically significant difference in the fiscal outcomes of in sample and out of sample municipalities. Figures 15 to 17 present the density distribution of in sample (grey) and out of sample (blue) municipalities. On the one hand, regardless of the fiscal outcome, there is a large overlap between both groups of municipalities. On the other hand, in sample municipalities have a thicker tail, which indicates more revenues, more expenditures, and better access to debt than out of sample municipalities. These characteristics should be considered when interpreting the results in Section IV.

**Figure 15 – Distribution of Revenues by Sample**

![Figure 15](image)

**Figure 16 – Distribution of Expenditures by Sample**

![Figure 16](image)

**Figure 17 – Distribution of Debt by Sample**

![Figure 17](image)

Notes: Author’s calculations based on INEGI.
Table 1 presents the summary statistics of the outcome variables. All values are presented in real 2019 MXN. The average revenues of a Mexican municipalities are over 300 million MXN with a large standard deviation and a maximum of over 10,847 million MXN. This means that the distribution of revenues is skewed to the right.\textsuperscript{20} Total expenditures follow a similar behavior as total revenues, with a mean over 316 million MXN and a maximum of over 13,480 million MXN. The average components of revenues and expenditures follow a similar pattern as the ones explained in Section II.

\begin{table}[h]
\centering
\begin{tabular}{|l|c|c|c|c|}
\hline
Outcome & Mean & Standard deviation & Min & Max \\
\hline
Total revenues & 301.66 & 732.38 & 1.09 & 10,847.38 \\
Taxes & 40.08 & 153.18 & 0.00 & 2,939.81 \\
Nonearmarked transfers & 106.83 & 250.51 & 0.00 & 4,150.73 \\
Earmarked transfers & 93.00 & 193.37 & 0.00 & 2,981.16 \\
Total expenditures\textsuperscript{1} & 316.56 & 781.20 & 1.09 & 13,480.14 \\
Debt & 14.89 & 73.10 & 0.00 & 3,621.53 \\
Infrastructure & 66.37 & 147.46 & 0.00 & 4,774.12 \\
Assistance & 30.40 & 96.25 & 0.00 & 2,058.78 \\
Services & 41.61 & 116.85 & 0.00 & 2,272.56 \\
Payroll & 105.12 & 284.11 & 0.00 & 5,211.27 \\
\hline
\end{tabular}
\caption{Summary Statistics}
\end{table}

\textsuperscript{1/} INEGI equals total revenues and expenditures, but the latter have additional components coded as debt. To differentiate between revenues and expenditures, I add up expenditures and debt.

Source: Author's calculations based on INEGI.

Second, to determine which municipalities have been treated, I use disaster declarations data published by SEGOB\textsuperscript{21} and put together by CENAPRED\textsuperscript{22}. This dataset covers disasters from 1999\textsuperscript{23} to 2019\textsuperscript{24}, and includes information about the type of event, main drivers of damages, as well as the start, publication, and end date. The treatment group is composed by 623 municipalities, while the control one has 355 municipalities.

\textsuperscript{20} So, the mean is greater than the median and the mode. In other words, most municipalities have lower revenues than the average and a smaller portion of them have significantly larger budgets.

\textsuperscript{21} SEGOB publishes them at the Official Journal of the Federation (DOF). For more details, please follow this link: https://www.dof.gob.mx/

\textsuperscript{22} For more details, please follow this link: http://www.atlasnacionalderiesgos.gob.mx/apps/Declaratorias/#

\textsuperscript{23} The first declarations were published in the 2000, but they were related to hazards that hit in 1999.

\textsuperscript{24} It includes information to date, but I truncate the dataset in 2019 to match the public finance dataset.
In terms of the empirical strategy, the literature is lacking a methodology that allows the estimation of the treatment effects of several treatments in a non-staggered design when the treatment A is not always received before than treatment B (de Chaisemartin & d’Haultfoeuille, 2022). For the third treatment group I had to relax the treatment assumption to estimate the effects of hurricanes and earthquakes as if their effects were the same type of treatment. As a result, the sample sizes for each subgroup are hurricanes (507), only earthquakes (50), and hit by both hazards (66). Municipalities hit by only hurricanes and both hazards are distributed throughout the entire panel, while municipalities hit by only earthquakes correspond to the 2017 big ones.25

Table 2 and Appendix A summarize disaster declarations by treatment type and number of treatments. On average, treated municipalities have experienced 2.5 events during the analysis period. The minimum number of disaster declarations per municipality was one, and the maximum was eleven. A small number of municipalities had more than one disaster declarations in the same year. However, as the fiscal outcomes data is aggregated at the year level, I only include the first declaration of any given year. Because hurricane and earthquakes hits and magnitudes are random, this procedure should not bias the estimates (Deryugina, 2017).

<table>
<thead>
<tr>
<th>Treatment Status</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Municipalities</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>978</td>
<td>20,538</td>
</tr>
<tr>
<td>Treated</td>
<td>1</td>
<td>11</td>
<td>2.5</td>
<td>623</td>
<td>13,083</td>
</tr>
<tr>
<td>Hurricanes</td>
<td>1</td>
<td>11</td>
<td>2.5</td>
<td>507</td>
<td>10,647</td>
</tr>
<tr>
<td>Earthquakes</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>50</td>
<td>1,050</td>
</tr>
<tr>
<td>Both treatments</td>
<td>1</td>
<td>8</td>
<td>3.8</td>
<td>66</td>
<td>1,386</td>
</tr>
<tr>
<td>Never-treated</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>355</td>
<td>7,455</td>
</tr>
</tbody>
</table>

Source: Author’s calculations based on SEGOB and CENAPRED.

IV. Results

In this Section, I summarize the results of the three treatment groups: hurricanes, earthquakes, and both treatments. The hurricanes and both treatments sections include the ATE and ACE

25 54 municipalities were hit by only earthquakes across four events. Four municipalities were hit in the first three events, while 50 were hit in the last one. This low number of switchers spread over a long period of time could lead to noisy estimations. So, I scoped down the estimations to focus only on the last event, which corresponds to the events of September 7th and 19th 2017.
estimands coming from equations (10) and (11), respectively. While the earthquakes section only includes the ATE estimands as the analysis was scoped down to focus only on one treatment. Also, I include the Joint Placebo Tests (JPT) using F-tests, where the null hypothesis states that long-difference placebos coming from equation (13) are not different than zero (e.g., parallel trends hold). Event study plots with the placebos, instantaneous, and dynamics effects for statistically significant outcomes are also included in the text.

Throughout the analysis, the outcome variable is specified in real MXN million as recent research have shown that parallel trends are sensitive to the chosen form of the outcome. For instance, if parallel trends hold for the mean of outcome \( Y_{g,t}(0) \), it generally won’t be the case\(^ {26} \) for \( \log(Y_{g,t}(0)) \) (Roth & Sant’Anna, 2021; Roth, Sant’Anna, Bilinski, & Poe, 2022). I tested this point taking the natural logarithm of the outcome and found that the parallel trends hold better using levels as pointed out in the literature. Finally, though I compare ATE and ACE estimands, I emphasize the results of ACE estimates given that municipalities have been hit up to eleven times during the period of analysis (see Table 2). So, it is likely that municipalities have received less federal aid in the second and subsequent events, magnifying the impacts of experiencing a natural disaster.

A. Hurricanes

Results on hurricanes impacts on revenues are presented in Table 3. Overall, I find that hurricanes do not have a statistically significant effect on total revenues. In this estimation, the null hypothesis holds when testing for parallel trends using the JPT \( p-value = 0.62 \). However, the composition of these revenues changes after experiencing one or more hurricanes. Hurricanes have a statistically significant negative effect on earmarked transfers, which decrease in 71.5 MXN million for one additional event. But a statistically significant positive effect on nonearmarked transfers, which increase in 77.1 MXN million for one additional event.

These changes are not statistically significant when looking at the total amount of federal transfers. So, municipalities are not getting more transfers, but they get more discretionary money. For both earmarked and nonearmarked transfers, the JPT rejects the null hypothesis that all placebos are not different than zero. However, as presented in Figures 18 and 19, placebos are

\(^{26}\) Or other monotonic transformations.
small in magnitude, much smaller than the actual estimates. This suggests that even if there are 
pre-trends not controlled by the proposed reduced form approach, their magnitude would only 
create a small bias in the estimates.
Table 3 – Hurricanes on Revenues

<table>
<thead>
<tr>
<th>Outcome</th>
<th>ATE</th>
<th>ACE</th>
<th>JPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenues</td>
<td>4.81</td>
<td>24.23</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>(16.45)</td>
<td>(78.47)</td>
<td></td>
</tr>
<tr>
<td>Taxes</td>
<td>-1.59</td>
<td>-7.34</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td>(2.30)</td>
<td>(10.97)</td>
<td></td>
</tr>
<tr>
<td>Transfers</td>
<td>0.94</td>
<td>5.62</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>(6.18)</td>
<td>(29.47)</td>
<td></td>
</tr>
<tr>
<td>Nonearmarked</td>
<td>16.07***</td>
<td>77.1***</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>(6.22)</td>
<td>(29.66)</td>
<td></td>
</tr>
<tr>
<td>Earmarked</td>
<td>-15.12**</td>
<td>-71.48**</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>(7.33)</td>
<td>(35.02)</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Estimations are computed by the Stata did_multiplegt command. Standard errors are estimated using 100 bootstrap replications clustered at the municipality level. The estimation has municipal-specific linear trends.

Figure 18 – Hurricanes on Nonearmarked  
Figure 19 – Hurricanes on Earmarked

Notes: To the right of zero, the figure shows the $\widehat{D}_{i,t}$ estimators of the effect of a first hurricane related disaster declaration on a municipal fiscal indicator in the year of the first event, and in later years. To the left, the figure shows the $\widehat{D}_{i,t}$ placebo estimators. At $x = -1$, the placebo is normalized to 0. So, $\widehat{D}_{i,t,0}$ is shown at $x = -2$, etc. 95% confidence intervals relying on a normal approximation are shown in red.

Regardless of the outcome variable, the ACE is always larger than the ATE (up to 6 times). In other words, calculating the ACE reveals that the average change in the composition of revenues is greater when municipalities are hit multiple times. So, experiencing multiple hurricanes
magnifies the increase in the amount of discretionary transfers and the decline in the amount of earmarked transfers that treated municipalities receive compared to never-treated ones. These changes hold and increase over time as presented in Figures 18 and 19.

Results on hurricanes impacts on expenditures are presented in Table 4. In aggregate, hurricanes do not have a statistically significant effect on total expenditures. In this estimation, the null hypothesis holds \((p − value = 0.75)\) when testing for parallel trends using JPT. However, the composition of these expenditures changes after experiencing one or more hurricanes. On the one hand, hurricanes have a statistically significant negative effect on public assistance and services, which decline 60.4 MXN million and services in 37.8 MXN million for one additional event, respectively.

On the other hand, hurricanes have a positive statistically significant effect on the payroll, which increases in 58.1 MXN million for one additional event. The null hypothesis holds when using JPT for assistance and payroll, but it is rejected for services \((p − value = 0.04)\). However, similar to the case of federal transfers, placebos are small in magnitude and behave around zero as presented in Figure 21. Long-difference placebos used in the JPT and dynamic effects for assistance and payroll are presented in Figures 20 and 22, respectively.

**Table 4 – Hurricanes on Expenditures**

<table>
<thead>
<tr>
<th>Outcome</th>
<th>ATE</th>
<th>ACE</th>
<th>JPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expenditures</td>
<td>12.23</td>
<td>59.66</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>(19.86)</td>
<td>(94.72)</td>
<td></td>
</tr>
<tr>
<td>Assistance</td>
<td>-12.70**</td>
<td>-60.41**</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>(5.41)</td>
<td>(25.77)</td>
<td></td>
</tr>
<tr>
<td>Services</td>
<td>-7.95***</td>
<td>-37.75***</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>(2.69)</td>
<td>(12.83)</td>
<td></td>
</tr>
<tr>
<td>Infrastructure</td>
<td>2.47</td>
<td>12</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>(7.94)</td>
<td>(37.77)</td>
<td></td>
</tr>
<tr>
<td>Payroll</td>
<td>12.07**</td>
<td>58.07**</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>(5.05)</td>
<td>(24.13)</td>
<td></td>
</tr>
<tr>
<td>Debt</td>
<td>7.42</td>
<td>35.42</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>(5.03)</td>
<td>(23.94)</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Estimations are computed by the Stata did_multiplegt command. Standard errors are estimated using 100 bootstrap replications clustered at the municipality level. The estimation has municipal-specific linear trends.
Notes: To the right of zero, the figure shows the $\text{DiD}_{x,t}$ estimators of the effect of a first hurricane related disaster declaration on a municipal fiscal indicator in the year of the first event, and in later years. To the left, the figure shows the $\text{DID}_{x,t,0}$ placebo estimators. At $x = -1$, the placebo is normalized to 0. So, $\text{DID}_{x,0}$ is shown at $x = -2$, etc. 95% confidence intervals relying on a normal approximation are shown in red.

Similar to revenues, the ACE is always larger than the ATE ($\text{up to 5 times}$) across expenditures outcomes. In other words, calculating the ACE reveals that the average change in the composition of expenditures is greater when municipalities are hit multiple times. So, experiencing multiple hurricanes magnifies the increase in payroll spending and the decline in services and social assistance spending of treated municipalities compared to never-treated ones. These changes hold and increase over time as presented in Figures 20 to 22.
B. Earthquakes

Results on earthquakes impacts on revenues are presented in Table 5. I find that the 2017 earthquakes had a statistically negative effect on total revenues, which decreased in 44.7 MXN million. This decline was driven by a statistically significant decline in federal transfers, which decreased in 38.2 MXN million. It is worth noticing that like with hurricanes, earthquakes have a negative statistically significant effect on earmarked transfers, which declined in 40.1 MXN million. However, unlike hurricanes, this decline was not compensated by a statistically significant increase in nonearmarked transfers. This imbalance led to a negative effect on total revenues.

Table 5 – Earthquakes on Revenues

<table>
<thead>
<tr>
<th>Outcome</th>
<th>ATE</th>
<th>JPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenues</td>
<td>-44.69**</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>(21.69)</td>
<td></td>
</tr>
<tr>
<td>Taxes</td>
<td>2.14</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>(7.87)</td>
<td></td>
</tr>
<tr>
<td>Transfers</td>
<td>-38.24*</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>(22.23)</td>
<td></td>
</tr>
<tr>
<td>Nonearmarked</td>
<td>1.82</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td>(5.67)</td>
<td></td>
</tr>
<tr>
<td>Earmarked</td>
<td>-40.07*</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>(21.42)</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Estimations are computed by the Stata did_multiplegt command. Standard errors are estimated using 100 bootstrap replications clustered at the municipality level. The estimation has municipal-specific linear trends.

When testing for parallel trends, the null hypothesis holds for total revenues and transfers, but not for earmarked transfers ($p – value = 0.08$). However, similar to the case of federal transfers, placebos are small in magnitude and behave around zero as in the case of hurricanes. So, the presence of pre-trends should not affect the interpretation of the treatment effects. Placebos and dynamic effects for revenues, transfers, and earmarked transfers are presented in Figures 23 to 25.
Figure 23 – Earthquakes on Revenues

Figure 24 – Earthquakes on Transfers

Figure 25 – Earthquakes on Earmarked

Notes: To the right of zero, the figure shows the $DiD_{x,f}$ estimators of the effect of a first earthquake related disaster declaration on a municipal fiscal indicator in the year of the first event, and in later years. To the left, the figure shows the $DiD_{x,0}^{pl}$ placebo estimators. At $x = -1$, the placebo is normalized to 0. So, $DiD_{x,0}^{pl}$ is shown at $x = -2$, etc. 95% confidence intervals relying on a normal approximation are shown in red.

Results on earthquakes impacts on expenditures are presented in Table 6. Overall, I find that earthquakes have a negative statistically significant effect on total expenditures, which decline in 66.2 MXN million. This result holds when using JPT to test for parallel trends ($p-value = 0.21$). Figure 26 summarizes the behavior of placebos and dynamic effects for total expenditures. The decrease in total expenditures is driven by a generalized decline in all of its components. However, only services have a statistically significant decline of 15.5 MXN million in municipalities hit by earthquakes, compared to the never-treated municipalities. In this estimation,
the null hypothesis holds when testing for parallel trends ($p$ – value = 0.24). The evolution of placebos and dynamic effects for public services is presented in Figure 27.

**Table 6 – Earthquakes on Expenditures**

<table>
<thead>
<tr>
<th>Outcome</th>
<th>ATE</th>
<th>JPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expenditures</td>
<td>-66.19*</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>(34.49)</td>
<td></td>
</tr>
<tr>
<td>Assistance</td>
<td>-2.49</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>(15.33)</td>
<td></td>
</tr>
<tr>
<td>Services</td>
<td>-15.53**</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>(6.44)</td>
<td></td>
</tr>
<tr>
<td>Infrastructure</td>
<td>-22.48</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>(17.13)</td>
<td></td>
</tr>
<tr>
<td>Payroll</td>
<td>-3.43</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>(4.96)</td>
<td></td>
</tr>
<tr>
<td>Debt</td>
<td>-21.49</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>(16.38)</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Estimations are computed by the Stata `did_multiplegt` command. Standard errors are estimated using 100 bootstrap replications clustered at the municipality level. The estimation has municipal-specific linear trends.
Figure 26 – Earthquakes on Expenditures

Figure 27 – Earthquakes on Services

Notes: To the right of zero, the figure shows the $\hat{D}_{i\delta}$ estimators of the effect of a first earthquake related disaster declaration on a municipal fiscal indicator in the year of the first event, and in later years.

To the left, the figure shows the $\hat{D}_{i\delta}^{\text{pt}}$ placebo estimators. At $x = -1$, the placebo is normalized to 0.

So, $\hat{D}_{i\delta}^{\text{pt}}$ is shown at $x = -2$, etc. 95% confidence intervals relying on a normal approximation are shown in red.

C. Both Treatments

Results on both treatments’ impacts on revenues are presented in Table 7. Regardless of the estimation, the ACE is always about three times larger than the ATE. This indicates that experiencing both treatments increases the magnitude of the treatment effects on revenues. However, regardless of the estimation, there are not statistically significant effects. The results in this subsection only describe the signs of the estimands, but do not claim causal relationships.

Overall, having been hit by both hurricanes and earthquakes has a positive but not statistically significant effect on total revenues and federal transfers. Noticeably, as in the case of hurricanes, there is a decrease in earmarked transfers, which is compensated by an increase in nonearmarked transfers. Likewise, there is a negative but also not statistically significant effect on local taxes. When testing for parallel trends, the null hypothesis is rejected in three (revenues, taxes, and earmarked transfers) of the five estimations.
Table 7 – Both Treatments on Revenues

<table>
<thead>
<tr>
<th>Outcome</th>
<th>ATE</th>
<th>ACE</th>
<th>JPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenues</td>
<td>25.98</td>
<td>88.22</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>(17.79)</td>
<td>(60.33)</td>
<td></td>
</tr>
<tr>
<td>Taxes</td>
<td>-4.11</td>
<td>-13.94</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>(5.82)</td>
<td>(19.75)</td>
<td></td>
</tr>
<tr>
<td>Transfers</td>
<td>3.59</td>
<td>12.22</td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td>(12.14)</td>
<td>(41.18)</td>
<td></td>
</tr>
<tr>
<td>Nonearmarked</td>
<td>18.29</td>
<td>62.1</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>(14.35)</td>
<td>(48.71)</td>
<td></td>
</tr>
<tr>
<td>Earmarked</td>
<td>-14.7</td>
<td>-49.88</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>(10.18)</td>
<td>(34.61)</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Estimations are computed by the Stata `did_multiplegt` command. Standard errors are estimated using 100 bootstrap replications clustered at the municipality level. The estimation has municipal-specific linear trends.

Results on both treatments’ impacts on expenditures are presented in Table 8. As in the case of revenues, the ACE is ~3.4 times larger than the ATE across indicators. This indicates that experiencing both treatments increases the magnitude of the treatment effects on revenues. Overall, I find that being hit by both treatments has a statistically significant increase in total expenditures, which increase in 128.8 MXN million for an additional event. When testing for parallel trends, the null hypothesis holds ($p-value = 0.23$). However, unlike previous cases, pre-treatment trends for total expenditures are not small in magnitude, which could be biasing the results. As presented in Figure 28, pre-treatment trends could be generating a downward bias to the estimated treatment effects.
Table 8 – Both Treatments on Expenditures

<table>
<thead>
<tr>
<th>Outcome</th>
<th>ATE</th>
<th>ACE</th>
<th>JPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expenditures</td>
<td>37.94*</td>
<td>128.79*</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>(20.28)</td>
<td>(68.77)</td>
<td></td>
</tr>
<tr>
<td>Assistance</td>
<td>1.91</td>
<td>6.53</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>(15.45)</td>
<td>(52.45)</td>
<td></td>
</tr>
<tr>
<td>Services</td>
<td>10.46*</td>
<td>35.51*</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>(5.78)</td>
<td>(19.61)</td>
<td></td>
</tr>
<tr>
<td>Infrastructure</td>
<td>-20.05</td>
<td>-68.06</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>(16.92)</td>
<td>(57.46)</td>
<td></td>
</tr>
<tr>
<td>Payroll</td>
<td>7.48</td>
<td>25.43</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>(6.96)</td>
<td>(23.63)</td>
<td></td>
</tr>
<tr>
<td>Debt</td>
<td>11.95**</td>
<td>40.56**</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>(4.98)</td>
<td>(16.91)</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Estimations are computed by the Stata did_multiplegt command. Standard errors are estimated using 100 bootstrap replications clustered at the municipality level. The estimation has municipal-specific linear trends.

The increase in total expenditures is mainly driven by a statistically significant increase in public services and debt, which increased by 35.5 and 40.6 MXN million for one additional event, respectively. When using JPT to test for parallel trends, the null hypothesis is rejected for public services ($p-value = 0.00$). As in the case of total expenditures, pre-treatment trends for services are not small in magnitude, which could be biasing the results (see Figure 28 and 30). As presented in Figure 30, pre-trends could be generating an upward bias of the estimated effects. In other words, this implies that I could be underestimating the effects on total expenditures but overestimating the effects on services. Placebos and dynamic effects for public debt are summarized in Figure 29.
Notes: To the right of zero, the figure shows the $DiD_{+}$ estimators of the effect of a first earthquake or hurricane related disaster declaration on a municipal fiscal indicator in the year of the first event, and in later years. To the left, the figure shows the $DI_{+, t}$ placebo estimators. At $x = -1$, the placebo is normalized to 0. So, $DiD_{+, 0}$ is shown at $x = -2$, etc. 95% confidence intervals relying on a normal approximation are shown in red.

