Natural Disasters: Exposure and Underinsurance*

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Abstract

Insurance coverage for natural disasters remains low in many exposed areas, particularly in
developing countries and developing small island states. Reduced availability or unaffordability
of insurance are commonly identified as primary causal factors in this low coverage. The
French overseas departments provide a rare example of a well-developed supply of natural
disasters insurance in Latin America and the Caribbean. This makes it possible to analyze
the determinants of insurance coverage on the demand side in these highly exposed regions.
Based on unique household-level micro-data, I estimate an insurance market model. I show
that the low insurance take-up rate in the French overseas departments is mainly due to
uninsurable housing and also likely to the anticipation of assistance.

Keywords: natural disasters, insurance, disaster aid, developing countries

JEL classification: Q54, G22, H84, D12

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1 Introduction

Natural disasters have had a considerable and growing impact on national economies; over the last few decades, damages associated with such events have frequently reached several percentage points of GDP.\(^1\) The drop in national output subsequent to natural disasters is mainly driven by uninsured losses (VonPeter et al., 2012). Indeed, as government is potentially the “insurer of last resort” after natural disasters, insurance coverage of private assets enables countries to partially transfer catastrophic risk to foreign actors.\(^2\)

However, insured losses still represent a small fraction of economic losses (MunichRe, 2015). Insurance coverage for natural disasters remains low in developing countries (Cavallo and Noy, 2009; Freeman et al., 2003) and developing small island states (Pelling and Uitto, 2001), most of them being highly exposed to natural disasters. In particular, Latin America and the Caribbean form one of the world’s most disaster-prone areas (Borensztein et al., 2009; Rasmussen, 2004), with damages exceeding 50% of GDP in the last decades (Appendix A.1). Yet they have the lowest levels of insurance coverage (Borensztein et al., 2009). Less than 4% of losses in Latin America and the Caribbean were insured between 1985 and 1999, ranking them last among the world’s regions along with Asia (4%), and behind Africa (9%) (Charveriat, 2000). The insurance take-up rate in Latin America and the Caribbean is particularly low among households (Charveriat, 2000).

Reduced availability or unaffordability of insurance are commonly identified as primary causal factors for low insurance coverage in hazard-prone regions of the world, including Latin America and the Caribbean. This restricted insurance supply is mainly due to unavailable or unaffordable reinsurance and also to limited standardized information on risk exposure (Cavallo and Noy, 2009). The French overseas departments provide a rare example of a well-developed and regulated supply of natural disasters insurance in Latin America, the Caribbean and other exposed small island countries.\(^3\) When one uses a structural approach,


\(^2\)In almost all developing countries, insurers rely heavily on international reinsurance (Outreville, 2000). Local insurance companies can cede a significant part of their risks to reinsurers, which are mainly foreign companies. For example, in the Caribbean, local insurers which cover households’ and firms’ possessions for natural disasters retain less than 20% of the amount they insure and cede the remaining share to reinsurers (Polner, 2000).

\(^3\)The French overseas departments were integrated into France as overseas departments in 1946 and are now integral parts of France. They include French Guiana (South America), Guadeloupe (Caribbean Sea), Martinique (Caribbean Sea) and Réunion (Indian Ocean). Mayotte (Indian Ocean) became a French overseas
this broad and regulated supply of coverage makes it possible to analyze the determinants of insurance coverage on the demand side.

Besides perception biases, several major reasons may explain the low demand for natural disasters insurance. First, insurance may be too expensive for households. Indeed when insurance is available, insurance premiums offered to households are high in Latin America and the Caribbean because of the restricted or expensive reinsurance supply (Auffret, 2003). For example, in Mexico, natural disasters premiums in earthquake-prone areas amount to 0.5% of the value of housing on an annual basis; in the Caribbean, natural disasters premiums exceed 1% of the insured value (Charveriat, 2000; Pollner, 1999).

Second, in developing countries, many houses are uninsurable buildings, because they do not meet building standards and have poor resilience to natural events. The proportion of uninsurable housing in Latin America, the Caribbean, and many other developing countries is high (Gilbert, 2001). In Mexico, uninsurable houses built with no solid materials or access to drinking water represent about 50% of total housing stock (Charveriat, 2000). 60% of total housing stock in the Caribbean is built without any technical report (IDB, 2000). In the French overseas departments, dwellings made of light materials (such as wood or sheet metal) of variable quality represented 13% of dwellings in 2006 (Casteran and Ricroch, 2008).

Third, assistance is a substitute for formal insurance and decreases demand for insurance. This phenomenon, called charity hazard, is a typical example of the Samaritan’s dilemma. Charity hazard has a considerable impact in many developing countries, including Latin America and the Caribbean (Gilbert, 2001). Indeed, the World Bank and the Inter-American Development Bank provide a considerable and growing amount of assistance to victims of natural disasters in the Caribbean region (Auffret, 2003). The French overseas departments benefit from financial assistance from the French government.