V. Discussion and Policy Implications

Overall, my findings show that natural disasters change the composition of revenues and the spending priorities of municipal governments. Also, my findings reveal that these changes are magnified when a municipality has experienced multiple natural disasters. On the revenues side, natural disasters do not have a statistically significant effect on local tax collection. This finding
is lined up with the null hypothesis as property taxes should not be correlated with the business cycle. Also, these estimates are aligned with previous research that shows that municipal officials have little incentives or interest in increasing tax collection (CEEY, 2013; Cibils & Ter-Minassian, 2015; The World Bank, 2013). This would suggest that local officials do not strengthen their self-generated revenues even when they see their own emergency management capacities exceeded.

Contrary to local taxes, natural disasters have a statistically significant change in the composition of federal transfers. Municipalities hit by hurricanes receive less earmarked transfers, but this change is offset by an increase of nonearmarked revenues. So, municipalities do not get more transfers, but they get more discretionary money. Municipalities hit by both hazards follow the same pattern, but these changes are not statistically significant. In the case of the 2017 earthquakes, municipalities received less earmarked transfers, but this decrease was not compensated by nonearmarked revenues driving a decline in total revenues.

These findings are not aligned with the null hypotheses as there are not federal rules to explain these changes. But they are lined up with Timmons and Broid (2013), who found that state level officials reallocate federal funds so municipalities can address different policies, including disasters. This finding adds up to the preexisting literature on the opportunistic behavior of state officials driven by the current fiscal federalism rules (Hernández Rodríguez, 2008; Hernández Trillo & Jarillo-Rabling, 2008).

On the expenditures side, municipalities hit by hurricanes decrease their services and assistance spending. This decline in public spending is offset by a statistically significant increase in the municipal payroll. Likewise, municipalities hit by the 2017 earthquakes decreased their public services spending. While municipalities hit by both hurricanes and earthquakes increased their expenditures driven by higher indebtedness levels. Noticeably, regardless of the disaster, municipalities hit by one event do not register a statistically significant change in their infrastructure spending. These findings suggest that the current fiscal rules also disincentivizes municipalities to reallocate funds to implement traditionally post-disaster policies. However, it is unclear why municipal officials do not reallocate money to traditional post-disaster priorities such as infrastructure and public assistance.

As previously suggested in Section II, deviations from the null hypotheses could be explained by the political economy literature. In this case, opportunistic state-level officials could take advantage of disasters to break federal rules in the use of transfers, funnelling more discretionary
money to friendly municipalities. Opponents may be less likely question such transfers when people are suffering the effects of a recent disaster. Also, an increase in payroll spending could be explain by a form of patronage, where opportunistic officials set up a jobs for the boys dynamic. The political economy hypothesis is reinforced as these effects are persistent over time, which could imply that strategic officials take advantage of the more “permission structure” created by disasters to pursue their narrow political interests. Future research should focus on understanding the underlying mechanisms that explain these changes in the spending priorities.

Finally, as Mexico lacks economic stabilization policies such as unemployment insurance or public medical payments, these changes in the spending priorities suggest that natural disasters could be having a large negative effect on the lives of the affected populations. This finding is the opposite of was has been found by Deryugina (2017), who concluded that victims in the US and developed countries are better insured against natural disasters than previously thought. These results contribute to the broader literature on disparities between developing and developed countries, as well as the one on regional disparities, income inequality, and poverty inside each country. In Chapter V, I test the role of remittances, which could be filling the gap left by the lack of government response.

A. Limitations

The estimations of this Chapter are not exempt of limitations. First, I can only code one event per year as fiscal outcomes are aggregated at the annual level. This is relevant as in a few cases there was more than one treatment in the same year. The interpretation of the ACE estimands as the effect created by one unit change in treatment is not entirely clean. Second, the literature lacking a methodology that allows the estimation of the treatment effects of several treatments in a non-staggered design when the treatment A is not always received before than treatment B (de Chaisemartin & d’Haultfoeuille, 2022b). For the third treatment group, the treatment assumption needed to be relaxed to estimate the effects of hurricanes and earthquakes as if their effects were the same.
V. To Remit or To Migrate? Consumption Smoothers After a Disaster

Introduction

Natural disasters can represent a shock to income by negatively impacting economic activity, health, access to public services, and housing infrastructure. To cope with the negative impacts, agents can take ex-post actions by making use of savings (Luo & Kinugasa, 2020; Mechler, 2009; Skidmore, 2001; Xiong, Celebi, & Welfens, 2022), accessing credit (Berg & Schrader, 2012; Keerthiratne, 2017; Ratcliffe, Congdon, Teles, Stanczyk, & Martin, 2020), or migrating (The World Bank, 2016; Mbaye, 2017). Affected agents also can rely on external help through government transfers (Del Valle et al., 2020; Deryugina, 2017) or remittances provided by relatives living abroad (Bettin & Zazzaro, 2018; David, 2011; Mohapatra, Joseph, & Ratha, 2012; Yang, 2008).

In developing countries, the pool of post-disaster coping alternatives is reduced by lower levels of savings and financial inclusion combined with weaker governmental post-disaster response (Bruhn & Love, 2014; Clarke & Dercon, 2016; Del Valle et al., 2020; Navis et al., 2020). Therefore, previous research has shown that alternatives such as migration or remittances become more important. On the migration side, there is a growing number of articles studying climate change driven migration (The World Bank, 2016; Mbaye, 2017). On the remittances side, there is a group of articles that analyze drivers of remittances (Amuedo-Dorantes & Pozo, 2006; Borja, 2012; Chami, Fullenkamp, & Jahjah, 2003; Lucas & Stark, 1985; Vargas-Silva, 2009), including post-disaster related remittances (Bettin & Zazzaro, 2018; David, 2011; Mohapatra et al., 2012; Yang, 2008).

These two strands of literature are interconnected as levels of remittances are inversely correlated with the economic activity of the migrants’ country of origin. In other words, if natural disasters negatively impact income, there should be an increase in remittance levels as long as the business cycle is solid in the migration country, also known as host country (Borja, 2012). This is known as altruistic behavior of remitters to their home country (Amuedo-Dorantes & Pozo, 2006;
Chami et al., 2003; Lucas & Stark, 1985). Alternatively, deviations from the null hypothesis could be explained by two causal mechanisms channels.

First, instead of relying on remittances, agents could migrate to smooth consumption after a disaster (Bank, 2016; Cohen, 2004; Mbaye, 2017). This behavior should be more pronounced in municipalities with a higher propensity to migrate (Borjas, 1987; Chiquiar & Hanson, 2005; Cohen, 2004; Cortina & Ochoa Reza, 2008). Second, it is possible that a change in remittance levels could be explained by a shift from formal to informal delivery channels (Clemens & McKenzie, 2018; Ferriani & Oddio, 2019; Hernández-Coss, 2005). In this specific case, results would not represent a decrease in remittance levels. Instead, results would imply a decline in remittances sent through financial institutions such as the ones that administrative data captures with more precision and would solely represent a change in measurement error.

In this Chapter, I aim to build on the interconnection of these two literature strands by asking the question (2) What is the behavior of economic agents and their safety nets after being hit by one or more natural disasters? To answer this question, I test the altruistic behavior hypothesis by estimating the treatment effects of having been hit by one or more earthquakes, hurricanes, or both on remittance levels in Mexico. Likewise, when testing the underlying causal mechanisms, the role of access to financial infrastructure and migration as post-disaster coping alternatives to smooth consumption is tested. Specifically, I test whether remittances change in municipalities with higher migration indexes or lower access to financial services.

Previous research on Mexico has focused on the government’s post-disaster response. At the federal level, Del Valle et al. (2020) estimated the impacts of FONDEN on economic activities. At the local level, Chapter IV of this dissertation estimated the effects on the levels and composition of municipal revenues, expenditures, and debt. Findings coming from these articles are mixed. Del Valle et al. (2020) find that federal transfers improve municipalities’ economic activity compared to municipalities hit by an event just below the FONDEN payout cutoff in magnitude. On the contrary, Chapter IV found that the current fiscal rules disincentivize municipalities to reallocate funds to implement post-disaster policies. In this Chapter, I build on the idea that government aid may be insufficient, and that agents may look for additional post-disaster coping alternatives to smooth consumption, such as remittances or migration.

In the estimations, I employ DiD estimators introduced in Chapter III. The treatment indicator is denoted by the disaster declarations issued by SEGOB. While the outcome of interest is denoted
by remittances data published the Mexican Central Bank (Banxico). I rely on a quarterly panel that starts in 2013 when Banxico started publishing remittances data at the municipal level, and it is truncated in 2019 to avoid noise in the treatment effect coming from the Covid-19 pandemic.

Contrary to what has been found in previous research, my findings reveal that remittance levels decrease in municipalities hit by a disaster compared to never-treated municipalities. Also, my findings reveal that these changes are magnified when a municipality has experienced multiple natural disasters. Experiencing multiple earthquakes or both earthquakes and hurricanes has a statistically significant negative effect on remittance levels. These findings also reject the null hypothesis of altruistic behavior, which points out that remittance levels increase after a negative shock in income in the remitters’ home country. To better understand these findings further investigation is needed. However, in this Chapter, I test two underling causal mechanisms that could be part of an alternative hypothesis.

First, I test the role of migration as post-disaster coping alternative. I find that being hit by an earthquake or the combination of both earthquakes and hurricanes is associated with a statistically significant sharper decrease of remittance levels in municipalities with high migration rates compared to municipalities with medium or lower migration rates. Second, I test the role of remittances delivery channels as a change in remittance levels could be explained by a shift from formal to informal delivery channels. The findings reveal that being hit by an earthquake or the combination of both earthquakes and hurricanes has a statistically significant negative effect on remittance levels in municipalities without access to financial institutions compared to municipalities with access to financial institutions. However, these treatment effects are smaller than the ones in municipalities with high migration indexes, suggesting that choosing migration over remittances is the main driver of the decline in remittance levels.

These findings contribute to the literature in two ways. First, it contributes to the literature on the drivers of remittances and the impacts of disasters on remittance levels. Contrary to the literature consensus, results suggest that remittance levels decline after a disaster. This deviation from the consensus could be explain by two factors. Unlike previous research that has analyzed remittances flows at the country level, I exploit within country variation at the municipality level.

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27 It may be the case that the altruistic behavior switches in terms of migration rather than remittances. However, testing this change is beyond the scope of this Chapter.
This is particularly relevant as natural disasters tend to be a local not a national phenomenon (Horwich, 2000; Yang, 2008). Additionally, a substitution effect in the use of the safety net is captured. Specifically, agents take advantage of being part of a network of migrants to help them migrate, instead of receiving remittances.

It also contributes to the literature focused on migration, migration drivers, and the Mexico-US migration. Traditionally, this literature has focused on analyzing economic clusters, characteristics of labor supply, or the interdependencies between Mexico and the USA (Cohen, 2004; Massey & Espinosa, 1997; Rosenblum & Brick, 2011). However, it has ignored that some regions are more exposed to natural disasters and that this exposure has pushed agents to migrate. Therefore, finding that remittance levels decrease partly because agents in treated municipalities out-migrate after a disaster represents a novel way of understanding Mexican migration to the USA.

The rest of the Chapter is organized as follows. Section I fleshes out background information on Mexico’s levels of migrants and remittances. Section II introduces a theoretical framework for remitters behavior. Section III describes the data, and Section IV presents the results. Finally, Section V discusses the policy implications.

I. Migration and Remittances

Mexican migration to the USA has followed different trends over time. The first one was in 1910s and 1920s driven mostly by the Mexican Revolution and seasonal jobs in agriculture and construction in the USA. After a decline during the 1930s, migration started rising again with the setup of a guest worker program aiming to address short-term labor shortages during wartime called Bracero Program (1942-1964). Though the Program expired in the mid-1960s, the demand for low-skilled workers in the USA remained strong (Gonzalez-Barrera, 2021; Rosenblum & Brick, 2011). Labor demand together with negative economic shocks in the Mexican economy were the main drivers of a sharp rise in Mexican migration after the 1970s, which peaked in 2007 and has decreased since (Gonzalez-Barrera, 2021).
Mexican migrants to the USA have historically come from the center, west central, southern regions of the country. To capture this pattern, the National Population Council (CONAPO) created the Migration Intensity Index (MII). The MII is calculated with data coming from the 2000, 2010, and 2020 population censuses and is composed by five ordered categories ranging from very low to very high. According to this index, 13 of the 32 Mexican states and 715 of the 2,471 municipalities are the places of origin of most Mexican out-migrants. These regional trends are summarized in Figures 31 and 32.

![Figure 31 – MII by State](image1)

![Figure 32 – MII by Municipality](image2)

Source: Author's calculations based on CONAPO.

The large number of Mexicans living in the USA has translated to high remittance levels. As presented in Figure 33, remittances have continuously increased over time, except for a decline during the financial crisis (2008-2010) and another decline between 2012-2013 driven by an appreciation of the Mexican peso (BBVA, 2013). In October 2021, remittances reached a historical record of 4,822 million USD. In the 2013-2019 period, the period of analysis, remittances also registered a steady rise, reaching a peak of 3,393.7 million USD in August 2019. Of the total

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28 The MII is calculated with the inputs of four questions asked in the census, which include the share of households with migrants over the last five years, the share of households with migrants that migrated to the US and returned home over the last five years, the share of households with migrants that were in the US over the last five years but returned home by the time of the census, and the share of households that receive remittances. For technical details, please follow these links: [https://www.gob.mx/conapo/documentos/indice-absoluto-de-intensidad-migratoria](https://www.gob.mx/conapo/documentos/indice-absoluto-de-intensidad-migratoria) and [https://www.gob.mx/conapo/documentos/indice-de-intensidad-migratoria-mexico-estados-unidos](https://www.gob.mx/conapo/documentos/indice-de-intensidad-migratoria-mexico-estados-unidos)

29 The states of Aguascalientes, Chihuahua, Durango, Guanajuato, Guerrero, Hidalgo, Jalisco, Michoacán, Morelos, Nayarit, Oaxaca, San Luis Potosí, and Zacatecas.
remittances, 95 percent come from the USA where 97 percent of all Mexican emigrants reside (Israel & Batalova, 2020).

**Figure 33 – Historical Evolution of Remittances**

![Graph showing historical evolution of remittances](image)

Notes: The dotted lines denote the analysis period (2013-2019).
Source: Author’s calculations based on Banxico.

While remittance levels seem to be increasing over time, some articles argue that this change may be illusory and driven by changes in measurement or delivery channels (Clemens & McKenzie, 2018; Hernández-Coss, 2005). On the measurement side, new policies can come into place and change the way remittances are counted. As an example of this case, in 2002, a new regulation in Mexico required all money transfer companies to report the value of their remittances triggering a significant increase after the reform was implemented (De Luna Martinez, 2005; Dinarte, Jaume, Medina-Cortina, & Winkler, 2021). Before this reform, only data coming from commercial banks was included in the official estimates (De Luna Martinez, 2005).

On the delivery channels side, the Mexican Central Bank (Banxico) collects and systematizes formally registered remittances data coming from financial institutions (e.g., electronic transfers and money orders) and from informally distributed remittances (e.g., cash and in-kind) via surveys to international travelers. However, it is unlikely that informal remittances are captured with the same precision as formal ones (Cañas, Coronado, & Orrenius, 2006, 2007), and some research argues that informal remittances are sizable (Alarcón, Iñiguez, & Hinojosa-Ojeda, 1998; López, Escala-Rabadan, & Hinojosa-Ojeda, 2001). For instance, Dinarte et al. (2021) argue that the rise in remittance levels during the Covid-19 pandemic could be better explained by a shift from informal to formal channels to remit rather than an increase in total remittances.
The miscalculation problem coming from the delivery channel could be observed when comparing the spatial distribution of the MII (see Figures 31 and 32), with the ones of remittances and access to financial infrastructure as presented in Figures 34 and 35. When comparing these figures, it is possible to observe at least two examples of this pattern. First, the southern state of Oaxaca is classified as a state with high MII, but with low access to financial infrastructure. Therefore, remittance levels captured by Banxico are lower than in other states with similar MII. The same pattern is observed in border municipalities of the northern state of Chihuahua. These municipalities are classified in the group of high MII, but as they lack access to financial infrastructure, the official remittance levels are lower than in other parts of the country with similar MII and better access to financial institutions. Access to financial institutions is addressed as robustness check in the empirical sections of this chapter.

**Figure 34 – Spatial Distribution of Municipal Remittances by Decile**

**Figure 35 – Spatial Distribution to Financial Infrastructure by Municipality**

Source: Author’s calculations based on Banxico.  
Source: Author’s calculations based on CNBV.

**II. Theoretical Approach**

What is the behavior of economic agents and their safety nets after a disaster? To answer this question, in this Section, a theoretical relationship is developed and framed by the literature on remittances drivers and remittances after a disaster. Then, a set of hypotheses are derived to be empirically tested in Section IV.
To develop the theoretical framework, I closely follow and adapt Yang (2008). The underlying idea states that individual consumption should not be affected by idiosyncratic income shocks such as the ones produced by earthquakes or hurricanes. I build on the idea that government aid may be insufficient, pushing agents to look for additional post-disaster coping alternatives to smooth consumption, such as remittances.

Consider municipalities (or counties) in two countries: Mexico and the USA, indexed by $g$ and $h$, respectively. Let us have a representative household for each municipality or county in the United States with a within-period utility $U$ for state of nature $s \in S$ at time $t$. Let utility satisfy Inada conditions $U' > 0$ and $U'' < 0$, and be a function of consumption $c_{st}$. According to Yang (2008), for the allocation of risk between countries to be Pareto-efficient, the ratio of marginal utilities must be a constant equal to:

$$\frac{U'_g(c_{gst})}{U'_h(c_{hs_t})} = \frac{\omega_h}{\omega_g} \forall g, h, s_t, \text{and } t$$

Where $\omega_g$ and $\omega_h$ represent the Pareto weights, which make the marginal utilities proportional to each other in municipalities and counties of each country. By imposing a Pareto equilibrium, consumption in any given municipality cannot be improved without harming consumption in any given county. Now, assuming a constant absolute risk aversion function and solving for consumption in Mexico $c_{gst}$, we get equation (14). This equation represents the efficient risk-sharing relationship, which depends on two factors. First, the mean consumption in the USA $\bar{c}_{st}$. Second, a constant effect determined by Mexico’s Pareto weights $\mathcal{W}$ relative to the USA.

$$c_{gst} = \bar{c}_{st} + \mathcal{W} \quad (14)$$

Adapting Fafchamps and Lund (2003) and Yang (2008), let consumption in Mexico $c_{gst}$ be the sum of income $y_{gst}$ and remittances received in Mexico $r_{gst}$ coming from the USA. So, rewriting this relationship in equation (14) and solving for remittances, we get equation (15):

$$r_{gst} = y_{gst} + \bar{c}_{st} + \mathcal{W} \quad (15)$$

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Finally, let us assume that income in Mexico $y_{g,st}$ is composed by a permanent component $\tilde{y}_g$ and a transitory one $z_{g,st}$. In this setup, only the transitory component depends on the state of the world, which could be affected by exogenous shocks such as earthquakes or hurricanes. To assess this and adapting Yang (2008), we can transform equation (15) into an empirically testable specification as presented in equation (16).

$$ r_{g,st} = \alpha_g + \gamma_t + \beta D_{g,t} + \epsilon_{g,t} $$  \hspace{1cm} (16)

This equation follows a traditional TWFE specification with unit and time fixed-effects, a treatment indicator, and a random component. The outcome of interest is denoted by remittance levels in Mexico $r_{g,st}$. The treatment indicator is denoted by $D_{g,t}$, which represents the exogenous shock in the transitory component of income $z_{g,st}$. Likewise, the permanent component of income $\tilde{y}_g$ and Pareto weights $\mathcal{W}$ are denoted by a municipality fixed-effect $\alpha_g$. The mean consumption levels in the USA $\overline{c_q}$ are denoted by a time fixed-effect $\gamma_t$. Finally, there is a mean-zero error term $\epsilon_{g,t}$. Notice that equation (3) is equal to equation (16), which is equivalent to a TWFE setup. However, as previously introduced in Chapter III, TWFE approaches lead to biased estimations in setting with variation in treatment timing and heterogeneous treatment effects. As such, the estimators derived in Chapter 3 are used.

A. Hypotheses

Overall, there are three well established remittances drivers\(^{31}\), but only one of them has been associated with remitters’ behavior after an disaster. Previous research has found that remittance levels rise after a disaster hit (Bettin & Zazzaro, 2018; David, 2011; Mohapatra et al., 2012; Yang, 2008). The underlying idea states that remitters send extra money when there is a negative income shock in their home country, as it is often produced by natural disasters. This behavior is called altruistic behavior (Chami et al., 2003; Lucas & Stark, 1985).

Altruistic remitters need a strong business cycle in the host country as they rely on their salaries to remit (Borja, 2012). In other words, if natural disasters negatively impact income, there should

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\(^{31}\) The second is called investment or asset accumulation behavior, where agents remit as a pro-cyclical measure. In other words, agents remit seeking investment opportunities in a strong business in their home country (Vargas-Silva, 2009). The third is called insurance behavior, which is similar to altruistic hypothesis, but is associated with a way to hedge increasing income risks in the host country (Amuedo-Dorantes & Pozo, 2006).
be an increase in remittance levels as long as the business cycle is solid in the host country. This condition is empirically true over the analysis period (2013-2019), where the business cycle remained continuously strong in the USA and that trend was reflected in the low unemployment rate. The historical evolution of Latino unemployment in the USA is summarized in Figure 36.

**Figure 36 – Historical Evolution of Latino Unemployment Rate in the USA**

![Graph showing the historical evolution of Latino unemployment rate in the USA](image)

Notes: The dotted lines denote the analysis period (2013-2019).
Source: Author’s calculations based on U.S. Bureau of Labor Statistics.

I build on previous research findings and sets the altruistic behavior as the null hypothesis for the estimations derived from equation (16). Following this equation, the null hypothesis expects an increase in remittance levels in municipalities hit by a natural disaster compared to remittance levels in municipalities that do not experience disasters. Alternatively, deviations from the null hypothesis could be explained by two causal mechanisms channels.

First, instead of receiving more remittances as consumption smoothing, agents could migrate as a post-disaster coping mechanism (Bank, 2016; Cohen, 2004; Mbaye, 2017). And this behavior could be seen more pronounced in municipalities with a higher propensity to migrate (Borjas, 1987; Chiquiar & Hanson, 2005; Cohen, 2004; Cortina & Ochoa Reza, 2008). In this case, remittance levels decline as affected agents take advantage of having relatives abroad and migrate instead of receiving remittances and staying home.

Second, as previously described in Section I, it is possible that a change in remittance levels could be explained by a shift from formal to informal channels (Clemens & McKenzie, 2018; Ferriani & Oddio, 2019; Hernández-Coss, 2005). In this specific case, results would not represent
a decrease in remittance levels. Instead, results would imply a decline in remittances sent through financial institutions such as the ones that administrative data captures with more precision and would solely be a change in measurement error. The null and alternative hypotheses tested in this Chapter are summarized in Figure 37.

**Figure 37 – Hypotheses**

![Figure 37 – Hypotheses](source: Author)

III. Data

In this Chapter, four sources of data are used to conduct the analysis. First, remittances data comes from Banxico. Banxico collects and systematizes remittances data coming from financial institutions and surveys. As previously described, this dataset is composed of two main data sources. First, financial institutions provide information on electronic transfers and money orders, which represent almost the totality of remittances captured by Banxico’s dataset. Second, survey data captures information on cash and in-kind remittances. The dataset is a quarterly panel at the municipal level (2,471 municipalities) that goes from 2013 to 2022. However, I truncate the panel in 2019 to avoid noise in the treatment effect coming from the Covid-19 pandemic (N = 2,471 × 28 = 69,188).

Table 9 presents the summary statistics of remittances by year. All values presented are in real 2019 USD. Remittances sent to Mexican municipalities have continuously increased over time.

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32 For more details, please follow this link: [https://www.banxico.org.mx/publicaciones-y-prensa/informes-trimestrales/recuadros/%7BCBD8DCED-4C67-1E1E-834C-DA5CB1AFA7CF%7D.pdf](https://www.banxico.org.mx/publicaciones-y-prensa/informes-trimestrales/recuadros/%7BCBD8DCED-4C67-1E1E-834C-DA5CB1AFA7CF%7D.pdf)

33 This survey was conducted by Banxico until 2018. Starting in 2019, INEGI is conducting the survey.
On average, a municipality receives over 3 million USD with a large standard deviation and a maximum of over 159.15 million USD. This means that the distribution of remittances is highly skewed to the right. This condition is addressed in Section IV.

Table 9 – Summary Statistics for Remittances

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remittances</td>
<td>3.01</td>
<td>8.25</td>
<td>0</td>
<td>159.15</td>
</tr>
<tr>
<td>2013</td>
<td>2.47</td>
<td>7.09</td>
<td>0</td>
<td>137.22</td>
</tr>
<tr>
<td>2014</td>
<td>2.58</td>
<td>7.39</td>
<td>0</td>
<td>159.15</td>
</tr>
<tr>
<td>2015</td>
<td>2.71</td>
<td>7.35</td>
<td>0</td>
<td>105.52</td>
</tr>
<tr>
<td>2016</td>
<td>2.91</td>
<td>7.85</td>
<td>0</td>
<td>107.39</td>
</tr>
<tr>
<td>2017</td>
<td>3.21</td>
<td>8.50</td>
<td>0</td>
<td>114.93</td>
</tr>
<tr>
<td>2018</td>
<td>3.48</td>
<td>9.27</td>
<td>0</td>
<td>129.58</td>
</tr>
<tr>
<td>2019</td>
<td>3.70</td>
<td>9.79</td>
<td>0</td>
<td>129.09</td>
</tr>
</tbody>
</table>

Source: Author’s calculations based on Banxico.

Second, to determine which municipalities have been treated, I use disaster declarations data published by SEGOB and put together by CENAPRED. This dataset covers disasters from 1999 to 2022. However, given that the remittances data starts in 2013, declarations data is truncated to the same year to match the dataset of the outcome of interest. Truncating the dataset does not affect the empirical strategy as de Chaisemartin and D’Haultfoeuille (2021a) estimator allows for the possibility that municipality’s outcome at time \( t \) be affected by their past and future treatments (see Identifying Assumptions in Chapter III).

Disasters declarations data includes information about the type of event, main drivers of damages, as well as the start, publication, and end date of the event. I use this information to divide municipalities into treatment and control groups. The treatment group is composed by 1,312 municipalities, while the control one has 1,159 municipalities. I further divide the treatment group into three subgroups by treatment type. Dividing the treatment group is relevant for policy and methodological reasons. In terms of policy, earthquakes and hurricanes are different type of

\[34\] So, the mean is greater than the median and the mode. In other words, most municipalities have lower revenues than the average and a smaller portion of them have significantly larger budgets.

\[35\] As mentioned in Chapter IV, SEGOB publishes them at the DOF. For more details, please follow this link: https://www.dof.gob.mx/

\[36\] For more details, please follow this link: http://www.atlasnacionalderiesgos.gob.mx/apps/Declaratorias/

\[37\] As mentioned in Chapter IV, the first declarations were published in the 2000, but they were related to hazards that hit in 1999.
hazards that generate different types of effects and responses. For instance, hurricanes are more frequent and tend to be more harmful for coastal or flood prone areas.

In terms of the empirical strategy, there does not exist a methodology that allows the estimation of the treatment effects of several treatments in a non-staggered design when the treatment A is not always received before than treatment B (de Chaisemartin & d’Haultfoeuille, 2022). Specifically, whether a hurricane comes before an earthquake or vice versa may matter. For the third treatment group the treatment assumption is relaxed to estimate the effects of hurricanes and earthquakes as if their effects were the same type of treatment. As a result, the sample sizes for each subgroup are only earthquakes (477), only hurricanes (549), and hit by both hazards (285). In the estimation, each of these three subgroups is compared against the never-treated pool of control municipalities.

Table 10 and Appendix B summarize disaster declarations by treatment status and number of treatments. On average, treated municipalities have experienced 1.6 events during the analysis period. The minimum number of disaster declarations per municipality was one, and the maximum was six. A small number of municipalities had more than one disaster declarations in the same quarter. However, as the remittances data is aggregated at the quarterly level, I only include the first declaration of any given quarter. Because hurricane and earthquakes hits and magnitudes are random, this procedure should not bias the estimates (Deryugina, 2017).

<table>
<thead>
<tr>
<th>Treatment Status</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Municipalities</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2,471</td>
<td>69,188</td>
</tr>
<tr>
<td>Treated</td>
<td>1</td>
<td>6</td>
<td>1.6</td>
<td>1,312</td>
<td>36,736</td>
</tr>
<tr>
<td>Earthquakes</td>
<td>1</td>
<td>3</td>
<td>1.1</td>
<td>477</td>
<td>13,356</td>
</tr>
<tr>
<td>Hurricanes</td>
<td>1</td>
<td>5</td>
<td>1.3</td>
<td>549</td>
<td>15,372</td>
</tr>
<tr>
<td>Both treatments</td>
<td>1</td>
<td>6</td>
<td>2.8</td>
<td>286</td>
<td>8,008</td>
</tr>
<tr>
<td>Never-treated</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1,159</td>
<td>32,452</td>
</tr>
</tbody>
</table>

Source: Author's calculations based on SEGOB and CENAPRED.
Third, to identify which states and municipalities have more migration-prone populations, I use MII data from CONAPO. As previously described, the index is calculated with data coming from the 2000, 2010, and 2020 population censuses. The index is composed by five ordered categories ranging from very low to very high. For simplicity purposes, I collapse those categories into two main classifications. The first category encompasses municipalities or municipalities in states with high or very high migration indexes in any given year. While the second category incorporates states or municipalities with medium or lower migration indexes in any given year. 

Table 11 summarizes states and municipalities by the proposed MII classification. The summary of states and municipalities by MII and treatment type is presented in Appendix B.

<table>
<thead>
<tr>
<th>Type</th>
<th>Level</th>
<th>MII</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Earthquakes</td>
<td>Municipality</td>
<td>487</td>
<td>1,147</td>
</tr>
<tr>
<td></td>
<td>State</td>
<td>808</td>
<td>826</td>
</tr>
<tr>
<td>Hurricanes</td>
<td>Municipality</td>
<td>479</td>
<td>1,227</td>
</tr>
<tr>
<td></td>
<td>State</td>
<td>826</td>
<td>880</td>
</tr>
<tr>
<td>Both treatments</td>
<td>Municipality</td>
<td>445</td>
<td>998</td>
</tr>
<tr>
<td></td>
<td>State</td>
<td>852</td>
<td>591</td>
</tr>
</tbody>
</table>

Source: Author's calculations based on CONAPO.

Finally, to assess whether having easy access to financial institutions affects remittance levels after a disaster, data from the National Banking and Securities Commission (CNBV) is used. The CNBV publishes data on the availability of financial institutions by municipality. This data summarizes the availability of commercial banks, development banks, savings and loan cooperative institutions (socaps), and financial cooperative associations (sofipos), which represent the main infrastructure for remittance collection through the formal channel. Table 12 summarizes the availability of financial institutions by treatment and treatment status in 2019.

---

38 For more details, please follow this links: https://www.gob.mx/conapo/documentos/indice-absoluto-de-intensidad-migratoria and https://www.gob.mx/conapo/documentos/indice-de-intensidad-migratoria-mexico-estados-unidos

39 For more details, please follow this link: https://www.gob.mx/cnbv/acciones-y-programas/bases-de-datos-de-inclusion-financiera

40 Secondary infrastructure include non-financial access points such as pharmacies and the Telecommunications of Mexico (Telecomm) network.
Table 12 – Availability of Financial Infrastructure by Municipality

<table>
<thead>
<tr>
<th>Type</th>
<th>Infrastructure</th>
<th>Treated</th>
<th>Control</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earthquakes</td>
<td>Access</td>
<td>165</td>
<td>654</td>
<td>819</td>
</tr>
<tr>
<td></td>
<td>No Access</td>
<td>312</td>
<td>497</td>
<td>809</td>
</tr>
<tr>
<td>Hurricanes</td>
<td>Access</td>
<td>337</td>
<td>654</td>
<td>991</td>
</tr>
<tr>
<td></td>
<td>No Access</td>
<td>212</td>
<td>497</td>
<td>709</td>
</tr>
<tr>
<td>Both treatments</td>
<td>Access</td>
<td>96</td>
<td>654</td>
<td>750</td>
</tr>
<tr>
<td></td>
<td>No Access</td>
<td>190</td>
<td>497</td>
<td>687</td>
</tr>
</tbody>
</table>

Source: Author's calculations based on CNBV.

IV. Results

In this Section, I summarize the results of the three treatment groups: earthquakes, hurricanes, and both treatments. Each subsection includes the ATE and ACE estimates coming from equations (10) and (11) respectively, which is set as an unbiased empirical specification of equation (16). Also, I include the Joint Placebo Tests (JPT) using F-tests, where the null hypothesis states that long-difference placebos coming from equation (13) are not different than zero (e.g., parallel trends hold). Event study plots with the placebos, instantaneous, and dynamics effects are also included in the text.

Though ATE and ACE estimands are presented, the results of ACE estimates are emphasized since municipalities have been hit up to six times during the period of analysis (see Table 10). Experiencing multiple treatments is relevant to model remittances as results of Chapter IV show that natural disasters have a negative impact on services and social assistance spending. So, remitters may send more money to their relatives living in the affected municipalities if conditions deteriorate after multiple events. Likewise, some individuals may migrate after the first event, but the ones that initially decided to stay, may also migrate if conditions in their municipalities worsen in subsequent events.

As remittances data is highly skewed to the right, I test its behavior taking the natural logarithm to de-scale the effect of municipalities with high remittance levels (see Figure 38). Unlike in Chapter IV, parallel trends hold after taking the logarithm of the outcome variable. So, throughout the analysis, the outcome variable is specified as the logarithm of remittances. As a result of this monotonic transformation, all estimands should be interpreted as percentage changes. Finally, I
follow equation (17) to remove any seasonal component in the outcome of interest. This equation regresses the quarterly indicator of remittances $Q_{g,t}$ over the log of remittance levels $\log(r_{g,t})$ to capture the share of the behavior of the outcome variable explained by the seasonal component. Then, I get rid of that seasonal component by using the residuals from the equation (17) as the outcome of interest for the estimations (e.g., by using the share of the outcome not explained by the seasonal component).

**Figure 38 – Remittances by Treatment Status**

![Graph showing remittances by treatment status]

Source: Author's calculations based on Banxico, SEGOB and CENAPRED.

\[
\log(r_{g,t}) = \alpha + \beta Q_{g,t} + \varepsilon_g \]

(17)

**A. Earthquakes**

Results of earthquake impacts on remittances are presented in Table 13. Overall, earthquakes have a statistically significant negative cumulative effect on remittances, which decrease by 6.2 percent for one additional event. In this estimation, the null hypothesis holds when testing for parallel trends using the JPT ($p-value = 0.26$). Both long-difference placebos used in the JPT and dynamic effects showing the decline in remittances can be seen in Figure 39.
Table 13 – Earthquakes Results

<table>
<thead>
<tr>
<th>Outcome</th>
<th>ATE</th>
<th>ACE</th>
<th>JPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remittances</td>
<td>-0.57***</td>
<td>-6.24***</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>(0.10)</td>
<td>(1.15)</td>
<td></td>
</tr>
<tr>
<td><strong>Migration Index - Municipalities</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High and Very High</td>
<td>-0.97***</td>
<td>-10.58***</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>(0.15)</td>
<td>(1.72)</td>
<td></td>
</tr>
<tr>
<td>Medium or Lower</td>
<td>-0.41***</td>
<td>-4.51***</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>(0.10)</td>
<td>(1.13)</td>
<td></td>
</tr>
<tr>
<td><strong>Migration Index - States</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High and Very High</td>
<td>-0.68***</td>
<td>-7.4***</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td>(0.13)</td>
<td>(1.46)</td>
<td></td>
</tr>
<tr>
<td>Medium or Lower</td>
<td>-0.48***</td>
<td>-5.3***</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>(0.15)</td>
<td>(1.71)</td>
<td></td>
</tr>
<tr>
<td><strong>Financial Institutions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Access</td>
<td>-0.15**</td>
<td>-1.73**</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>(0.07)</td>
<td>(0.79)</td>
<td></td>
</tr>
<tr>
<td>No Access</td>
<td>-0.28**</td>
<td>-3.13**</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td>(0.13)</td>
<td>(1.49)</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Estimations are computed by the Stata did_multiplegt command. Standard errors are estimated using 100 bootstrap replications clustered at the municipality level. The Joint Placebo Test is a F-test where the null hypothesis states that all placebos are not statistically significant.
Figure 39 – Earthquakes on Remittances

Notes: To the right of zero, the figure shows the $DiD_{x,t}$ estimators of the effect of a first earthquake related disaster declaration on remittances at the quarter of the first event, and in later quarters. To the left, the figure shows the $DID^p_{x,t}$ placebo estimators. At $x = -1$, the placebo is normalized to 0. So, $DiD^p_{x,0}$ is shown at $x = -2$, etc. 95% confidence intervals relying on a normal approximation are shown in red.

When breaking down by migration index at the municipal level, earthquakes have a statistically significant larger cumulative impact on municipalities with high MII (10.6 percent) than in the ones with medium or lower MII (4.5 percent). This difference in the magnitude of the decline can be seen in the behavior of the dynamic effects presented in Figures 40 and 41. These results also hold when breaking down by migration index at the state level. After an earthquake, there is a larger statistically significant cumulative decline in remittances of 7.4 percent in states with high MII compared to municipalities in states with medium or lower MII, where remittances have a statistically significant cumulative decline of only 5.3 percent. Figures 42 and 43 summarize the behavior of the dynamic effects.

When testing for parallel trends, the null hypothesis holds in all estimations except when conditioning on municipalities in states with medium or lower MII ($p-value = 0.07$) as presented in Figure 43. In this figure, it is possible to observe a small downward bias in the placebos causing the rejection of the null hypothesis. However, placebos are small in magnitude, much smaller than the actual estimates. This suggests that even if there are pre-trends not controlled by the proposed reduced form approach, their magnitude would only create a small bias in the estimates.
Notes: To the right of zero, the figure shows the DiDi* estimators of the effect of a first earthquake related disaster declaration on remittances at the quarter of the first event, and in later quarters. To the left, the figure shows the DID* placebo estimators. At $x = -1$, the placebo is normalized to 0. So, DiDi* is shown at $x = -2$, etc. 95% confidence intervals relying on a normal approximation are shown in red.

Likewise, earthquakes have a larger statistically significant cumulative impact on municipalities without financial infrastructure (3.1 percent) compared to the statistically significant cumulative decrease in municipalities with at least one financial institution (1.7 percent). When testing for parallel trends, the F-test rejects the null hypothesis when conditioning on municipalities with access to financial institutions ($p-value = 0.09$). This rejection could be driven by the noise from both placebos and estimands, which can be seen in large confidence intervals as presented in Figures 44 and 45.
Regardless of the estimation, the ACE is always larger than the ATE (~11 times). In other words, calculating the ACE reveals that the average change in remittance levels is greater when municipalities are hit multiple times. When breaking down the analysis based on MII and access to financial services, the findings show that the decline in remittances is sharper in municipalities with migration-prone populations. This decline holds over time suggesting that remittance levels decline because affected individuals make use of their safety nets abroad and migrate as conditions in their home municipalities worsen after experiencing multiple events (see Figures 39 to 45).

B. Hurricanes

Results of hurricanes impacts on remittances are presented in Table 14. Regardless of the estimation, there are not statistically significant effects. So, results in this subsection only describe the signs of the estimands, but do not claim causal relationships. Like in earthquakes, hurricanes have a large ACE compared to the ATE across estimations (up to ~10 times). Hurricanes have a small cumulative negative effect on remittances of 0.5 percent for every additional event. When testing for parallel trends, the null hypothesis holds. However, placebos do not follow a well-defined upward or downward pre-trend. So, it is more difficult to assess whether the estimates are
being over- or under-estimated. Both long-difference placebos used in the JPT and dynamic effects showing the decline in remittances can be seen in Figure 46.

**Table 14 – Hurricanes Results**

<table>
<thead>
<tr>
<th>Outcome</th>
<th>ATE</th>
<th>ACE</th>
<th>JPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remittances</td>
<td>-0.05</td>
<td>-0.47</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>(0.06)</td>
<td>(0.56)</td>
<td></td>
</tr>
<tr>
<td><strong>Migration Index - Municipalities</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High and Very High</td>
<td>-0.15</td>
<td>-1.39</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>(0.10)</td>
<td>(0.88)</td>
<td></td>
</tr>
<tr>
<td>Medium or Lower</td>
<td>0.00</td>
<td>-0.08</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>(0.08)</td>
<td>(0.68)</td>
<td></td>
</tr>
<tr>
<td><strong>Migration Index - States</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High and Very High</td>
<td>0.04</td>
<td>0.39</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>(0.09)</td>
<td>(0.80)</td>
<td></td>
</tr>
<tr>
<td>Medium or Lower</td>
<td>-0.15</td>
<td>-1.17</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>(0.09)</td>
<td>(0.64)</td>
<td></td>
</tr>
<tr>
<td><strong>Financial Institutions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Access</td>
<td>-0.02</td>
<td>-0.11</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>(0.05)</td>
<td>(0.39)</td>
<td></td>
</tr>
<tr>
<td>No Access</td>
<td>-0.12</td>
<td>-1.21</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>(0.16)</td>
<td>(1.34)</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Estimations are computed by the Stata did_multiplegt command. Standard errors are estimated using 100 bootstrap replications clustered at the municipality level. The Joint Placebo Test is a F-test where the null hypothesis states that all placebos are not statistically significant.
Figure 46 – Hurricanes on Remittances

Notes: To the right of zero, the figure shows the $\text{DiD}_{x,t}$ estimators of the effect of a first hurricane related disaster declaration on remittances at the quarter of the first event, and in later quarters. To the left, the figure shows the $\text{DID}^\text{pl}_{x,t}$ placebo estimators. At $x = -1$, the placebo is normalized to 0. So, $\text{DiD}^\text{pl}_{x,0}$ is shown at $x = -2$, etc. 95% confidence intervals relying on a normal approximation are shown in red.

As in the case of earthquakes, when breaking down by migration index at the municipal level, hurricanes have a larger negative impact on municipalities with high MII (1.4 percent) than in the ones with medium or lower MII (0.08 percent). This result does not hold when breaking down by migration index at the state level. After a hurricane, remittances increase in 0.4 percent in states with high MII. In contrast, municipalities in states with medium or lower MII show a cumulative decrease 1.2 percent. The null hypothesis is rejected in three of the four estimations. It only holds in the estimation of high and very high MII at the state level. As in the previous estimation, placebos follow an erratic behavior, which make more difficult to assess whether the estimates are being over- or under-estimated. Figures 47 to 50 summarize the behavior of placebos and dynamic effects.
Notes: To the right of zero, the figure shows the $DiD_{x,\ell}$ estimators of the effect of a first hurricane related disaster declaration on remittances at the quarter of the first event, and in later quarters. To the left, the figure shows the $DiD_{x,\ell}$ placebo estimators. At $x = -1$, the placebo is normalized to 0. So, $DiD_{x,0}^{PT}$ is shown at $x = -2$, etc. 95% confidence intervals relying on a normal approximation are shown in red.

Lastly, hurricanes have a larger negative impact on municipalities without access to financial institutions (1.2 percent) than in the ones with access to at least one financial institution (0.1 percent). When testing for parallel trends, the null hypothesis is rejected in both cases. Also, the erratic behavior of the placebos persists regardless of the estimation and the result coming from the joint placebo test. This implies that municipalities only hit by hurricanes are fundamentally different that never-treated municipalities. In the Mexican case, this could be driven by the fact that treated municipalities are mostly coastal, where fishing and tourism could make migration a
less attractive alternative to smooth consumption compared to inland never-treated municipalities. Additional time-varying confounders are needed to make a cleaner comparison between never-treated municipalities and municipalities hit by hurricanes. Figures 51 and 52 summarize the behavior of placebos and dynamic effects.

\[ \text{Figure 51 – Hurricanes on Remittances in Municipalities with Financial Institutions} \]

\[ \text{Figure 52 – Hurricanes on Remittances in Municipalities without Financial Institutions} \]

Notes: To the right of zero, the figure shows the \( \hat{D}_{\text{iD}} \) estimators of the effect of a first hurricane related disaster declaration on remittances at the quarter of the first event, and in later quarters. To the left, the figure shows the \( \hat{D}_{\text{I-D}} \), placebo estimators. At \( x = -1 \), the placebo is normalized to 0. So, \( \hat{D}_{\text{iD}} \) is shown at \( x = -2 \), etc. 95% confidence intervals relying on a normal approximation are shown in red.

C. Both Treatments

Results of earthquake impacts on remittances are presented in Table 15. Overall, being hit by both treatments have a statistically significant negative cumulative effect on remittances, which decrease by 3.0 percent for one additional event. In this estimation, the null hypothesis is rejected when testing for parallel trends using the JPT (\( p - \text{value} = 0.02 \)). However, placebos are small in magnitude, much smaller than the actual estimates. Even if there are pre-trends not controlled by the proposed reduced form approach, their magnitude would only create a small bias in the estimates. Both long-difference placebos used in the JPT and dynamic effects showing the decline in remittances can be seen in Figure 53.
### Table 15 – Both Treatments on Remittances

<table>
<thead>
<tr>
<th>Outcome</th>
<th>ATE</th>
<th>ACE</th>
<th>JPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remittances</td>
<td>-0.54***</td>
<td>-3.01***</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>(0.10)</td>
<td>(0.55)</td>
<td></td>
</tr>
<tr>
<td>Migration Index - Municipalities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High and Very High</td>
<td>-0.65***</td>
<td>-3.86***</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>(0.16)</td>
<td>(0.95)</td>
<td></td>
</tr>
<tr>
<td>Medium or Lower</td>
<td>-0.48***</td>
<td>-2.57***</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>(0.11)</td>
<td>(0.61)</td>
<td></td>
</tr>
<tr>
<td>Migration Index - States</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High and Very High</td>
<td>-0.53***</td>
<td>-3.01***</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>(0.10)</td>
<td>(0.60)</td>
<td></td>
</tr>
<tr>
<td>Medium or Lower</td>
<td>-0.67</td>
<td>-2.93</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>(0.42)</td>
<td>(1.80)</td>
<td></td>
</tr>
<tr>
<td>Financial Institutions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Access</td>
<td>-0.09</td>
<td>-0.52</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>(0.09)</td>
<td>(0.47)</td>
<td></td>
</tr>
<tr>
<td>No Access</td>
<td>-0.3**</td>
<td>-1.74**</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>(0.13)</td>
<td>(0.75)</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Estimations are computed by the Stata `did_multiplegt` command. Standard errors are estimated using 100 bootstrap replications clustered at the municipality level. The Joint Placebo Test is a F-test where the null hypothesis states that all placebos are not statistically significant.
Notes: To the right of zero, the figure shows the $DiD_{+t}$ estimators of the effect of a first earthquake or hurricane related disaster declaration on remittances at the quarter of the first event, and in later quarters. To the left, the figure shows the $DID_{+t}$ placebo estimators. At $x = -1$, the placebo is normalized to 0. So, $DiD_{+t,0}$ is shown at $x = -2$, etc. 95% confidence intervals relying on a normal approximation are shown in red.

When breaking down by migration index at the municipal level, experiencing both treatments have a statistically significant larger cumulative impact on municipalities with high MII (3.9 percent) than in the ones with medium or lower MII (2.6 percent). This difference in the magnitude of the decline can be seen in the behavior of the dynamic effects presented in Figures 54 and 55. These results also hold when breaking down by migration index at the state level. In these estimations, experiencing both treatments is associated with a larger statistically significant cumulative decline in remittances of 3.0 percent in states with high MII compared to municipalities in states with medium or lower MII, where remittances have a non-statistically significant decline of only 2.9 percent for one additional event. Figures 56 and 57 summarize the behavior of the dynamic effects.

When testing for parallel trends, the null hypothesis holds in all estimations except when conditioning on municipalities in states with high or very high MII ($p-value = 0.04$) as presented in Figure 56. In this figure, it is possible to observe the placebo at $t - 6$ is creating a downward bias in the placebos causing the rejection of the null hypothesis. However, other than this particular placebo, placebos are small in magnitude, much smaller than the actual estimates. This suggests that even if there are pre-trends not controlled by the proposed reduced form approach, their magnitude would only create a small bias in the estimates.
Notes: To the right of zero, the figure shows the $DiD_{*,f}$ estimators of the effect of a first earthquake or hurricane related disaster declaration on remittances at the quarter of the first event, and in later quarters. To the left, the figure shows the $DiD_{*,f}^{pl}$ placebo estimators. At $x = -1$, the placebo is normalized to 0. So, $DiD_{*,f}^{pl}$ is shown at $x = -2$, etc. 95% confidence intervals relying on a normal approximation are shown in red.

Finally, experiencing both treatments have a larger statistically significant cumulative impact on municipalities without financial infrastructure (1.7 percent) compared to the non-statistically significant decrease in municipalities with at least one financial institution (0.5 percent). Moreover, when testing parallel trends, the null hypothesis holds for both estimations assessing the role of access to financial institutions. Placebos and dynamic effects are presented in Figures 58 and 59.
Figure 58 – Both Treatments on Remittances in Municipalities with Financial Institutions

Figure 59 – Both Treatments on Remittances in Municipalities without Financial Institutions

Notes: To the right of zero, the figure shows the $\text{DiD}_{*+t}$ estimators of the effect of a first earthquake or hurricane related disaster declaration on remittances at the quarter of the first event, and in later quarters. To the left, the figure shows the $\text{DiD}_{*+t}^\text{pl}$ placebo estimators. At $x = -1$, the placebo is normalized to 0. So, $\text{DiD}_{*+t}^\text{pl}$ is shown at $x = -2$, etc. 95% confidence intervals relying on a normal approximation are shown in red.

As in the previous two cases, regardless of the estimation, the ACE is always larger than the ATE ($\sim$ up to 6 times). In other words, calculating the ACE reveals that the average decline in remittance levels is greater when municipalities are hit multiple times. As in the case of earthquakes, when breaking down the analysis based on MII and access to financial services, the findings show that the decline in remittances is sharper in municipalities with migration-prone populations. This decline holds and increases over time suggesting that remittance levels decline because affected individuals make use of their safety nets abroad and migrate as conditions in their home municipalities worsen after experiencing multiple events (see Figures 53 to 59).

V. Discussion and Policy Implications

Contrary to what has been found in previous research, my findings reveal that remittance levels decrease in municipalities hit by a disaster compared to never-treated municipalities. Also, my findings reveal that these changes are magnified when a municipality has experienced multiple natural disasters. Experiencing multiple earthquakes or both earthquakes and hurricanes has a statistically significant negative effect on remittance levels. These findings reject the null
hypothesis of altruistic behavior\textsuperscript{41}, which points out that remittance levels increase after a negative shock in income in the remitters’ home country. To better understand these findings further investigation is needed. However, in this Chapter, I test two underlying causal mechanisms that could be part of an alternative hypothesis.

First, I test the role of migration as an alternative post-disaster alternative to smooth consumption. According to previous research on climate change migrants, instead of receiving more remittances as consumption smoother, agents migrate as post-disaster coping mechanism (Bank, 2016; Cohen, 2004; Mbaye, 2017). And this behavior could be seen more pronounced in municipalities with a higher share of migrants (Borjas, 1987; Chiquiar & Hanson, 2005; Cohen, 2004; Cortina & Ochoa Reza, 2008). I use the MII data constructed by CONAPO to divide sample into municipalities and municipalities in states with high or greater and medium or lower migration intensity. Experiencing an earthquake or both earthquakes and hurricanes has a larger impact on municipalities with high migration indexes compared to municipalities with medium or lower migration indexes.

Second, I test whether the change in remittance levels could be explained by a shift from formal to informal channels (Clemens & McKenzie, 2018; Ferriani & Oddio, 2019; Hernández-Coss, 2005). The underlying idea states that, if access to financial services plays a role, the decline in remittance levels should be sharper in municipalities without access to financial institutions. My findings suggest that experiencing an earthquake or the combination of both earthquakes and hurricanes has a statistically significant sharper negative effect on remittance levels in municipalities without access to financial institutions compared to municipalities with access to financial institutions. However, these treatment effects are smaller than the ones in municipalities with high migration indexes, suggesting that choosing migration over remittances is the main driver of the decline in remittance levels.

Therefore, findings coming from testing the alternative hypothesis suggest that remittance levels decrease partly because agents in treated municipalities out-migrate after a disaster. In other words, the affected agents migrate as part of their post-disaster coping alternatives to smooth consumption. Though these results are lined up with the emergent literature on climate change

\textsuperscript{41} It may be the case that the altruistic behavior switches in terms of migration rather than remittances. However, testing this change is beyond the scope of this Chapter.
migrants, these findings represent a novel way of understanding Mexican migration to the USA and regional disparities within the country.

Traditionally, this literature has focused on analyzing economic clusters, characteristics of labor supply, or the interdependencies between Mexico and the USA (Cohen, 2004; Massey & Espinosa, 1997; Rosenblum & Brick, 2011). However, it has ignored that some regions are more exposed to natural disasters and that this exposure together with lower levels of savings and financial inclusion combined with weaker governmental post-disaster response have pushed agents to migrate as part of their post-disaster coping alternatives to smooth consumption.

In terms of policy, these findings along with findings of the previous chapter of this dissertation suggest that the current risk-financing system could be improved. By conditioning federal aid on insurance take up, the current system is designed to decentralize financing and improve access to insurance markets for local bureaucracies. The underlying idea of this setup is that stronger local bureaucracies are better in addressing the negative impacts of natural disasters, which are a local phenomenon. However, the findings suggest that the current system is not strengthening municipal finance and it is causing outmigration in the affected municipalities. So, the system is not fulfilling its goal of decentralizing post-disaster financial channels while improving disaster response.

To understand which are the policy levers that could be pulled to improve this system, it is necessary to contextualize this policy problem in the broader research on the Mexican fiscal federalism. In this case, even if FONDEN rules were creating the desired incentives, the net outcomes could be different if state level officials take advantage of disasters to break federal rules in the use of transfers, funneling more discretionional money to friendly municipalities. Also, as municipal officials can get more discretionional money, they have no incentives to improve their access to insurance markets, or to spend that money in disaster response and recovery policies. Therefore, a potential leverage point could be a change in the Fiscal Coordination Law (LCF) that ensures that state-level officials follow federal criteria when using, distributing, and monitoring federal transfers.

A. Limitations

The estimations of this Chapter are not exempt of limitations. First, as remittances by municipality are aggregated at the quarterly level, only one event per quarter can be coded. This is relevant as in a few rare cases there was more than one treatment in the same quarter. So, the
interpretation of the ACE estimands as the effect created by one unit change in treatment is not entirely clean. Second, a methodology that allows the estimation of the treatment effects of several treatments in a non-staggered design when the treatment A is not always received before than treatment B (de Chaisemartin & d’Haultfoeuille, 2022) is lacking. The third treatment group I had to relax the treatment assumption to estimate the effects of hurricanes and earthquakes as if their effects were the same.

Finally, the characteristics of agents that decide to stay and use remittances as coping mechanisms are not captured. With remittances data aggregated at the municipal level, I only capture negative treatment effects. However, breaking down the analysis at the household level would also capture the characteristics of households that choose remittances over migration. Future research should analyze response mechanisms using data at the household levels.
VI. How Can We Better Evaluate Risk-Financing Tools? An Evaluation of the Mexican Catastrophe Bonds Program

Introduction

The risk of economic shocks related to natural hazards is expected to increase due to climate change and population movements to hazard-prone areas (IPCC, 2012, 2013). However, not all countries would be uniformly affected by these shocks. Governments of emerging economies more frequently face post-disaster deficits in financing reconstruction, response, and relief, which can severely affect their long-term development and their ability to finance needed social and economic programs (Cardenas, Hochrainer, Mechler, Pflug, & Linnerooth-Bayer, 2007). In this context, there is a critical need to evaluate and improve risk-financing instruments, which are policy tools that ensure post-disaster money for response and recovery operations.

Previous research has evaluated risk-financing instruments looking at their price (Dieckmann, 2010; Götte & Gürtler, 2020; Gurtler, Hibbeln, & Winkelvos, 2014; Härdle & López Cabrera, 2010; Morana & Sbrana, 2019), underlying modeling (Etzion, Kypraios, & Forgues, 2019), or their design (Baca & Jain, 2018; Cardenas, Hochrainer, Mechler, Pflug, & Linnerooth-Bayer, 2007; Michel-Kerjan, Zelenko, Cardenas, & Turgel, 2011; OECD & The World Bank, 2019). However, the literature is lacking more comprehensive evaluation frameworks that assess risk-financing tools using a broader range of criteria and reflecting the interests of a broader range of stakeholders.

In this Chapter, I aim to fill this research gap by asking the question (3) How can we better evaluate risk-financing tools? To answer this question, I propose a more general evaluation framework than what has been done in previous research. Then, this policy framework is used to evaluate the Mexican catastrophe bonds program as a case study. Mexico’s exposure to hazards and its leading use of CAT bonds makes it a good case study for highly exposed developing countries considering similar instruments. The CAT bonds program is the main risk-financing tool against large hazards of the Mexican government. It is comprised of parametric CAT bonds, which are designed to insure the country against its two costliest hazards: hurricanes and earthquakes. Mexico’s CAT bonds program is further described in Section II.
The proposed framework evaluates risk financing tools relative to eight criteria. These criteria can be divided into two groups following the CIPP evaluation model proposed by Stufflebeam (1983). The first group belongs to the input evaluation stage, which aims to identify designs that help achieve the desired results previously defined by government officials. In terms of risk-financing instruments, this group of criteria looks at the design of different risk-financing tools and match them with a set of previously defined needs. In the evaluation framework, this group includes criteria such as risk-layer alignment, proactiveness, and risk-management classification. Failing against these criteria would imply that the selected risk-financing instrument is not a good fit to fulfill the defined goals and should be changed.

The second group of criteria belongs to the process/product evaluation stages. These stages seek to identify whether the program is being implemented as planned, whether it is succeeding, or needs to be adjusted. Unlike in the input stage, the process/product evaluation stages are dynamic as the program implementation or success could change over time. Likewise, as the program implementation or success could differ across interests, these stages involve additional stakeholders such as taxpayers, insurance companies, or investors. In the proposed evaluation framework, this group includes criteria such as timeliness, transparency, exposure accuracy, pricing, and nonpayment risk. Failing against these criteria would imply that the selected risk-financing instrument needs to be adjusted to fulfill the defined goals.

Noticeably, the proposed evaluation framework does not incorporate the context stage of the CIPP model. In this phase, government officials identify the problem and set the objectives to be achieved. The proposed framework assumes that the needs assessment has already been done by officials. It helps them to choose, monitor, and adjust a risk-financing tool based on predefined goals. Likewise, though I have attempted to include all the relevant criteria available in the literature, further research may yield additional criteria or context specific dimensions that decisionmakers could consider when selecting or evaluating a risk-financing tool. This framework should be understood as a basic set of criteria with fairly general metrics that must be adapted to context specific dimensions and available data.

When illustrating how the proposed framework could be used against the Mexican case, results reveal that the Mexican CAT bonds program performs well against the criteria of the input evaluation stage. Mexican officials were looking for risk-financing tools which design allowed them to hedge ahead of time the financing risk coming from large hurricanes and earthquakes. By
design, CAT bonds meet these predefined needs because they are best suited to hedge risk coming from low probability, but high severity events such as large hurricanes and earthquakes (risk-layer alignment criterion). CAT bonds also allow officials to plan as the contracts are set up before the event hits (proactiveness criterion). Finally, CAT bonds are a sound tool to hedge risk as they allow officials to transfer post-disaster financing risk to a counterparty of investors (risk-management classification criterion).

However, results reveal that the Mexican CAT bonds program could be adjusted to improve its performance in the process/product evaluation stages. As presented in Section III, data on observed events suggests that there is a mismatch between financial damages and triggering events (exposure accuracy criterion). In the case of earthquakes, the only payout was triggered after the 2017 Chiapas earthquake, which was large in magnitude, but had relatively low associated damages. In contrast, payouts were not triggered after the 2017 Puebla earthquake, which has been the most destructive in recent Mexican history.

In the case of hurricanes, I find that the triggering central pressure thresholds were similarly likely to be triggered by very destructive and non-destructive storms. Moreover, when reviewing disaster declarations, rainfall, not central pressure, has been the most important driver of damages. This mismatch between financial damages and triggering events could be driven by problems in the underlying modeling, the selection of triggering parameters, or a combination of both. These findings are lined up with previous research that discusses the limitations of the risk modeling and triggering parameters (Artemis, 2016; Etzion et al., 2019).

Likewise, the program’s transparency has been decreasing over time (transparency criterion). Specifically, information on the insured areas and triggering parameters have become less transparent over time. This lack of transparency could diminish the public confidence in the program and restricts external evaluations of CAT bonds. Making these parameters more transparent could also be desirable because problems with the underlying model or triggering thresholds harm all the involved stakeholders.

In terms of pricing, Mexican officials have been paying more than the actuarially fair price (pricing criterion). Mexican officials have paid between 130 (e.g., Class C notes in the 2012 issuance) and 420 percent of the modeled expected loss (e.g., Class D notes for the 2009 issuance). Hence, officials have been systematically overpaying to hedge risk using CAT bonds. In terms of payout speed (timeliness criterion), the time needed for a CAT bond payout for Mexican officials
has fallen within the market average of three months. Finally, Mexican CAT bonds include more mechanisms to minimize the nonpayment risk than comparable tools (nonpayment risk criterion). Among the mechanisms, the collaboration with The World Bank stands out as it has provided more certainty to all the involved parties.

This Chapter improves the understanding of risk-financing tools in a way that may help policymakers. It is the first analysis of CAT bonds that articulates a broader set of criteria and perspectives to assess the program's performance in hedging catastrophic risk, rather than focusing on technical characteristics of bonds from an investor perspective. Using a more comprehensive evaluation framework could improve these contracts' suitability to the Mexican exposure to risk in subsequent bond issuances. Similarly, governments worldwide considering the use of similar instruments can apply or adapt the proposed evaluation framework to their own settings and determine the best risk-financing instrument for their situation.

The rest of the Chapter is organized as follows. Section I provides background on the CAT bonds market and introduces its literature. Section II lays out the policy evaluation framework and its metrics. Section III introduces the Mexican CAT bonds program to then illustrate how the proposed framework could be used against the Mexican case. Finally, Section V present the policy implications and the last section summarizes the concluding remarks.

I. Literature Review

A. The CAT Bonds Market

CAT bonds were first designed in 1997 when insurance companies reevaluated their risk exposure in coastal areas after Hurricane Andrew struck in 1992 (Polacek, 2018). A CAT bond is a security that has two main parties. The issuer (also known as risk-cedent) who transfers its risk to the second party called risk-taker, which is composed of capital markets investors. On the one hand, the bond pays the issuer if a predefined disaster risk is realized. On the other hand, CAT bonds are attractive to investors because their risks are uncorrelated with the business cycle and, hence, provide natural diversification (Financial Glossary, 2011; Polacek, 2018). As described in Figure 60, the CAT bonds market had a slow take-off during its first years, jumped up after Hurricane Katrina and then settled down during the 2008-2009 economic crisis. Since then, both bonds issuance and the amount outstanding have increased.
Based on their market share, there are at least three different types of CAT bonds as presented in Figure 61. The most common one, with around two-thirds of the market share, is called indemnity triggers. This bond works similarly to traditional reinsurance, where the policyholder pays a premium and the insurer agrees to pay for damages specified in the insurance policy that occur during the life of the contract (Polacek, 2015, 2018). The second most common is called industry loss index, which has a market share of around 20 percent (Artemis, 2021). Its payout is triggered when the insurance industry loss reaches a predefined threshold, and the aggregate losses are modeled by a third party. The third one is called parametric, this type of bond payouts when a predefined set of parameters on the characteristics of the event are met (e.g., magnitude, depth, and location) and represents over five percent of the market.
In terms of payout speed, the fastest types are the *industry loss* and *parametric*, which payout around three months after the triggering event (Polacek, 2018). On the contrary, payouts coming from *indemnity trigger* bonds take between two and three years (Artemis, 2021; Polacek, 2018). Payout speed is a function of the needed criteria to release the payout. *Industry loss* bonds have both a predefined model and threshold that speeds up the payout process (Polacek, 2018). Similarly, *parametric* bonds have a predefined both a third-party agency to verify the occurrence of the event and a set of triggering parameters make these bonds pay out within two or three months. Finally, the payout process is much longer for *indemnity trigger* bonds as actual damages need to be observed and verified.

### B. CAT Bonds Literature

The CAT bonds literature is diverse in topics and methods. In this review, I attempt to cover all the literature to extract relevant criteria to build a policy evaluation framework. In doing so, this review groups the literature into three groups: pricing, new triggering parameters or payment structures, and descriptions of the decisionmaking process and evaluations of different CAT bond issuances. Moreover, I frame each group of the literature in terms of the CIPP model.

The first and largest group focuses on understanding the CAT bonds prices. Within this group there are three strands. The first pricing strand proposes and tests economic valuation frameworks to estimate the price of the bonds (Coval, Jurek, & Stafford, 2009; Härdle & López Cabrera, 2010;

The second pricing strand studies the CAT bonds multipliers, which are a way to calculate the price as a ratio of the risk premium over the expected loss. Evidence in this area is mixed. Dieckmann (2010) shows that CAT bond multipliers equally between two and three times expected losses after controlling for bond-specific characteristics. Gurtler et al. (2014) estimate the impact of financial crisis and natural catastrophes on CAT bonds premiums. Within their results, authors find evidence that both events increase the premiums. Also, they find a positive correlation between premiums and corporate spreads. This finding could imply that CAT bonds are correlated with market movements. In other words, that CAT bonds are not entirely uncorrelated with the business cycle. Alternatively, Morana and Sbrana (2019) found evidence of significant undervaluation of global warming risk in the CAT bonds market.

The third pricing strand uses econometric techniques to analyze market inefficiencies when pricing CAT bonds. In particular, Götze and Gürtler (2020) found that the CAT bond market does not satisfy the demand for catastrophe risk transfer efficiently due to sponsor-related factors. Among them, the most important ones are the sponsor's tenure, market coverage, rating, credit default swap spread, and its ability to issue innovative "on the run" CAT bonds. Overall, as the pricing literature looks at the actual prices of CAT bonds, this literature could be placed as part of the process/product evaluation stage of the CIPP model.

The second group in the CAT bonds literature focuses on proposing new triggering parameters to minimize basis risk, that is, the discrepancy between the loss and the payment (Franco, 2010; Goda, 2015; Mousavi, Akkar, & Erdik, 2019). Specifically, Franco (2010) presented an algorithm to minimize the triggering error and applied it to propose areas to be insured in Costa Rica. Mousavi et al. (2019) studied the suitability of average peak ground acceleration (PGA) as a ground-motion proxy for parametric designs. They tested it using Monte Carlo simulations to create a case for Istanbul, Turkey. Their results showed that PGA could be used confidently for
parametric CAT bonds, particularly applications associated with dense coverage of seismic networks.

In the intersection between pricing and triggering parameters, Goda (2015) proposed a new payment structure to minimize basis risk. Specifically, the author presented a multiple-discrete payment structure to substitute the current station-intensity-based trigger method for binary payments and tested it in Vancouver, Canada. In other words, the author proposed a more flexible structure of multiple payments based on different intensities and locations, in replacement of the current binary payment structure. Similar to the pricing literature, this second group looks at the actual implementation of CAT bonds, this literature could be placed as part of the process/product evaluation stage of the CIPP model.

Finally, the third group of papers described the decisionmaking process and evaluations of different CAT bond issuances (Baca & Jain, 2018; Cardenas et al., 2007; Etzion et al., 2019; Michel-Kerjan et al., 2011; OECD & The World Bank, 2019). On the decisionmaking process side, Cardenas et al. (2007) and Michel-Kerjan et al. (2011) analyzed the Mexican case from the perspective of the risk cedent in the 2006 and 2009 bonds issuances. The OECD and The World Bank (2019) compared governments' practices in managing the financial implications of disasters, including a description of the Mexican risk-financing tools. Whereas Baca and Jain (2018) introduced CAT bonds' structure, value, and market dynamics, aiming to demystify these tools for debt managers. In doing so, the authors laid out a set of criteria that a decisionmaker should consider when choosing a risk-financing tool. In terms of the CIPP model, these criteria belongs to the input evaluation stage.

On the evaluation side, Etzion et al. (2019) analyzed all CAT bonds issuances through March 2016. The authors found that the statistical modeling which underlies CAT bonds is not demonstrably better than guesswork at predicting the financial consequences of extreme events. This would imply that, even if CAT bonds fulfill the criteria in the input evaluation stage, the actual implementation of the bonds could make them fail against the process/product evaluation stages of the CIPP model.

In this Chapter, all the relevant dimensions of the literature are brought together to build a comprehensive policy evaluation framework of risk-financing tools. Specifically, this policy framework brings together the input and the process/product evaluation stages, which so far have been separated in the literature. In the next Section, I flesh out the details of the policy evaluation
framework. Then, in Section III, I illustrate the proposed framework assessing the Mexican CAT bonds program.

II. Policy Evaluation Framework

The proposed framework evaluates risk financing tools relative to eight criteria. These criteria can be divided into two groups following the CIPP evaluation model proposed by Stufflebeam (1983). The first group belongs to the input evaluation stage, which aims to identify designs that help achieve the desired results previously defined by government officials. In terms of risk-financing instruments, this group of criteria looks at the design of different risk-financing tools and matches them with a set of previously defined needs. Failing against these criteria would imply that the selected risk-financing instrument is not a good fit to fulfill the defined goals and should be changed. In the evaluation framework, this group includes criteria such as risk-layer alignment, proactiveness, and risk-management classification.

The second group of criteria belongs to the process/product evaluation stages. These stages seek to identify whether the program is being implemented as planned, whether it is succeeding, or needs to be adjusted. Unlike in the input stage, the process/product evaluation stages are dynamic as the program implementation or success could change over time. Likewise, as the program implementation or success could differ across interests, these stages involve additional stakeholders such as taxpayers, insurance companies, or investors. Failing against these criteria would imply that the selected risk-financing instrument needs to be adjusted to fulfill the defined goals. In the proposed evaluation framework, this group includes criteria such as timeliness, transparency, exposure accuracy, pricing, and nonpayment risk.

In building this framework, I attempted to cover all the literature on fiscal resilience to disasters. However, further research may yield additional criteria or context specific dimensions that decisionmakers could consider when selecting or evaluating a risk-financing tool. This framework should be understood as a basic set of criteria with fairly general metrics that must be adapted to context specific dimensions and available data. In most cases, the term metrics is used as a general attribute of performance rather than a fully operationalized quantity. However, program evaluators are encouraged to use fully operationalized quantities when possible. Section IV further describes the limitations and potential extensions of this evaluation framework.
A. Policy Evaluation Framework

Input Stage

Risk-Layer Alignment

The first criterion is called risk-layer alignment. According to Baca and Jain (2018), Cardenas et al. (2007), and Michel-Kerjan et al. (2011) the expected costs of the underlying risk should be lined up with the characteristics of the selected risk-financing tool. For the former, these articles group natural hazards into three risk layers based on their expected costs. In other words, they divide hazards calculating their probability of materialization and expected severity of impact.\(^4\) Events with high probability of materialization, but low expected severity of impact are classified in the low-risk layer. Alternatively, events with low probability of materialization, but high expected severity of impact are categorized in the high-risk layer. Figure 62 represents the three risk layers.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure62.png}
\caption{Risk-Layer Alignment}
\label{fig:62}
\end{figure}

For the latter, these papers group risk-financing tools based on how their inherent characteristics match the expected costs in terms of opportunity costs. For instance, if officials want to use savings as a risk-financing strategy to address high-risk layer hazards, their opportunity cost would be very high. This is the case as officials would need lots of savings to pay for potentially severe events, but the probability of materialization of those events is very low. In this scenario, officials would be missing the opportunity to address other policy problems when saving that money. In terms of the policy evaluation framework metrics, if a risk-financing tool matches

\[^4\] Notice that, though the proposed division is discrete and qualitative, it is theoretically possible to calculate the expected costs of the exposure of any given country.
its corresponding risk-layer, this criterion is evaluated as appropriate. Figure 63 introduces how risk-financing tools are divided into three broad categories with some examples of each one.

Figure 63 – Risk-Layer Alignment Metric

![Risk-Layer Alignment Metric Diagram]

Source: Author based on Baca and Jain (2018).

Proactiveness

The second criterion is called proactiveness. According to Cardenas et al. (2007), Michel-Kerjan et al. (2011), and OECD and The World Bank (2019) officials should consider that some risk-financing tools are proactive or reactive by design. To do so, these papers divide risk-financing strategies into ex-ante and ex-post groups. Proactive tools are called ex-ante strategies, as they must be designed before the strike of the hazard. If well designed, they allow policymakers to plan and be prepared for an event. This group is composed of tools such as reserve funds, contingency budgets, contingency credits, insurance, or CAT bonds. Table 16 summarizes common ex-ante and ex-post risk-financing strategies.

Table 16 – Risk-Financing Strategies

<table>
<thead>
<tr>
<th>Ex-Ante</th>
<th>Ex-Post</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reserve fund:</strong> savings account that allows multiyear allocations.</td>
<td><strong>Budget reallocation:</strong> reallocation of money coming from other programs of the approved budget.</td>
</tr>
<tr>
<td><strong>Contingency budget:</strong> special budget program constrained to the fiscal year.</td>
<td><strong>Debt financing:</strong> issuance of government bonds.</td>
</tr>
<tr>
<td><strong>Contingency credit:</strong> predefined loans to be used in case of emergency.</td>
<td><strong>Taxation:</strong> increase or impose special taxes.</td>
</tr>
<tr>
<td><strong>(Re)insurance:</strong> risk-transferring contracts where the counterpart is (re)insurance companies.</td>
<td><strong>International borrowing:</strong> international loans.</td>
</tr>
<tr>
<td><strong>CAT bonds:</strong> risk-transferring contracts where the counterpart are the financial markets.</td>
<td><strong>International aid:</strong> donations coming from other countries.</td>
</tr>
</tbody>
</table>

Source: Author based on Cardenas et al. (2007), Michel-Kerjan et al. (2011), and OECD and The World Bank (2019).
Reactive tools are called ex-post strategies because they are a group of contingent policy alternatives to be chosen after the strike of a hazard. This group is composed of tools such as budget reallocation, debt financing, taxation, international borrowing, or international debt. As these tools are designed and implemented in the middle of an emergency, they are often insufficient and can lead to post-disaster deficits (Cardenas et al., 2007; Michel-Kerjan et al., 2011). This input stage criterion is usually constrained by the country’s level of development\(^{43}\) and the policy priorities\(^{44}\) of officials. However, in terms of the policy evaluation framework metrics, I evaluate as appropriate all risk-financing tools that belong to the ex-ante group. This is the case as these designs allow policymakers to plan for optimal post-disaster funding.

**Risk-Management Classification**

The third and last input stage criterion is called risk-management classification. According to Baca and Jain (2018) and Michel-Kerjan et al. (2011) officials should consider that risk-financing tools retain or transfer risk by design. For the former type, officials implicitly or explicitly assume the burden of the potential losses and act accordingly. For instance, one way to act accordingly is saving money in case of an emergency. This group is composed of tools such as reserve funds, contingency budgets, contingency credits, and all ex-post instruments. For the latter type, officials transfer the risk to a third party, who assumes the responsibility of paying the potential losses. In return, the third party gets predefined premiums or coupons. Table 17 summarizes the division of risk-financing strategies by risk management classification.

**Table 17 – Risk Management Classification**

<table>
<thead>
<tr>
<th>Risk-Retention</th>
<th>Risk-Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>All ex-post instruments</td>
<td>(Re)insurance</td>
</tr>
<tr>
<td>Reserve fund</td>
<td>CAT bonds</td>
</tr>
<tr>
<td>Contingency budget</td>
<td></td>
</tr>
<tr>
<td>Contingency credit</td>
<td></td>
</tr>
</tbody>
</table>

Source: Author based on Baca and Jain (2018).

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43 For instance, proactive strategies require a robust collection of revenue (e.g., to design a reserve fund or contingency budgets), access to credit (e.g., to get access to contingency credit lines), or access to financial markets (e.g., to issue CAT bonds).

44 For instance, as natural disasters are low-probability events, some officials could be willing to focus on other policy priorities and choose an ex-post strategy in case of a natural disaster.
Then, these articles match each risk-management type with a risk-layer of the risk-layer alignment criterion. In this relationship, the higher the expected costs (e.g., high-risk layer), the better it is to transfer risk, and vice versa; the lower the expected costs (e.g., low-risk layer), the better to retain risk. The underlying idea states that officials should transfer the risk of hazards in the high-risk layer as tackling it with their own resources (e.g., retaining it) may create fiscal imbalances. In terms of the policy evaluation framework metrics, if a risk-financing tool belongs to a risk-management type that matches the suggested risk-layer, the criterion is evaluated as appropriate. The relationship between risk-layers and risk-management classification is described in Figure 64.

**Figure 64 – Risk-Management Metric**

Source: Author based on Baca and Jain (2018).

**Process and Product Stages**

**Timeliness**

The first criterion is called timeliness. According to Baca and Jain (2018), Cardenas et al. (2007), and Michel-Kerjan et al. (2011) officials should set up risk-financing instruments that payout or grant access to their funds promptly. Having timely access to disaster-response funds could allow policymakers mitigate the potential losses of an event. In terms of the policy evaluation framework metrics, timeliness is the time to get access to the funds or payout.

Details on how quickly funds need to become available to mitigate losses are context specific as they are a function of the country’s risk-financing strategy and would need to be determined by policymakers. Regardless of the context specific details, the following comparisons are used. Timeliness can be compared against the payout speed of other risk-financing tools. Often times, there are no counterfactual payout speeds for different tools. The average payout speed of the market of each comparison tool is used. Also, in case the evaluated tool has already been modified
or issued in different occasions. To assess timeliness, the evolution over time is used. Finally, I propose to assess the time to get access to the funds considering the interest of different stakeholders. For instance, the affected governments or populations could be seeking a fast payout, but that objective may not be share by the risk-taker counterparty that must pay the associated costs.

**Transparency**

The second criterion is called transparency. According to Baca and Jain (2018), Cardenas et al. (2007), and Michel-Kerjan et al. (2011) transparency is especially important for investors. These authors refer specifically to risk-transfer tools such as CAT bonds, where investors are the risk-taker party and require all possible information of the risk they are taking. I build off this argument and expand it to all kinds of risk-financing tools using Basak and van der Werf (2019) framework. This way, the transparency criterion could be generalized, and its performance could be assessed across all the involved stakeholders.

Basak and van der Werf (2019) show that there is a principal-agent relationship in the climate change financing mechanisms. This relationship could lead to suboptimal results in cases where the agent’s incentives differ from those of the principal. One way to align incentives is by reducing the information asymmetries across stakeholders. Based on this idea, the more the tool's rules are transparent to all stakeholders, the more the information asymmetries are reduced and, therefore, the better the performance of the risk-financing tool. In terms of the policy evaluation framework metrics, transparency is the access level to the risk-financing tool rules.

For a more complete evaluation, the following comparisons are considered. Transparency can be compared against the access level to the rules provided by other risk-financing tools. Often times, there are no counterfactual payout speeds for different tools. the theoretical design of each comparison tool is used. Also, in case the evaluated tool has already been modified or issued in different occasions, transparency is assessed based on its evolution over time. Finally, as previously mentioned, the access level to the risk-financing tool rules of different stakeholders is considered. For instance, the affected governments or populations could be interested in hiding the real risks from the risk-taker counterparty that must pay the associated costs.
Exposure Accuracy

The third criterion is called exposure accuracy. According to Artemis (2016), Etzion et al. (2019), and Michel-Kerjan et al. (2011) the instruments’ payout rules should be lined up with the exposure to the hedged risks. These rules include the underlying model (Etzion et al., 2019), the triggering parameters (Artemis, 2016; Michel-Kerjan et al., 2011), or both. For instance, some risk-financing tools pay out the entire amount of validated losses, but some other pay out only when the event magnitude exceeds a predetermined threshold. If the payout threshold or triggering parameters are inaccurate, the payouts could be triggered in events with minor damages or not triggered even if an event cause major damages. Hence, it is fundamental to assess whether the modeling, triggering parameters, or both are meaningful indicators of hazard-related damages.

There are several overlapping ways to measure exposure accuracy. First, an evaluator could break down the underlying model to assess the validity of its assumptions. Second, an evaluator could analyze the performance of the triggering parameters when predicting damages. Third, an evaluator could compare the payouts against observed events. All options provide meaningful insights of exposure accuracy, and I encourage program evaluators to implement all of them when possible. However, in terms of the policy evaluation framework metrics, I propose to evaluate exposure accuracy by looking at the payouts in observed events. This approach may be the most straightforward way to evaluate this criterion as it neither requires the details of the underlying modeling (which are often infeasible due to copyright restrictions of the modeling agency), nor involves technical assessments of different triggering parameters.

For a more complete evaluation, I propose the following comparisons. I propose to assess exposure accuracy by looking at its evolution over time if the tool has already been modified or issued in different occasions. Also, I propose to evaluate the tool considering the interest of different stakeholders. For instance, there could be a scenario where payouts are triggered in both low- and high-damages events. Thus, harming the interests of the risk-taker. Finally, I do not believe that it is impossible to compare the exposure accuracy of the tool against the theoretical accuracy of other risk-financing tools. However, I encourage program evaluators to consider this dimension to the extent possible, as well.

Pricing

Criteria four and five are pricing and nonpayment risk. These criteria are characteristics of risk-transfer strategies, where a risk-cedent party transfers its risk to a risk-taker in exchange of a
predefined payment such as premiums or coupons. These criteria are targeted only for risk-transfer instruments.

Starting with pricing, according to Baca and Jain (2018), Cardenas et al. (2007), Härdle and López Cabrera (2010), and Michel-Kerjan et al. (2011) the instrument’s price should be attractive to all the involved parties. On the risk-cedent side, officials should choose instruments which price is within their budget constraints. On the risk-taker side, the price of premiums or coupons should be large enough to accept taking the potential costs. Thus, the price should be affordable for risk-cedents and profitable for investors.

Following these authors, in terms of the policy evaluation framework metrics, I evaluate price looking at the multiplier. The multiplier is the ratio of the price of the premium or coupon over the expected loss. In other words, it integrates the what the compensation of the risk-taker (e.g., premium or coupon) in exchange for covering the transferred risk (e.g., expected loss). If the outcome of the ratio is < 1, the risk-cedent is underpaying, and vice versa; if the outcome of the ratio is > 1, the risk-cedent is overpaying.

For a more complete evaluation, I propose the following comparisons. Pricing can be compared against the multipliers of other risk-financing tools. Often times, there are no counterfactual multipliers for different tools. The average multiplier of the market of each comparison tool is used. Also, in case the evaluated tool has already been modified or issued in different occasions, assessing pricing by looking at its evolution over time is important. Finally, the interest of different stakeholder is used to evaluate the multipliers. For instance, the risk-cedent party may be interested in keeping the ratio at or below 1. In contrast, the risk-taker party may be interested in keeping the ratio at or above 1.

Nonpayment Risk

The fifth criterion is called nonpayment risk. According to Baca and Jain (2018), Cardenas et al. (2007), and Michel-Kerjan et al. (2011) it is in the best interest of the involved parties to minimize the nonpayment risk. The risk-cedent party needs an instrument ready to payout without uncertainty. Alternatively, the risk-taker looks for investment instruments that assure an uninterrupted and certain payment of premiums or coupons.

In terms of the policy evaluation framework metrics, I evaluate nonpayment risk by looking at the mechanisms of any given tool that aim to minimize this risk. The lower the number of mechanisms, the higher the risk level, and vice versa; the greater the number of mechanisms, the
lower the risk level. For a more complete evaluation, I propose the following comparisons. The mechanisms of any given tool could be compared against the theoretical mechanisms by design of other risk-financing instruments. Also, in case the evaluated tool has already been modified or issued in different occasions, assessing the evolution of nonpayment risk is important. Finally, I propose to assess the mechanisms to minimize risk relative to the interests of the stakeholders. Table 18 summarizes all the evaluation criteria, and Table 19 summarizes each metric.
Table 18 – Summary of Evaluation Parameters

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>For all risk-financing instruments</strong></td>
<td></td>
</tr>
<tr>
<td>Risk-Layer Alignment</td>
<td>The characteristics of the selected risk-financing tool should be lined up with the expected costs of the underlying risk.</td>
</tr>
<tr>
<td>Proactiveness</td>
<td>Officials should consider that some risk-financing tools are proactive or reactive by design.</td>
</tr>
<tr>
<td>Risk Management Classification</td>
<td>Officials should consider that risk-financing tools retain or transfer risk by design.</td>
</tr>
<tr>
<td>Timeliness</td>
<td>Officials should aim for instruments that let them respond promptly.</td>
</tr>
<tr>
<td>Transparency</td>
<td>The rules, terms, and conditions of the tool should be transparent.</td>
</tr>
<tr>
<td>Exposure Accuracy</td>
<td>The instruments’ payouts should be lined up with the exposure to the hedged risks.</td>
</tr>
<tr>
<td><strong>For risk-transfer instruments</strong></td>
<td></td>
</tr>
<tr>
<td>Pricing</td>
<td>The price of the instrument should be attractive to all the involved parties.</td>
</tr>
<tr>
<td>Nonpayment Risk</td>
<td>It is in the best interest of the involved parties to minimize the nonpayment risk.</td>
</tr>
</tbody>
</table>

Source: Author.
Table 19 – Metrics

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>For all risk-financing instruments</strong></td>
<td></td>
</tr>
<tr>
<td>Risk-Layer Alignment</td>
<td>Match between risk-layers and risk-financing tools</td>
</tr>
<tr>
<td>Proactiveness</td>
<td>Ex-ante vs ex-post designs</td>
</tr>
<tr>
<td>Risk Management Classification</td>
<td>Match between risk-layers and risk-financing tools divided into risk-retention and risk-transfer</td>
</tr>
<tr>
<td>Timeliness</td>
<td>Time to get access to the funds or payout</td>
</tr>
<tr>
<td>Transparency</td>
<td>Access level to the risk-financing tool rules</td>
</tr>
<tr>
<td>Exposure Accuracy</td>
<td>Payouts in observed events</td>
</tr>
<tr>
<td><strong>For risk-transfer instruments</strong></td>
<td></td>
</tr>
<tr>
<td>Pricing</td>
<td>Price multiplier (coupon/expected loss).</td>
</tr>
<tr>
<td>Nonpayment Risk</td>
<td>Risk level</td>
</tr>
</tbody>
</table>

Source: Author.

III. Program Evaluation

This Section presents the results of the evaluation of the Mexican CAT bonds program used to illustrate the proposed policy framework. In doing so, I divide it into three subsections. First, the characteristics and goals of the Mexican CAT bonds program are introduced. Second, a set of scoping decisions to contextualize the evaluation of the program. Third, the results by criterion are fleshed out following the Metrics described in Section II.

A. The Mexican CAT Bonds Program

In 2006, Mexico became the first emerging economy to transfer part of its public-sector natural catastrophe risk to the international capital markets via CAT bonds (Cardenas et al., 2007). As previously introduced in Chapter II, the Mexican CAT bonds program is the last layer of a three-layer risk-financing strategy, where layer one covers minor events, layer two intermediate events, and layer three covers catastrophic events. In the Mexican case, the main goal of CAT bonds is
covering the associated costs coming from large earthquakes and hurricanes. Throughout this Section, I evaluate each criterion relative to this predefined goal.

The overall operating structure starts with the Mexican government transferring risk to an insurance company. By law, this company must be located in Mexico, and it has always been Agroasemex. Next, the insurance company transfers the risk to a reinsurance company (e.g., Swiss Re) in order to ensure its solvency. Thirdly, the reinsurance company sets up a derivative counterparty contract with a special purpose vehicle (SPV).

A SPV is a separate company created by a parent agency to isolate financial risk (making its obligations secure and assuring repayment to investors). Then, through the SPV, CAT bonds are issued as floating notes (e.g., bonds) to capital market investors. This way, the SPV hedges its obligations to the reinsurance company. Finally, the proceeds received from investors are deposited in a collateral account and invested in risk-free assets (such as treasury bonds). The design of the notes is carried out by a reinsurance company, an investment bank, or both. Figure 65 summarizes the CAT Bonds structure.

**Figure 65 – CAT Bonds Structure**

![Diagram of CAT Bonds Structure](image)

Source: Author.

Mexican CAT bonds have always been parametric. This means that a predefined payout is triggered only if the event exceeds the thresholds of predefined parameters. For example, for earthquakes, the triggering parameters are depth and magnitude by location. Whereas for hurricanes, the parameter is central pressure by location. If an event is realized, Mexican officials must notify a third-party agency (e.g., USGS or NOAA), which assesses the characteristics of the
event and informs the involved parties. In case the event triggered the parameters, Mexican officials get the payout through a special payment account.

Mexican officials have transferred earthquake and hurricane risks in six and four issuances, respectively. For earthquakes, the issuance years have been 2006, 2009, 2012, 2017, 2018, 2020. Whereas for hurricanes, the issuances took place in 2009, 2012, 2017, and 2020. The tenure of these contracts has varied between two to four years, and the coupons are fixed during that period. Table 20 summarizes the main characteristics of each issuance.

<table>
<thead>
<tr>
<th>Issuance Year</th>
<th>Total Insured Amount Million USD</th>
<th>Tenure Years</th>
<th>Special Purpose Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>160</td>
<td>3</td>
<td>CAT-Mex</td>
</tr>
<tr>
<td>2009</td>
<td>290</td>
<td>3</td>
<td>CAT Mex Multicat</td>
</tr>
<tr>
<td>2012</td>
<td>315</td>
<td>3</td>
<td>Multi CAT</td>
</tr>
<tr>
<td>2017</td>
<td>360</td>
<td>3</td>
<td>FONDEN CAT Bond</td>
</tr>
<tr>
<td>2018</td>
<td>260</td>
<td>2</td>
<td>Pacific Alliance CAT Bond</td>
</tr>
<tr>
<td>2020</td>
<td>485</td>
<td>4</td>
<td>FONDEN CAT Bond</td>
</tr>
</tbody>
</table>

Source: Author.

B. Data and Sources of Variability

Scoping Decisions

The first scoping decision constrains the evaluation of Mexican CAT bonds against three alternative risk-financing tools. First, all ex-post tools are disregarded as they can be insufficient, as they do not provide incentives for risk reduction (Linnerooth-Bayer, Mechler, & Pflug, 2005), and would represent a setback to the current more proactive planning in Mexico. Second, reserve funds and contingency budgets are removed after the recent elimination of FONDEN. Therefore, the Mexican CAT bonds program is compared against contingency credits, reinsurance (traditional and parametric), and other types of CAT bonds (indemnity trigger, industry index, and modeled loss).

The second scoping decision constrains the evaluation to three stakeholders. To narrow down the list, the core of the transaction focuses to identify two stakeholders: risk-cedent and risk-
The latter is represented by the investors, whereas the former is represented by two parties: government and taxpayers. Making this distinction allows the incorporation of the principal-agent framework used by Basak and van der Werf (2019), as the interests of these two members of the risk-cedent party are not always aligned when selecting risk-financing instruments. The relationship between stakeholders is summarized in Figure 66. Finally, the third scoping decision constraints the evaluation over time to specific time periods. To narrow down the list of years, only on the time periods of each of the six issuances of Mexican CAT bonds are considered, 2006, 2009, 2012, 2017, 2018, and 2020.

**Figure 66 – Stakeholders**

*Notes: This figure describes the relationship between stakeholders and risk-financing tools in the Mexican CAT bonds case. The top left side shows the relationship between the risk-cedent stakeholders: population and federal government, where taxpayers provide funding to the government in return of response and recovery operations. In the center, the federal government sets up risk-financing strategies to ensure its access to post-disaster funding. These risk-financing tools are composed of a reserve fund and CAT bonds. Finally, in the bottom right, investors are linked to CAT bonds by providing the principal amount when purchasing the bonds.*

*Source: Author.*

**Data and Sources of Variability**

According to the evaluation framework proposed in Section II, input stage criteria indicate whether the selected tool is the right one given a particular risk. By construction, these evaluation criteria can only be measured against alternative risk-financing tools. To assess the CAT bonds

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45 In contrast, intermediaries play only secondary roles that should be described but are not part of the main analysis.
program using the metrics for input stage criteria, I use the following data sources. First, to evaluate risk-layer alignment, I follow Baca and Jain (2018), Cardenas et al. (2007), and Michel-Kerjan et al. (2011). Second, to evaluate proactiveness, I follow Cardenas et al. (2007), Michel-Kerjan et al. (2011), and OECD and The World Bank (2019). Finally, to evaluate risk-management classification, I follow Baca and Jain (2018) and Michel-Kerjan et al. (2011). Table 21 summarizes the relationship between the evaluation criteria, sources of variability, and sources of data.

Table 21 – Sources of Variability

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Comparison / Variability</th>
<th>Source of Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk-Layer Alignment</td>
<td>Other tools</td>
<td>Baca and Jain (2018), Cardenas et al. (2007), Michel-Kerjan et al. (2011)</td>
</tr>
<tr>
<td>Proactiveness</td>
<td>Other tools</td>
<td>Cardenas et al. (2007), Michel-Kerjan et al. (2011), and OECD and The World Bank (2019)</td>
</tr>
<tr>
<td>Risk-Management Classification</td>
<td>Other tools</td>
<td>Baca and Jain (2018) and Michel-Kerjan et al. (2011)</td>
</tr>
<tr>
<td>Timeliness</td>
<td>Other tools, across stakeholders, itself over time</td>
<td>Artemis (2021), IMF (2021), Polacek (2018), CAT Bonds Report, and each of the six FTPS</td>
</tr>
<tr>
<td>Transparency</td>
<td>Other tools, across stakeholders, and itself over time</td>
<td>IMF (2021), Michel-Kerjan et al. (2011), Polacek (2018), Cardenas et al. (2007), CAT Bonds Report, and each of the six FTPS</td>
</tr>
<tr>
<td>Exposure Accuracy</td>
<td>Across stakeholders, itself over time</td>
<td>AIR Worldwide (2018), Bravo Lujano (2020), California Institute of Technology (2009), CENAPRED, INEGI (2021a), National Oceanic and Atmospheric Administration (2021), Servicio Geológico Mexicano (2017b), Servicio Sismológico Nacional (2021), Wisner, Blaikie, Cannon, and David (2003), and each of the six FTPS.</td>
</tr>
<tr>
<td>Pricing</td>
<td>Other tools, across stakeholders, and itself over time</td>
<td>Artemis (2021) and each of the six FTPS</td>
</tr>
<tr>
<td>Nonpayment Risk</td>
<td>Other tools, across stakeholders and itself over time</td>
<td>Baca and Jain (2018), Cardenas et al. (2007), Michel-Kerjan et al. (2011), and each of the six FTPS</td>
</tr>
</tbody>
</table>

Source: Author.
Likewise, based on the evaluation framework, parameters indicate whether the operational details of the selected tool can be improved. By construction, these evaluation criteria need actual data on the setup of the risk-financing instrument to be evaluated. In this case, to assess the CAT bonds program using the parameters’ metrics, I use the Mexican CAT bonds contracts, the country’s exposure, the underlying rationale of the Ministry of Finance when setting up the program, and other risk-financing strategies. Specifically, I follow four sources of information.

First, data on the CAT bonds program comes from the "Final Terms Pricing Supplements" (FTPS) for each CAT bond issuance. These documents were obtained through the Mexican Information Act (MIA) and add up to 1,451 pages about each contract's details, including the involved stakeholders, payouts, pricing, and triggering parameters. Second, information on the disasters' observed costs comes from CENAPRED. This data is publicly available and can be found in CENAPRED's reports\(^46\) and the transparency web page called open data\(^47\) (datos abiertos), managed by the federal government. Likewise, information on exposure to hurricanes and earthquakes comes from AIR Worldwide (2018), Bravo Lujano (2020), California Institute of Technology (2009), National Oceanic and Atmospheric Administration (2021), Servicio Geológico Mexicano (2017b), Servicio Sismológico Nacional (2021).

Third, data on the underlying rationale of the Ministry of Finance when setting up the program comes from the Ministry of Finance CAT Bonds Report (Memoria Documental: Bono Catastrófico). Similarly to the FTPS, it was obtained through the MIA. Fourth, data about other risk-financing instruments and the CAT bonds market comes from ARTEMIS,\(^48\) a news, analysis and data media service specialized in risk-transfer instruments. Additional data about the alternative risk-financing instruments comes from Baca and Jain (2018), Cardenas et al. (2007), IMF (2021), Michel-Kerjan et al. (2011), and Polacek (2018) as further described below.

Specifically, to evaluate timeliness, I follow Artemis (2021), IMF (2021), Polacek (2018), and each of the six FTPS. The first three data sources are used to compare the Mexican CAT bonds’ payout speed relative to other risk-financing tools. While the FTPS are used to compare the evolution of the payout speed over time and across stakeholders. To evaluate transparency, I follow

\(^{46}\) For more details, please follow this link: http://www.cenapred.unam.mx/PublicacionesWebGobMX/buscaindex

\(^{47}\) For more details, please follow this link: https://www.datos.gob.mx/busca/organization/cenapred

\(^{48}\) For more details, please follow this link: https://www.artemis.bm/
IMF (2021), Michel-Kerjan et al. (2011), Polacek (2018), Cardenas et al. (2007), the Ministry of Finance CAT Bonds Report, and each of the six FTPS. The first three data sources are used to compare the Mexican CAT bonds’ transparency relative to other risk-financing tools. While the last two data sources are used to evaluate their transparency across stakeholders and over time.

To evaluate exposure accuracy, I follow AIR Worldwide (2018), Bravo Lujano (2020), California Institute of Technology (2009), CENAPRED’s data about disasters’ observed costs, INEGI (2021a), National Oceanic and Atmospheric Administration (2021), Servicio Geológico Mexicano (2017b), Servicio Sismológico Nacional (2021), Wisner et al. (2003), and each of the six FTPS. The FTPS are used to assess the evolution over time of the bonds’ exposure accuracy. While the rest of the data sources are used to evaluate the accuracy across stakeholders. This criterion cannot be measured relative to alternative risk-financing tools because there are not counterfactual scenarios of the accuracy of other risk-financing strategies.

To assess pricing, I follow Artemis (2021) and each of the six FTPS. Both sources of information are used to evaluate the Mexican CAT bonds’ price relative to the price of other risk-financing tools. While the FTPS are used to compare the evolution of the payout speed over time and across stakeholders. Finally, to assess nonpayment risk, I follow Baca and Jain (2018), Cardenas et al. (2007), Michel-Kerjan et al. (2011), and each of the six FTPS. The first three sources of information are used to evaluate the Mexican CAT bonds’ nonpayment mechanisms relative to the mechanisms in other risk-financing tools. While the FTPS are used to compare the evolution of these mechanisms over time and across stakeholders.

C. Input Evaluation

The first input stage criterion is the risk-layer alignment. According to the metrics introduced in Section II, an appropriate risk-layer alignment is the one that matches the characteristics of the selected risk-financing tool with the expected costs of the hedged risk. To determine how well these characteristics are matched, I follow the framework proposed by Baca and Jain (2018), Cardenas et al. (2007), and Michel-Kerjan et al. (2011) as previously presented in Figure 63. These authors point out that risk-financing tools such as CAT bonds are appropriate when hedging against events in the high-risk layer given the low opportunity costs associated with their implementation. For instance, CAT bonds only require the payment of coupons which are a lower
financial burden that the required savings needed to pay for potentially severe events such as the want Mexican officials are seeking to hedge.

The same underlying reasoning could be followed when comparing CAT bonds relative to other risk-financing instruments. Insurance is an appropriate tool to hedge risk coming from the high-risk layer, and contingency credits to hedge risk coming from the medium-risk layer. Hence, based on the risk-layer alignment metric, any type of CAT bond or insurance would successfully fulfill this criterion. While contingency credit lines would be an incorrect alternative for the goals of Mexican officials. Based on the proposed metric and the predefined goals, Mexican CAT bonds successfully fulfill the risk-layer alignment criterion. The relationship between risk-layers and Mexican CAT bonds is summarized in Figure 67.

Figure 67 – Risk-Layer Alignment Results

Source: Author based on Baca and Jain (2018).

The second input stage criterion is proactiveness. According to the metrics, proactive risk-financing tools are preferred over reactive ones, as the former allow policymakers to plan for optimal post-disaster funding. To determine which tools are proactive and reactive, I follow the categorization proposed by Cardenas et al. (2007), Michel-Kerjan et al. (2011), and OECD and The World Bank (2019), as previously presented in Table 16. As CAT bonds are set up to hedge risk from future events, they allow for optimal planning and are categorized as a proactive risk-financing tool. Based on the proposed metric, Mexican CAT bonds successfully fulfill the proactiveness criterion.

The same underlying reasoning could be followed when comparing CAT bonds relative to other risk-financing instruments. In this case, insurance and contingency credit lines also allow for optimal planning as they hedge risk from future events. Hence, based on the proactiveness metric, any type of CAT bond, insurance, or contingency lines of credit would successfully fulfill this
criterion. The relationship between proactiveness and Mexican CAT bonds is summarized in Table 22.

### Table 22 – Proactiveness Results

<table>
<thead>
<tr>
<th>Ex-Ante</th>
<th>Ex-Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reserve fund</td>
<td>Budget reallocation</td>
</tr>
<tr>
<td>Contingency budget</td>
<td>Debt financing.</td>
</tr>
<tr>
<td>Contingency credit</td>
<td>Taxation</td>
</tr>
<tr>
<td>(Re)insurance</td>
<td>International borrowing</td>
</tr>
<tr>
<td>CAT bonds</td>
<td>International aid</td>
</tr>
</tbody>
</table>

Source: Author based on Cardenas et al. (2007), Michel-Kerjan et al. (2011), and OECD and The World Bank (2019).

The third and last input stage criterion is risk-management classification. According to the metrics, a correct risk-management classification is the one that matches the risk-retention or risk-transfer characteristics of the tool with the expected costs of the hedged risk. To determine how well these characteristics are matched, I follow the framework proposed by Baca and Jain (2018) and Michel-Kerjan et al. (2011), as previously summarized in Figure 64. In CAT bonds, one party (in this case Mexican officials) transfers risk to a counterparty composed by capital markets investors. In doing so, officials are transferring the solvency burden to cover potential losses to investors. This transaction is particularly important when hedging against events in the high-risk layer. As Mexican CAT bonds are designed to cover losses coming from large hurricanes or earthquakes (e.g., high-risk layer), these bonds successfully fulfill the risk-management classification criterion.

### Figure 68 – Risk-Management Classification Results

Source: Author based on Baca and Jain (2018).

The same underlying reasoning could be followed when comparing CAT bonds relative to other risk-financing instruments. Insurance is a risk-transfer instrument as government officials transfer their risk to an insurance company in exchange of premiums. Alternatively, contingency credits are risk-retention tools as they allow immediate access to funding, but officials must pay
back the entire loan. Hence, based on the risk-management classification metrics, any type of CAT bond or insurance would successfully fulfill this criterion. While contingency credit lines would be an incorrect alternative for the goals of Mexican officials. The relationship between risk-management classification and CAT Mexican CAT bonds is summarized in Figure 68.

To wrap up, Table 23 summarizes the results of the input stage criteria by risk-financing tool. For each result, the black the better, the red the worse the inherent characteristics of the tool match each criterion. Mexican CAT bonds, together with other types of CAT bonds, and reinsurance successfully fulfill each criterion. In other words, any of these tools could be a good risk-financing alternative for the goals of Mexican officials. In contrast, contingency credits do not fulfill two of the three input stage criteria. The following subsection extends this assessment to the remaining criteria of the process/product evaluation stage.

Table 23 – Input Stage Criteria: Summary of Results

<table>
<thead>
<tr>
<th>Input Stage Criteria</th>
<th>Mexican CAT bonds</th>
<th>Other types of CAT bonds</th>
<th>(Re)insurance</th>
<th>Contingency Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk-Layer Alignment</td>
<td>Aligned</td>
<td>Aligned</td>
<td>Aligned</td>
<td>Not Aligned</td>
</tr>
<tr>
<td>Proactiveness</td>
<td>Proactive</td>
<td>Proactive</td>
<td>Proactive</td>
<td>Proactive</td>
</tr>
<tr>
<td>Risk management classification</td>
<td>Risk-transfer</td>
<td>Risk-transfer</td>
<td>Risk-transfer</td>
<td>Risk-retention</td>
</tr>
</tbody>
</table>

Source: Author.

D. Process and Product Evaluation

Timeliness

The first process/product stage criterion is timeliness. According to the evaluation framework metrics’, the faster officials have access to the funds or get the payout, the better they can ensure a timely flow of benefits to needy populations. The payout speed should be put into context and be measured relative to context specific comparison groups or sources of variability. The timeliness of Mexican CAT bonds is compared against the alternative risk financing tools listed in the Scoping Decisions subsection, across stakeholders, and over time.
Starting with the comparison against alternative risk-financing instruments, the expected payout times of the Mexican CAT bonds is compared to other tools. Specifically, the average payout times of the Mexican CAT bonds described in the FTPS of each issuance, against the average payout times *indemnity, parametric, and industry loss* setups\(^{49}\) described by Artemis (2021), Polacek (2015), and (Polacek, 2018) and payout times of contingency credits sponsored\(^{50}\) by the International Monetary Fund (IMF, 2020, 2021).

The fastest payouts could be obtained through contingency credits, which are setup for almost immediate response. The second fastest tools are the *industry loss, parametric (including Mexican CAT bonds), and modeled loss*, which payout around three months after the triggering event (FTPS, 2006, 2009, 2012, 2017, 2018, 2020; Polacek, 2015, 2018). Finally, the slowest is the *indemnity trigger* kind of instruments, as it takes between two and three years to estimate the losses and pay out the bond (Artemis, 2021; Polacek, 2015, 2018). Figure 69 describes this relationship.

![Figure 69 – Timeliness](image)

*Note: Ratings are notional, only order matters. Source: Author.*

The second and third dimensions are the timeliness variation within Mexican CAT bonds over time and across stakeholders. For these dimensions, I review the FTPS of each issuance and calculate the agreed payout time. The payout time is a function of three categories: notice, report, and payment. First, the event notice is a predefined window of days where officials have to notify the event of the reporting agency. Second, the report stage is the period in which the third-party agency verifies whether the magnitude of the event exceed the predefined thresholds. Finally, the

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\(^{49}\) With no distinction between CAT bonds and insurance.

\(^{50}\) In this Chapter, I use the IMF as an example of a contingency credit lines sponsor. However, there could be more or different sponsors that may lead to different results.
payment stage is the window of days between the confirmation of the reporting agency and the payout issuance.

The pre-specified number of days varies by issuance and hazard. For instance, in the 2012 issuance, the FTPS stated, regardless of the hazards, a 25 calendar days window for the notification, a 15-business days period for the report, and five business days for the payment. In contrast, the 2017 issuance stated that, for earthquakes, there would be a 30-day window for calculation date (instead of event notification and report). Whereas for hurricanes, the period would be up to 120 days. The terms used to describe the time frames varied by issuance and are not equivalent, so it is difficult to compare them over time. Therefore, the actual time needed to get a payout in the two events triggered by the bonds was reviewed.

According to the SHCP (2018), Mexico has gotten two payouts. The first one was in 2015 after Hurricane Patricia made landfall on the Pacific Coast in October. The second was in 2017 after the southern state of Chiapas was hit by a Mw 8.2 earthquake on September the 7th. The first event took over four months to get the payout (from 10/28/2015 to 03/09/2016). While for the second event, it took less than two months (from 09/20/2017 to 11/13/2017). This means that the needed time to get a CAT bond payout for Mexican officials has fallen within the market average of three months. Finally, as the speed of payouts has been within the market average, timeliness is assessed as neutral (or as expected) across stakeholders.

Transparency

The second process/product stage criterion is transparency. According to the evaluation framework metrics’, the more the tool's rules are transparent to all stakeholders, the more the information asymmetries are reduced and, therefore, the better the performance of the risk-financing tool. The transparency of Mexican CAT bonds is compared to its evolution over time, across stakeholders, and against alternative risk-financing strategies.

To assess transparency over time and across stakeholders, I focus on the core elements of parametric instruments such as Mexican CAT bonds. Parametric bonds are risk-transfer tools where a risk-cedent transfers risk to a risk-taker. In return, investors get coupons and, if no event triggers the payout, the principal amount back at the maturity of the bond. As scoped down at the beginning of this Section, the risk-cedent is composed of both taxpayers and government, while the risk-taker is composed of investors. Parametric bonds are triggered when there is an event with
a magnitude that exceeds a set of predefined thresholds. In the Mexican case, these triggering parameters have been central pressure and location for hurricanes, and depth, magnitude, and location for earthquakes.

Therefore, the transparency of the bond is evaluated by checking whether information on the insured amount, price, insured areas, and triggering parameters are published and visible to stakeholders. For each FTPS issuance, I compare the transparency of these indicators has changed over time or across stakeholders. The bonds are fully transparent for the government and investors, but their transparency has diminished for taxpayers as presented in Table 24. First, in the 2006 issuance, the FTPS did not specify what the expected loss was. Without this calculation, it is impossible to calculate the multiplier and, therefore, taxpayers do not know how much they are over or underpaying for the bond. To calculate the multiplier, the expected loss described by Cardenas et al. (2007) is used, as further discussed in the pricing results.

**Table 24 – Transparency for Taxpayers**

<table>
<thead>
<tr>
<th>Issuance</th>
<th>Insured Amount</th>
<th>Multiplier</th>
<th>Insured Areas</th>
<th>Triggering Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>Yes</td>
<td>Incomplete</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2009</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2012</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2017</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>2018</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>2020</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Source: Author based on FTPS.

Second, the triggering parameters and the insured areas are not specified in the FTPS of 2017, 2018, and 2020 issuances. The FTPS refer to an Excel file, but this file is confidential according to the MIA due to the terms and conditions of the modeling agency. I challenged this response but got rejected by the National Institute for Transparency, Access to Information and Personal Data Protection (INAI). Without this information, taxpayers (and affected populations) do not know what type of events can trigger a payout. This change was driven by changes in the underlying model. The 2009 and 2012 issuances where completely transparent, but starting in 2017, the insured areas and their triggering parameters became more granular. As a result, it is likely that the modeling agency started to be worried about potential reverse engineering replications as further discussed in the exposure accuracy results.
The third dimension is the transparency variation of Mexican CAT bonds relative to alternative risk-financing tools. For this, I compare the FTPS of each issuance relative to the transparency design of contingency credits as described by IMF (2021), and against the transparency design of other types of CAT bonds and insurance as described by Cardenas et al. (2007), Michel-Kerjan et al. (2011), and Polacek (2018). I compare actual bonds against transparency designs (e.g., theoretical designs) because there are not counterfactual scenarios of the transparency of other risk-financing strategies. However, this is an imperfect comparison because parametric CAT bonds are meant to be transparent by design, but as shown above, their actual implementation could lead to deviations of their intended structure.

Contingency lines of credit have the most transparent designs as they are published for public access by the sponsor agency (IMF, 2021). The second most transparent group of tools are the industry loss and parametric (including Mexican CAT bonds), which are as transparent as the index, triggering parameters, or underlying modeling are accessible to all stakeholders, respectively (Cardenas et al., 2007; FTPS, 2006, 2009, 2012, 2017, 2018, 2020; Michel-Kerjan et al., 2011; Polacek, 2015, 2018). Finally, the least transparent tools are the indemnity trigger kind of instruments, as the verification of all the claimed costs is long and often not transparent (Michel-Kerjan et al., 2011; Polacek, 2015, 2018). The relationship between Mexican CAT bonds and alternative risk-financings instruments is summarized in Figure 70.

**Figure 70 – Transparency Relative to Alternative Risk-Financing Tools**

![Figure 70](image)

Note: Ratings are notional, only order matters.
Source: Author.

Exposure Accuracy

The third process/product stage criterion is exposure accuracy. According to the evaluation framework metrics’, the instruments’ payouts should be lined up with the underlying risks. This
alignment could be measure looking at the performance of the underlying model (Etzion et al., 2019), the triggering parameters (Artemis, 2016; Michel-Kerjan et al., 2011), or both against observed events. The latter alternative is used given the copyright restrictions of the modeling agency. In doing so, first, a framework to understand risk and provide some context for the Mexican case was introduced. Then, the triggering parameters of Mexican CAT bonds are compared to their evolution over time and across stakeholders.

To define risk, I follow a simplified version of the Pressure and Release model (Wisner et al., 2003). This model shows that risk is a function of hazards and vulnerability. The first term refers to the characteristics of the hazard, in this case, earthquakes and hurricanes. The second refers to the root causes (e.g., political, or economic systems), dynamic pressures (e.g., rapid urbanization), and unsafe conditions (e.g., unprotected buildings) that compose vulnerability. An in-depth analysis of risk is beyond the scope of this work, but include an overview to provide some context in the evaluation of the Mexican CAT bonds parameters.

**Earthquakes Risk**

On the hazard's side, the Mexican territory is located on five lithospheric plates (Servicio Geológico Mexicano, 2017a). The North American plate covers most of the territory, but it collides with the Pacific, Rivera, Cocos, and Caribbean plates along the Pacific Coast of the country and the Baja California peninsula. Each plate is moving in different directions, but particularly, the Cocos tectonic plate is forcing its way down beneath the continental edge of the North American one, creating a subduction zone (California Institute of Technology, 2009; Servicio Geológico Mexicano, 2017a). Subduction zones are prone to generate large earthquakes and often have a chain of volcanoes called volcanic arc. In Mexico, the subduction zone is located in the southern Pacific region, and the volcanic arc crosses the country from west to east.

According to the Mexican National Seismological Agency (SSN) database, in the 1900-2021 period\(^{51}\), there were three earthquakes greater or equal than magnitude 8 on the Richter scale (M\(_L\)); 23 quakes between 7 and 7.9 M\(_L\); more than 1,300 between 5 and 6.9 M\(_L\); and almost 196 thousand quakes lower or equal than 4.9 M\(_L\) (SSN, 2021). Figure 71 shows the epicenters of all earthquakes

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\(^{51}\) There is not consistent information on the characteristics of earthquakes before 1900.
that have struck the country in the last 120 years. As previously described, most epicenters take place in the subduction zone along the Pacific Coast.

**Figure 71 – Historical Earthquake Epicenters (1990-2021)**

On the vulnerability side, Mexican officials face a threefold challenge. First, most of the epicenters are located along the Pacific Coast, where the four poorest states of the country (Michoacán, Guerrero, Oaxaca, and Chiapas) are located. Second, because of the previously described geological setup, seismic waves often strike Greater Mexico City, the most populated city and where the capital is located. Third, 27 of the 32 states are located in areas with some level of earthquake risk. Therefore, most states have some degree of exposure to earthquakes, and there is greater exposure in the poorest states and the biggest city. This combination is prone to magnify the negative consequences of the hazard. To address this exposure, officials have divided the country into four risk zones (see Figure 72), and Greater Mexico City into three risk zones (see Figure 73).
On the hazards side, Mexico is exposed to tropical storms from both the Pacific and Atlantic Coasts. From 1980 to 2010, on average, there were 15.2 named storms on the Pacific side and 11.5 named storms on the Atlantic side (Bravo Lujano, 2020). However, that average has risen to 18.2 and 15.2 events in the last nine years, respectively. Geographically, 17 of the 32 states are coastal states. Ten of the 17 coastal states are the most exposed to tropical storms, according to CENAPRED. Six of them are located in the Pacific coast, where Baja California, Baja California Sur, Sinaloa, Jalisco, Colima, and Michoacán are highly exposed. The remaining four are located in the Gulf of Mexico (Tamaulipas) and the Caribbean (Peninsular states: Quintana Roo, Yucatán, and Campeche). Figure 74 this exposure by showing the paths of all tropical storms that have triggered disaster declarations.
Furthermore, most coastal states have a mountainous topography. Mountains act as barriers to the flow of storms and impact the rate at which a landfalling storm dissipates. In addition, as winds from the cyclone are forced over the mountains, the lifting of the air increases rainfall. This means that tropical cyclones in Mexico—even those with relatively low wind speeds—can be accompanied by significant flooding (AIR Worldwide, 2018). In other words, most coastal states are at high risk of being flooded, and some mainland areas are exposed to as much flood risk as the coastal areas. This relationship is presented in Figures 75 and 76.

**Figure 75 – Tropical Storms Exposure**

**Figure 76 – Flood Risk Index**

Source: CENAPRED.
Like earthquakes, most states have some degree of exposure to tropical storms on the vulnerability side. However, unlike large earthquakes, tropical storms strike almost every year, making them costlier than quakes. In the Pacific, Hurricane season runs from May the 25th to November the 30th, whereas in the Atlantic, the season starts on June the 1st and ends on the same date (National Oceanic and Atmospheric Administration, 2021). In other words, tropical storms hit during the warmest months of the year. This periodicity makes them challenging for states that rely the most on tourism and recreational activities, and in Mexico, all these states are coastal (INEGI, 2021a, 2021b).

**Evaluation**

For earthquakes, the triggering parameters have been depth and magnitude by zone. While for hurricanes, the parameter has been central pressure by zone. The evolution of the insured zones as it is an element they have in common, then evaluate the evolution of the depth, magnitude, and central pressure. For both earthquakes and hurricanes, the insured zones have become larger over time.

For earthquakes, the first two issuances (2006 and 2009) were composed of three big insured boxes that covered the subduction zone and Mexico City. In the third issuance (2012), these boxes were expanded to insure a larger central region and Baja California. In the fourth issuance (2017), the insured area was composed of 325 small boxes of 1 by 1 degree each that insured most of the country’s territory. In the fifth issuance (2018), the number of boxes was reduced to 105. Finally, in the last issuance (2020), the insured area increased again to 249 boxes, which covered almost all the country. The geographical evolution of the insured areas is summarized in Figures 77 to 82.

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52 Either being hit by the storm or being affected by the associated rainfall, as presented in Figures 75 and 76.

53 The states most dependent on tourism and recreational services are Quintana Roo, Baja California Sur, Nayarit, Guerrero, and Oaxaca, all of them are coastal states.
For hurricanes, the first issuance (2009) focused on Baja California, Jalisco, Colima, Michoacan, and the Caribbean face of the Yucatan peninsula. By focusing on these areas, the bonds were mostly matching CENAPRED’s map on Tropical Storms Exposure (see Figure 75). The second issuance (2012) expanded the insured area in the Pacific and included the state of Tamaulipas. The third one (2017) insured the entire Coast by splitting the Atlantic and Pacific Coasts into ten and eleven gates, respectively. Lastly, in the fourth issuance (2020), the Atlantic Coast was divided into ten gates, each with three sub-gates. While the Pacific Coast was divided into eleven gates, each of them with three sub-gates. Table 25 shows the evolution over time of the insured area. Likewise, Figures 83 to 86 summarize the geographical distribution of the insured zones.

Table 25 – Insured Area

<table>
<thead>
<tr>
<th>Issuance</th>
<th>Earthquakes $km^2$</th>
<th>Hurricanes $km$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>398</td>
<td>-</td>
</tr>
<tr>
<td>2009</td>
<td>569</td>
<td>5,115</td>
</tr>
<tr>
<td>2012</td>
<td>729</td>
<td>6,401</td>
</tr>
<tr>
<td>2017</td>
<td>3,700</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>1,423</td>
<td>&gt; 11,000</td>
</tr>
<tr>
<td>2020</td>
<td>2,835</td>
<td></td>
</tr>
</tbody>
</table>

1/ Estimated values based on insured coordinates.

Source: Author based on FTPS.
Now, consider the evolution of the triggering parameters to evaluate their performance against observed events. Starting with earthquakes, as previously mentioned, the parameters have been depth and magnitude. An earthquake depth matters as the closer to the surface, the more potential damage the event can cause. In Mexican CAT bonds, the maximum profundity has been 200 km, and the minimum has been 70 km. While, for magnitude, the minimum magnitude has been $M_w$ 6.6, and the maximum one has been $M_w$ 9.6. Tables 26 and 27 present the evolution of the triggering parameters over time.
### Table 26 – Depth Conditions

<table>
<thead>
<tr>
<th>Issuance</th>
<th>Northwest Cocos&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Central Cocos&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Central Mexico w/o Mexico City</th>
<th>Central Mexico with Mexico City</th>
<th>Mexico City</th>
<th>Baja California</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>&lt;= 200</td>
<td>&lt;= 200</td>
<td>&lt;=150</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>&lt;= 200</td>
<td>&lt;= 200</td>
<td></td>
<td></td>
<td></td>
<td>&lt;= 80</td>
</tr>
<tr>
<td>2012</td>
<td>&lt;= 200</td>
<td>&lt;= 200</td>
<td>&lt;= 70</td>
<td></td>
<td>&lt;= 200</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td></td>
<td></td>
<td></td>
<td>&lt;= 200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2018&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;= 120</td>
<td></td>
</tr>
</tbody>
</table>

Source: Author based on FTPS.

### Table 27 – Magnitude Conditions

<table>
<thead>
<tr>
<th>Issuance</th>
<th>Northwest Cocos&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Central Cocos&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Central Mexico w/o Mexico City</th>
<th>Central Mexico with Mexico City</th>
<th>Mexico City</th>
<th>Baja California</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>&gt;= 8.0</td>
<td>&gt;= 8.0</td>
<td>&gt;= 7.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>&gt;= 7.9</td>
<td>&gt;= 8.0</td>
<td>&gt;= 7.4</td>
<td></td>
<td></td>
<td>&gt;= 7.6</td>
</tr>
<tr>
<td>2012</td>
<td>&gt;= 7.9</td>
<td>&gt;= 8.1</td>
<td>&gt;= 7.4</td>
<td></td>
<td>&gt;= 7.6</td>
<td>&gt;= 7.0</td>
</tr>
<tr>
<td>2017&lt;sup&gt;2, 5&lt;/sup&gt;</td>
<td>7.4 - 7.6, 7.7 - 7.8, 7.9 - 8.0, 8.1 - 8.5, 8.6 - 9.0, 9.1 - 9.5, 9.6 - 9.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2018&lt;sup&gt;3, 5&lt;/sup&gt;</td>
<td>6.6 &lt;= Mw &lt; 6.9, 6.9 &lt;= Mw &lt; 7.2, ..., 9.6 &lt;= Mw</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020&lt;sup&gt;4, 5&lt;/sup&gt;</td>
<td>7.0 - 7.1, 7.2 - 7.3, ..., 8.9 - 9.0</td>
<td>6.6 - 6.7, 6.8 - 6.9, ..., 8.7 - 8.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>1</sup> Refers to the Cocos tectonic plate located in the along the Mexican Pacific Coast.

<sup>2</sup> The insured area was divided into 325 boxes of size 1° by 1°.

<sup>3</sup> The insured area was divided into 105 boxes of size 1° by 1°.

<sup>4</sup> The insured area was divided into 249 boxes of size 1° by 1°.

<sup>5</sup> To get the exact magnitude by box by payout (25%, 50%, 75%, and 100%), the FTPS refer to the Air Data File, but this file is confidential.

Source: Author based on FTPS.
A comprehensive analysis about how well-calibrated these parameters are to hedge risk is beyond the scope of this Chapter. However, their effectiveness is explored using the 2017 earthquakes as an example since those events have been the strongest of the last 36 years. In 2017, two major earthquakes struck the country: the Chiapas Earthquake 09/07 and the Puebla Earthquake 09/19. While both earthquakes had similar depth (47.4 vs. 48 km, respectively), they had very different magnitudes. The Chiapas earthquake was notoriously stronger than the Puebla one (Mw 8.2 vs. 7.1, respectively).

When looking at their associated costs of damages, the Chiapas earthquake hit four states and severely affected more people, households, schools, and businesses than the Puebla earthquake. However, the Chiapas earthquake only was associated with MXN 19.2 billion in costs, while the Puebla earthquake was associated with MXN 62.1 billion in costs. So, if the Chiapas earthquake was stronger and affected more buildings and people, why did it cause less monetary damages? The answer is quite straightforward. It is because it did not severely hit Mexico City. Total related damages in Mexico City represented more than 70 percent of the total damages of the Puebla earthquake and more than double of the total damages related to the Chiapas earthquake. Table 28 summarizes the total damages related to these two events.
If this example is used to evaluate the performance of the triggering parameters, that the least expensive event (e.g., the Chiapas earthquake) activated a 100 percent payout. In contrast, the most expensive event (e.g., the Puebla earthquake) did not meet the triggering criteria because the minimum triggering threshold was set in $M_w$ 7.4, and the event was $M_w$ 7.1. In other words, the CAT bonds did not insure an event like the Puebla earthquake, which, though weaker than the Chiapas one, has been the most destructive in recent Mexican history.

Moving forward to analyze hurricanes, as described above, the triggering parameter has been central pressure. Central pressure is the best predictor of wind speed, where lower values of central pressure are associated with higher wind speeds. Even if the Puebla earthquake had met the triggering criteria, as the Chiapas earthquake triggered 100 percent of the principal amount invested, there was no money left to cover additional events.

Table 28 – Total Damages of the 2017 Earthquakes

<table>
<thead>
<tr>
<th>State</th>
<th>Deaths</th>
<th>Population</th>
<th>Damaged</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Affected</td>
<td>Severely Affected</td>
<td>Household</td>
</tr>
<tr>
<td>Chiapas Earthquake 09/07 (Mw 8.2 and 47.4 km depth)</td>
<td></td>
<td>1,187,585</td>
<td>262,536</td>
<td>65,634</td>
</tr>
<tr>
<td>Oaxaca</td>
<td>79</td>
<td>1,820,000</td>
<td>59,248</td>
<td>14,812</td>
</tr>
<tr>
<td>Chiapas</td>
<td>16</td>
<td>1,903,811</td>
<td>63,204</td>
<td>15,801</td>
</tr>
<tr>
<td>Tabasco</td>
<td>4</td>
<td>4,050,452</td>
<td>113,380</td>
<td>28,345</td>
</tr>
<tr>
<td>Veracruz</td>
<td>0</td>
<td>535,053</td>
<td>15,712</td>
<td>3,928</td>
</tr>
<tr>
<td>Subtotal</td>
<td>99</td>
<td>3,455,389</td>
<td>449,628</td>
<td>112,407</td>
</tr>
<tr>
<td>Mexico City</td>
<td>228</td>
<td>1,800,000</td>
<td>59,248</td>
<td>14,812</td>
</tr>
<tr>
<td>Morelos</td>
<td>74</td>
<td>1,903,811</td>
<td>63,204</td>
<td>15,801</td>
</tr>
<tr>
<td>Puebla</td>
<td>45</td>
<td>4,050,452</td>
<td>113,380</td>
<td>28,345</td>
</tr>
<tr>
<td>Guerrero State of Mexico</td>
<td>6</td>
<td>535,053</td>
<td>15,712</td>
<td>3,928</td>
</tr>
<tr>
<td>Tlaxcala</td>
<td>0</td>
<td>145</td>
<td>136</td>
<td>34</td>
</tr>
<tr>
<td>Oaxaca</td>
<td>1</td>
<td>240,421</td>
<td>10,036,57</td>
<td>5,640</td>
</tr>
<tr>
<td>Subtotal</td>
<td>369</td>
<td>3</td>
<td>281,560</td>
<td>70,390</td>
</tr>
<tr>
<td>Total</td>
<td>468</td>
<td>4</td>
<td>731,188</td>
<td>182,797</td>
</tr>
</tbody>
</table>

Source: CENAPRED (2019).

If this example is used to evaluate the performance of the triggering parameters, that the least expensive event (e.g., the Chiapas earthquake) activated a 100 percent payout. In contrast, the most expensive event (e.g., the Puebla earthquake) did not meet the triggering criteria because the minimum triggering threshold was set in $M_w$ 7.4, and the event was $M_w$ 7.1. In other words, the CAT bonds did not insure an event like the Puebla earthquake, which, though weaker than the Chiapas one, has been the most destructive in recent Mexican history.

Moving forward to analyze hurricanes, as described above, the triggering parameter has been central pressure. Central pressure is the best predictor of wind speed, where lower values of central pressure are associated with higher wind speeds. Even if the Puebla earthquake had met the triggering criteria, as the Chiapas earthquake triggered 100 percent of the principal amount invested, there was no money left to cover additional events.

---

54 Even if the Puebla earthquake had met the triggering criteria, as the Chiapas earthquake triggered 100 percent of the principal amount invested, there was no money left to cover additional events.
pressure are strongly correlated with stronger winds. The central pressure triggering threshold has varied over time. In 2009, it started with 944 mb, but in the last issuance, it insures events as weak as 955 mb. This means that the threshold has been relaxed to insure against more hurricanes. Tables 29 and 30 present the evolution of the triggering parameters over time.

Table 29 – Central Pressure Conditions 1/2
Millibars

<table>
<thead>
<tr>
<th></th>
<th>Baja California</th>
<th>Central Pacific</th>
<th>Yucatan</th>
<th>North Gulf</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>&lt;= 944</td>
<td>&lt;= 944</td>
<td>&lt;= 920</td>
<td></td>
</tr>
<tr>
<td>2012⁴</td>
<td>920 &lt; CP &lt;= 932</td>
<td>&lt;= 920</td>
<td></td>
<td>&lt;= 920</td>
</tr>
</tbody>
</table>

¹⁴/ Payouts of 50% and 100%, respectively.

Source: Author based on FTPS.

Table 30 – Central Pressure Conditions 2/2
Millibars

<table>
<thead>
<tr>
<th></th>
<th>Gulf Coast⁵</th>
<th>Pacific Coast⁵</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017²</td>
<td>932 &lt; CP &lt;= 935</td>
<td>935 &lt; CP &lt;= 935</td>
</tr>
<tr>
<td></td>
<td>920 &lt; CP &lt;= 932</td>
<td>920 &lt; CP &lt;= 932</td>
</tr>
<tr>
<td></td>
<td>CP &lt;= 920</td>
<td>CP &lt;= 920</td>
</tr>
<tr>
<td></td>
<td>955 - 951,</td>
<td>935 - 931,</td>
</tr>
<tr>
<td></td>
<td>950 - 946,</td>
<td>930 - 926,</td>
</tr>
<tr>
<td>2020³</td>
<td>...,</td>
<td>...,</td>
</tr>
<tr>
<td></td>
<td>925 - 921,</td>
<td>919 - 915</td>
</tr>
<tr>
<td></td>
<td>920</td>
<td></td>
</tr>
</tbody>
</table>

²/ The Atlantic and Pacific Coasts were split up into 10 and 11 storm boxes, respectively. Each central pressure bracket was lined up with payouts of 25%, 50%, and 100%, respectively.

3/ The Atlantic and Pacific Coasts were split up into 10 and 14 storm boxes, respectively, each with 3 sub-boxes. Each sub-box was lined up with different payout rates (25%, 50%, and 100%). To get the exact conditions, the FTPS refer to the Air Data File, but this file is confidential.

Source: Author based on FTPS.
As with earthquakes, I use observed storms to assess the performance of this parameter in hedging risk. I compare the top ten most and least destructive storms against the central pressure thresholds of the 2012 issuance. In the ten most destructive, only hurricane Dean (2007) could have triggered a payout. While, in the ten least damaging, only hurricane Ivan (2004) could have triggered the bonds. This comparison is presented in Figures 87 and 88. In other words, the triggering central pressure thresholds were similarly likely to be triggered by very destructive and non-destructive storms.

Figure 87 – Top 10 Most Destructive Storms (2000-2019)

Figure 88 – Top 10 Least Destructive Storms (2000-2019)

Source: Author calculations based on CENAPRED Annual Reports, NOAA, and the FTPS 2012.

If central pressure is not entirely driving damages, what is missing? To answer this, the 93 disaster declarations associated with all the tropical storms of the last 20 years were reviewed. The main destruction driver has been rainfall not central pressure, with 70 appearances. In contrast, wind speed (e.g., central pressure) only appears 15 times, and it has always appeared together with rainfall. This finding could be explained by the fact that Mexico’s building stock is dominated by masonry and concrete construction, which are relatively wind resistant (AIR Worldwide, 2018).

55 Since the 2000, when Mexican officials started following a systematized method to calculate total damages.
56 I chose this issuance following two reasons. First, because it is the last one where I got detailed information of the triggering parameters by zone, as described in the transparency section. Second, because during this issuance Mexico got a 50 percent payout in 2015, after Hurricane Patricia.
57 Technically, hurricane Ivan did not make landfall, it passed right next to the Yucatan Peninsula to then hit twice the United States. However, this could be an example of a storm barely hitting the country, causing relatively few damages, and triggering a payout.
58 42 times alone and 28 times with flooding, landslides, wind, or tidal wave.
Finally, if the triggering parameters are not as accurate or as complete as the should be, which stakeholders are winning or losing? Having a weak exposure accuracy could be harming all stakeholders. For cases like hurricane Ivan, investors could be paying for events with low associated damages. Alternatively, for cases like the 2017 Puebla earthquake, officials could be missing payouts in highly expensive events. Notably, the two events that have triggered a payout had relatively low associated damages.

Pricing

The fourth process/product stage criterion is pricing. Based on the evaluation framework metrics’, I use the Mexican CAT bonds multiplier and measures it relative to its evolution over time, across stakeholders, and against alternative risk-financing strategies. As previously explained, the multiplier is the ratio of the coupons over the expected losses, where coupons are premiums that the issuer pays to the risk-taker, and expected losses are the estimated probabilities of the materialization of a triggering event. If the outcome of the ratio is < 1, the risk-cedent is underpaying, and vice versa; if the outcome of the ratio is > 1, the risk-cedent is overpaying.

Starting with the variation over time, the multiplier began with an average of 2.1. Its level went up when the World Bank took over in the second issuance, to then start falling in the following issuances. One notable exception are Class A notes, which insure low frequency but high severity earthquakes. Class A notes multiplier went up after the 2017 Chiapas earthquake, which triggered a 100 percent payout. As a result, these notes have the most expensive coupons, with a multiplier over 3 when others have remained below 2. Table 31 summarizes the evolution over time of the multipliers. Likewise, Table 36 and 37 in Appendix C summarize the evolution over time of the coupons and expected losses.
The level of the multiplier is compared across stakeholders. Mexican officials have been systematically overpaying in all CAT bonds issuances. Mexican officials have overpaid between 130 (e.g., Class C notes in the 2012 issuance) and 420 percent of the modeled expected loss (e.g., Class D notes for the 2009 issuance). In overpaying, both components of the risk-cedent party could be losing. On the one hand, taxpayers receive fewer public services as some of their tax pesos are being used to overpay the CAT bonds. On the other, officials face a more restrictive budget constraint in the provision of public services. However, it is not possible to determine how off these multipliers are without a relative comparison. Here is where I introduce the comparison relative to alternative risk-financing tools.

When comparing against other tools, a data availability constraint binds because an ideal comparison would require access to the FTPS of all issuances of comparable cases. So, I make two imperfect comparisons. First, the difference between the insurance-linked securities (ILS)\(^{59}\) market average and the Mexican multipliers is calculated. By construction, any positive value indicates that the ILS average was greater than the Mexican one, and vice versa; any negative value indicates that the ILS average was lower than the Mexican average. ILS average multipliers have been greater than Mexican ones in all issuances, except for 2018. Figure 89 summarizes the relationship

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\(^{59}\) ILS are investment assets uncorrelated with financial markets as their value is linked to non-financial risks including natural hazards. CAT bonds are a special type of ILS.
between ILS and Mexican CAT bonds average multipliers and Figure 100 summarizes the underlying trend (see Appendix C).

**Figure 89 – Difference between ILS Average and Mexican Multipliers**

*Source: Artemis (2021) and FTPS.*

**Figure 90 – Alianza del Pacifico 2018: Multipliers by Country**

*Source: FTPS 2018.*

Second, I compare the multipliers of the Alianza del Pacifico 2018 issuance. This was a joint issuance with comparable countries (Chile, Colombia, and Peru) insuring against the same risk (earthquakes). I find that for low probability but high severity earthquakes, Mexico (Class A) paid the same coupon as Chile (250 basis points) for a less likely event (0.86 vs. 0.79 percent). In other words, either Mexico overpaid more than Chile. Likewise, I find that for higher probability but less severity earthquakes, Mexico (Class B) paid a more expensive multiplier than Peru. Therefore, I conclude that, in 2018, Mexico has paid more for insuring earthquakes than comparable countries. Figure 90 summarizes the Alianza del Pacifico 2018 issuance.

Nonpayment Risk

The fifth and last process/product stage criterion is nonpayment risk. According to the evaluation framework metrics’, it is desired that the selected risk-financing tool includes mechanisms to minimize the nonpayment risk. I compare the nonpayment mechanisms of Mexican CAT bonds relative to its evolution over time, across stakeholders, and against alternative risk-financing strategies. Starting with the evolution of Mexican CAT bonds over time, I review the nonpayment mechanisms included in each of the FTPS issuances. The program includes mechanisms that minimize the nonpayment risk from the risk-cedent and risk-taker perspectives. Therefore, the nonpayment mechanisms have improved over time and for across stakeholders.
On the risk-cedent side, the program has always included a SPV. Having a SPV isolates financial risk on the principal. This makes the obligations secure, and it is also attractive to risk-takers as it assures repayment to investors. In the first three issuances the SPV was based in an offshore company in the Cayman Islands. More recently, the SPV was replaced by the Global Debt Issuance Facility that belongs to The World Bank. This change allows to keep the certainty provided by the SPV and to reduce the associated costs of setting up the SPV, which were assigned to the risk-cedent party.

On the risk-taker side, the partnership with The World Bank has provided certainty in the timely payment of coupons. As an intermediary, The Bank guarantees the flow of coupons to risk-takers. While, if needed, The Bank provides access to credit lines to risk-cedents. The SPV and the partnership with The World Bank has benefited all parties. Mexican officials are certain of receiving the payout if an event triggers the parameters. Hence, taxpayers also have some degree of certainty of receiving part of the money during the response and recovery operations. Alternatively, investors face no credit risk as the principal amount is invested in risk free securities and the flow of coupons is ensured by The Bank.

The third dimension is the variation of nonpayment mechanisms of Mexican CAT bonds relative to alternative risk-financing tools. For this, I compare the FTPS of each issuance relative to the nonpayment mechanisms designs of other types of CAT bonds and insurance as described by Baca and Jain (2018), Cardenas et al. (2007), and Michel-Kerjan et al. (2011). I compare actual bonds against nonpayment mechanisms designs because there are not counterfactual scenarios of these mechanisms of other risk-financing strategies. However, this is an imperfect comparison because the actual implementation could lead to deviations of their intended structure.

Mexican CAT bonds have lower nonpayment risk than the design of other types of CAT bonds or reinsurance. The combination of SPVs and the intermediary role of The World Bank decrease the nonpayment risk of Mexican bonds. Other types of CAT bonds are placed second as they usually rely on SPV structures. In contrast, reinsurance always has a real possibility of defaulting. That is why I rate them as riskier in comparison with CAT bonds. The relationship between Mexican CAT bonds and alternative risk-financings instruments is summarized in Figure 91. Moreover, Table 32 summarizes the process/product evaluation results.
Figure 91 – Nonpayment Risk Relative to Alternative Risk-Financing Tools

Note: Ratings are notional, only order matters.
Source: Author.
Table 32 – Process/Product Evaluation Results

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Evolution over time</th>
<th>Against Other Tools</th>
<th>Across Stakeholders</th>
<th>Stoplight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timeliness</td>
<td>Payout speed within the market average of two to four months</td>
<td>Payout speed slower than contingency lines of credit, but faster than indemnity trigger tools</td>
<td>As expected for all the involved parties</td>
<td>Green</td>
</tr>
<tr>
<td>Transparency</td>
<td>Decreasing transparency for taxpayers. Specifically, less access to triggering parameters by insured area</td>
<td>Less transparent than the design of contingency credits, but more transparent than indemnity trigger tools</td>
<td>Fully transparent for officials and investors, less transparent for taxpayers</td>
<td>Red</td>
</tr>
<tr>
<td>Exposure</td>
<td>Insured areas got bigger, and triggering thresholds were modified to insure more types of events. But there is a mismatch between financial damages and observed triggering events</td>
<td>Problems with the accuracy of the underlying model or the triggering parameters are harmful for all the involved parties</td>
<td>Problems with the accuracy of the underlying model or the triggering parameters are harmful for all the involved parties</td>
<td>Red</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Decreasing to converge at the actuarially fair price, except for the notes that have triggered 100 percent payout</td>
<td>Mexican CAT bonds multiplier is lower than the ILS market, but greater than the multiplier of comparable countries in the 2018 Alianza del Pacifico issuance</td>
<td>Beneficial for risk-takers as risk-cedents are overpaying</td>
<td>Yellow</td>
</tr>
<tr>
<td>Pricing</td>
<td>Solid and improving with the collaboration with The World Bank</td>
<td>Includes more mechanisms to minimize the nonpayment risk than comparable tools</td>
<td>Beneficial for all the involved parties</td>
<td>Green</td>
</tr>
</tbody>
</table>

Source: Author.
IV. Policy Implications and Recommendations

As presented in the previous Section, results reveal that the Mexican CAT bonds program performs well against the criteria of the input evaluation stage. Mexican officials were looking for risk-financing tools which design allowed them to hedge ahead of time the financing risk coming from large hurricanes and earthquakes. By design, CAT bonds meet these predefined needs because they are best suited to hedge risk coming from low probability, but high severity events such as large hurricanes and earthquakes (risk-layer alignment criterion). CAT bonds also allow officials to plan ahead of time as the contracts are set up before the event hits (proactiveness criterion). Finally, CAT bonds are a sound tool to hedge risk as they allow officials to transfer post-disaster financing risk to a counterparty of investors (risk-management classification criterion).

However, results reveal that the Mexican CAT bonds program could be adjusted to improve its performance in the process/product evaluation stages. Starting with pricing, officials should be aware that they are overpaying for the bonds even when they do not have control over price. Specially as the price of ILS instruments is expected to increase as climate change materializes (S&P, 2021). To reduce the dependence on ILS tools for response and recovery operations, I suggest designing and implementing more strategies in the preparedness and mitigation stages.

For the exposure accuracy, I show that payouts are not aligned with the risks of the country. In the case of earthquakes, CAT bonds did not insure an event like the Puebla earthquake, which, though weaker than the Chiapas triggering event, has been the most destructive in recent Mexican history. In the case of hurricanes, the triggering central pressure thresholds were similarly likely to be triggered by very destructive and non-destructive storms. Moreover, when reviewing disaster declarations, rainfall, not central pressure, has been the most important driver of damages.

It is unclear whether this inaccuracy is explained by problems with the underlying model, triggering thresholds, or both. Its recommended that Mexican officials to include additional stakeholders to assess the suitability of the parameters and the reliability of the underlying modeling. Currently, the principal stakeholder on the risk-transfer side is composed by officials from the Ministry of Finance. These officials are highly qualified in finance and economics but could be lacking relevant knowledge in natural sciences. Working in collaboration with engineers of the Geophysics Department of the National Autonomous University of Mexico (UNAM),
CENAPRED, or CONAGUA officials could improve the accuracy of both the triggering parameters and underlying model.

Likewise, information about the insured areas and triggering parameters of the last three issuances are not accessible to Mexican taxpayers. This lack of transparency could diminish the public confidence in this program and restricts external evaluations of CAT bonds. It is recommended that Mexican officials pull their lever as the risk-cedent party and require the modeling agency to make the triggering parameters more accessible to all stakeholders. This should be feasible as it was the case in the first three issuances. It could also be desired as having problems with the underlying model or triggering thresholds harms all the involved stakeholders.

Finally, it is worth noting that I find that Mexican CAT bonds include more mechanisms to minimize the nonpayment risk than comparable tools, and that the needed time to get a CAT bond payout for Mexican officials has fallen within the market average of three months. It is recommended federal officials to make sure following issuances fulfill the same speed and nonpayment risk standards. In specific, it is recommended continuing and strengthen the collaboration with The World Bank.

A. Limitations

This research has several limitations. First, the proposed framework evaluates the design and actual implementation of any given risk-financing tool. Still, it does not assess how well the money was spent in response or recovery operations. Thus, any given tool could excel in this framework and still not help out in the recovery of the affected governments or populations. There are two ways to assess the actual spending of risk-financing tools. First, it would be needed to track and verify that the money is getting to the affected stakeholders. Second, it would be needed to compare stakeholders that experienced an event and received government aid against a comparable group of stakeholders.\textsuperscript{60} In Chapters IV and V of this dissertation, I conducted similar research for the overall risk-financing strategy in Mexico. Further research could break down the analysis by risk-financing tools.

Second, even though the policy framework was designed to include all relevant dimensions of the literature, further research may yield additional criteria or context specific dimensions that

\textsuperscript{60} For instance, stakeholders that experienced an event but did not receive government aid or never-treated stakeholders.
decisionmakers could consider when selecting or evaluating a risk-financing tool. Likewise, even if the framework includes all relevant criteria, it may not be possible to fully assess each criterion. For instance, I could not directly test the underlying modeling of the Mexican CAT bonds because of copyright restrictions of the modeling agency. An indirect evaluation of the exposure accuracy comparing observed events with actual payouts had to be used.

Third, the evaluation assumes two risk-cedent stakeholders: government and taxpayers. This assumption implies that there is no diversity within those two groups that can affect the evaluation outcome. For instance, it does not consider that some taxpayers (or local governments) are at higher risk than others, and their objective functions might differ. In this case, taxpayers in high-risk areas could be willing to spend more public funding on risk-financing tools compared to taxpayers in low-risk areas.
VII. General Conclusions and Next Steps

The overarching aim of this dissertation was to understand these problems by asking what are the available financial mechanisms in a disaster aftermath? This overarching question could be analyzed from several research perspectives. This dissertation focuses on three of them and was divided into six additional chapters. In Chapter I, I provided a broad introduction to the policy problem and research questions. In Chapter II, I introduced the landscape on the costs and risk-financing strategies to cope with disasters in Mexico. In doing so, I provided an empirical justification to scope down the analysis of this dissertation to hurricanes and earthquakes. In Chapter III, I presented the DiD estimator used to conduct the empirical analysis of Chapters IV and V.

In Chapter IV, the treatment effects of having been hit by one or more hurricanes, earthquakes, or both on the levels and composition of government revenues and expenditures is estimated at the municipal level. Overall, the findings revealed that natural disasters change the composition of revenues and the spending priorities of municipal governments. On the revenues side, natural disasters have a statistically significant change in the composition of federal transfers. Municipalities do not get more transfers, but they get more discretionary funds. On the expenditures side, hurricanes decrease municipal services and assistance spending, while earthquakes decrease the services spending. These findings suggested that local policy decisions deviate from federal criteria when distributing federal transfers to municipalities in the aftermath of a disaster. Likewise, these findings suggested that the current fiscal rules also disincentivize municipalities to collect more taxes or reallocate funds to implement post-disaster policies.

In Chapter V, the behavior of economic agents and their safety nets after being hit by one or multiple natural disasters was analyzed. Overall, the findings revealed that remittance levels decrease after a municipality has been hit by an earthquake or both earthquakes and hurricanes. Further, two underlying causal mechanisms of these results were tested. First, the role of migration as a post-disaster alternative to smooth consumption. Being treated is associated with a sharper decrease of remittance levels on municipalities with high migration indexes. Second, the role of remittances channels as a change in remittance levels could be explained by a shift from formal to informal channels were tested. These findings suggested that experiencing an earthquake or the
combination of both earthquakes and hurricanes has a statistically significant sharper negative effect on remittance levels in municipalities without access to financial institutions compared to municipalities with access to financial institutions. However, these treatment effects are smaller than the ones in municipalities with high migration indexes, suggesting that choosing migration over remittances is the main driver of the decline in remittance levels. In other words, the affected agents migrate as part of their post-disaster coping alternatives to smooth consumption.

Finally, in Chapter VI, a more general evaluation framework than what has been done in previous research was proposed. Then, this policy framework was used to assess the Mexican catastrophe bonds program as a case study. When illustrating how the proposed framework could be used against the Mexican case, results revealed that the Mexican CAT bonds program performs well against the criteria of the input evaluation stage. However, the Mexican CAT bonds program could be adjusted to improve its performance in the process/product evaluation stages. First, data on observed events revealed that the payouts have been triggered in events with low associated damages, and not triggered in events with high associated damages. This suggests that the triggering parameters or the underlying model could be improved to better match the main goal of the program. Second, the program’s transparency has been decreasing over time. Especially, regarding the relationship between the triggering parameters and insured areas, which is particularly relevant as it seems that triggering parameters could be improved to be a better predictor of damages. Finally, the evaluation revealed that Mexican officials have been paying more than the actuarially fair price.

Overall, the findings of the three research questions imply that the current financial mechanisms may not be effective in mitigating disaster related impacts. So, natural disasters could be having a large negative effect on the lives of the affected populations. To identify potential policy levers, these results should be framed based on the disaster response and broader policy systems. In terms of disaster policy, policymakers should assess whether the current federal aid rules create the intended incentives on local governments. However, even if federal aid incentives are lined up as intended, policymakers should frame these results within a broader policy context. First, findings should be framed looking at the fiscal federalism system. Local governments may be disincentivized to collect more taxes, address post-disaster operations or increase their insurance take up if they receive more non-disaster related transfers. Especially, if these transfers are nonearmarked transfers as suggested in findings of Chapter IV. Second, findings should be
framed looking at broader historical trends. In this case, there is a high spatial correlation between states hit by both hurricanes and earthquakes and states with lower economic output. These findings may be partially driven by post-disaster migration as suggested in findings of Chapter V, but policymakers should explore further this relationship between natural disasters and regional disparities.

This dissertation was not exempt of limitations. In Chapter IV, it is unclear why municipal officials do not reallocate money to traditionally post-disaster priorities such as infrastructure and public assistance. On possible hypothesis comes from the political economy literature and states that even if FONDEN rules were creating the desired incentives, the net outcomes could be different if state level officials take advantage of disasters to break federal rules in the use of transfers, funneling more discrentional money to friendly municipalities. In this scenario, as municipal officials could be getting more discrentional money, they would not have incentives to improve their access to insurance markets, or to spend that money in disaster response and recovery policies.

One way to assess this hypothesis would be estimating if municipalities with higher levels of federal aid (e.g., more access to insurance) perform better than municipalities with lower levels of federal aid. And see whether municipalities in the latter pool offset the lack of federal aid with nonearmarked transfers coming from the federal government through their states. Future research should focus on understanding the underlying mechanisms that explain these changes in the spending priorities to further identify leverage points for policy improvements in both the fiscal federalism and disaster response systems.

In Chapter V, data aggregated at the municipal level does not allow capturing the characteristics of agents that decide to stay and use remittances as coping mechanisms. It is also unclear whether disaster driven migration is external or domestic. Future research should analyze response mechanisms using data with further levels of disaggregation (e.g., households). Likewise, future research should study whether migrants move to the USA or to other states within Mexico, and calculate the implications (e.g., output, welfare, health, among others) of those population movements.

In Chapters IV and V, the temporal aggregation the outcomes of interest (annual for fiscal data and quarterly for remittances) constraints the estimation of the treatment effects. This is relevant as in a few cases there was more than one treatment in the same year or quarter. So the
interpretation of the estimands as the effect created by one unit change in treatment is not entirely clean. While this limitation cannot be overcome, the research question could be changed from estimating the effects of being hit to estimating the marginal effects of disasters based on their intensity. Thus, the interpretation switches from the number of occurrences to the variations in magnitude.

To estimate the variation in magnitude, it is necessary to take a step back and understand what drives damages. Answering this question is relevant to build on this dissertation. In Chapters IV and V, the relationship between disaster declarations and event intensity was not entirely neat (especially in the case of hurricanes). In Chapter VI, I showed that CAT bonds have been triggered by two events with low associated damages, and not triggered in events with high associated damages. Future research should first understand what drives damages and then use those variables to estimate the marginal effects of disasters based on their intensity, and to change the triggering parameters of CAT bonds.

Finally, in pursuing breadth, Chapter VI lacks depth in the evaluation of Mexican CAT bonds. This depth could focus on evaluating the implications for the Mexican case, but also on illustrating and improving the metrics of the policy evaluation criteria. These criteria was based on the fiscal resilience to disasters literature, but this literature lacks robust empirical foundations. This lack of foundations could be driven by the infrequent nature of large natural disasters. Future research should keep building on to improve the empirical foundations of this literature. This is particularly relevant in a future where the frequency and magnitude of natural hazards is expected to increase.
Appendix

Appendix A

**Figure 92 – Municipalities by Treatment Status**

Source: Author's calculations based SEGOB and CENAPRED.

**Figure 93 – Municipalities only hit by Hurricanes**

Source: Author's calculations based SEGOB and CENAPRED.
Figure 94 – Municipalities only hit by Earthquakes

Source: Author's calculations based SEGOB and CENAPRED.

Figure 95 – Municipalities hit by Hurricanes and Earthquakes

Source: Author's calculations based SEGOB and CENAPRED.
Appendix B

A. Spatial Distribution of Treatments

Figure 96 – Municipalities by Treatment Status

Source: Author's calculations based SEGOB and CENAPRED.

Figure 97 – Municipalities only hit by Earthquakes

Source: Author's calculations based SEGOB and CENAPRED.
Figure 98 – Municipalities only hit by Hurricanes

Source: Author’s calculations based SEGOB and CENAPRED.

Figure 99 – Municipalities only hit by Earthquakes and Hurricanes

Source: Author’s calculations based SEGOB and CENAPRED.
B. *MII by Treatment*

**Table 33 – MII for Earthquakes by Municipality**

<table>
<thead>
<tr>
<th>Municipality</th>
<th>Treated</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>139</td>
<td>338</td>
</tr>
<tr>
<td>Low</td>
<td>348</td>
<td>809</td>
</tr>
<tr>
<td>State</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>219</td>
<td>258</td>
</tr>
<tr>
<td>Low</td>
<td>589</td>
<td>568</td>
</tr>
</tbody>
</table>

Note: There are two never-treated municipalities not included in the MII dataset (San Felipe in Baja California and Dzitbalché in Campeche), which reduces the sample size from 45,808 to 45,752 observations.

**Table 34 – MII for Hurricanes by Municipality**

<table>
<thead>
<tr>
<th>Municipality</th>
<th>Treated</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>131</td>
<td>418</td>
</tr>
<tr>
<td>Low</td>
<td>348</td>
<td>809</td>
</tr>
<tr>
<td>State</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>237</td>
<td>312</td>
</tr>
<tr>
<td>Low</td>
<td>589</td>
<td>568</td>
</tr>
</tbody>
</table>

Note: There are two never-treated municipalities not included in the MII dataset (San Felipe in Baja California and Dzitbalché in Campeche), which reduces the sample size from 47,824 to 47,768 observations.

**Table 35 – MII for Both Treatments by Municipality**

<table>
<thead>
<tr>
<th>Municipality</th>
<th>Treated</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>348</td>
<td>97</td>
</tr>
<tr>
<td>Low</td>
<td>809</td>
<td>189</td>
</tr>
<tr>
<td>State</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>589</td>
<td>263</td>
</tr>
<tr>
<td>Low</td>
<td>568</td>
<td>23</td>
</tr>
</tbody>
</table>

Note: There are two never-treated municipalities not included in the MII dataset (San Felipe in Baja California and Dzitbalché in Campeche), which reduces the sample size from 40,460 to 40,404 observations.
Appendix C

A. Pricing

Table 36 – Coupons (a)

<table>
<thead>
<tr>
<th>Issuance</th>
<th>Class A</th>
<th>Class B</th>
<th>Class C</th>
<th>Class D</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>2.4</td>
<td>2.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>11.5</td>
<td>10.3</td>
<td>10.3</td>
<td>10.3</td>
</tr>
<tr>
<td>2012</td>
<td>8.0</td>
<td>7.8</td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>4.5</td>
<td>9.3</td>
<td>5.9</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>2.5</td>
<td>8.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>3.5</td>
<td>9.0</td>
<td>10.0</td>
<td>6.5</td>
</tr>
</tbody>
</table>

1/ Earthquakes for all issuances.
4/ Hurricanes in 2009 (Yucatan) and 2020 (Pacific).

Source: Author based on FTPS.

Table 37 – Expected Loss (b)

<table>
<thead>
<tr>
<th>Issuance</th>
<th>Class A</th>
<th>Class B</th>
<th>Class C</th>
<th>Class D</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>1.1</td>
<td>1.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>4.9</td>
<td>4.3</td>
<td>4.4</td>
<td>2.5</td>
</tr>
<tr>
<td>2012</td>
<td>4.4</td>
<td>2.7</td>
<td>5.7</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>3.4</td>
<td>5.6</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>0.8</td>
<td>6.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>0.9</td>
<td>5.8</td>
<td>5.6</td>
<td>4.1</td>
</tr>
</tbody>
</table>

1/ Earthquakes for all issuances.
4/ Hurricanes in 2009 (Yucatan) and 2020 (Pacific).

Source: Author based on FTPS.
Figure 100 – ILS Average Multipliers

Source: Author based on Artemis.
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