Charity hazard can be all the more important that the expected award of assistance is endogenous. Indeed, the neighbors’ decision to remain uninsured increases neighborhood eligibility for assistance and so decreases the individual benefit of purchasing insurance. 5

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4 All these low-quality dwellings are legal. In the Caribbean region, building standards and location restrictions are either nonexistent or outdated and inadequate (Auffret, 2003). In the French overseas departments, no building permit is required by law to build a house, because property law allows households to own the walls of their dwelling without owning the ground on which it is built.

5 This mechanism is predicted in theory for many types of public aid. Arvan and Nickerson (2006) consider
Neighbors’ insurance choices also impact individual decision via peer effects. Indeed, social norms impact the decision to purchase insurance, because individuals may think that their relatives have similar preferences to them or have already contributed the search costs of obtaining information on risk, insurance or relief (Kunreuther and Pauly, 2005).

Finally, insurance obligations logically impact the demand for insurance. Purchasing home insurance is often a condition for obtaining a mortgage. However, some homeowners with outstanding loans may not renew their insurance contracts once they have settled in. Indeed, as few checks are performed once people have moved in, some households choose to cancel insurance expenditure as soon as possible. This situation prevails in most Caribbean countries (Auffret, 2003). In the French overseas departments, purchasing home insurance is also compulsory for tenants. Similarly, business practices indicate that little monitoring of insurance renewal is performed by landowners once their tenants have moved in.

I have built a unique household-level micro-database combining detailed information on the insured and the uninsured to estimate a model of insurance supply and demand within the French overseas departments. Following the characterization of uninsurable housing by the Inter-American Development Bank (IDB, 2000), I test for the impact of uninsurable housing on insurance demand by using proxies for low-quality dwellings. As no proxy for expected assistance is available, I build a test for the presence of charity hazard based on the impact of past sinistrality. Indeed, past disasters likely increase households’ estimated probability of suffering another disaster but also their expectation of receiving assistance, because this expectation is based on experience.

This paper provides demand-side explanations for the low insurance take-up rate in disaster-prone areas and compares their magnitude. I show that the low demand is mainly due to uninsurable housing and also likely to charity hazard. These results contribute to endogenous governmental compensation and show that an individual’s purchase of insurance coverage creates negative externalities by diminishing neighborhood eligibility for such aid. Besides, Friedl et al. (2014) show that social comparison makes insurance of correlated risks - as is the case with natural disasters - less attractive because of inequality aversion.

6In France, if the dwelling is destroyed, the homeowner has still to repay his loan. Thus, the homeowner bears the main part of the risk. However, the destruction of the dwelling implies the loss of the collateral for the bank.

7In the United States, banks or financial institutions can also require the purchase of flood insurance before granting a mortgage (Browne and Hoyt, 2000); there is very little monitoring of insurance renewal and many households do not renew their flood insurance policies (Kunreuther and Pauly, 2005).

8A companion paper in French draws initial basic and robust qualitative conclusions (Calvet and Grislain-Letrémy, 2011).
the growing literature on charity hazard in the case of natural disasters (Landry and Jahan-Parvar, 2011; Raschky et al., 2013). The price of the subsidized insurance offered in the French overseas departments does not significantly contribute to decrease insurance demand, as confirmed by the low price elasticity of insurance demand. Income elasticity of insurance demand is also estimated and its order of magnitude is comparable with other studies. I also show that neighbors’ insurance choices impact individual insurance decisions through peer effects and, to a lesser extent, through neighborhood eligibility for assistance. Finally, the existing insurance obligations (de facto for homeowners with outstanding loans, as in most Caribbean countries, and de jure for French tenants) are operant but do not guarantee that targeted households are insured, as some households may not renew their insurance contracts once they have settled in.

The paper is organized as follows. Section 2 presents the supply of natural disasters insurance provided in the French overseas departments. Section 3 details the data. Section 4 presents an overview of the model and Section 5 details its specification. Estimation results are commented in Section 6. Section 7 concludes.

2 Insurance supply in the French overseas departments

In Latin America and the Caribbean, developments in the supply of insurance for households remain isolated. In Brazil, the government-owned reinsurance institute is largely responsible for developing the supply of flood reinsurance; in Puerto Rico, a reserve for catastrophe losses was created in 1994 to improve the availability and the affordability of catastrophe insurance; in Manizales (Colombia), the city allows any resident to buy insurance from a private insurer through the municipal tax collection system (Charveriat, 2000; Fay and Wellenstein, 2005). Besides, this insurance supply can be fragile. Montserrat is a particularly telling example. In 1997, after several volcanic eruptions, insurance companies responsible for most policies withdrew from the island entirely (Oxford Analytica, 1997).

The French overseas departments provide a rare example of a well-developed and regulated supply of natural disasters insurance in Latin America, the Caribbean and other exposed small island countries. The French system of natural disasters insurance has been implemented in the French overseas departments since August 1, 1990. The government
provides an unlimited guarantee to this system and, in return, regulates the scope and the price of natural disasters coverage.

**Comprehensive home insurance.** The French law requires that comprehensive home insurance (which covers theft, fire, explosion or water damage) provides coverage of the dwelling for natural disasters.\(^9\) There is no obligation for insurers to offer home insurance, even to tenants, who have the legal obligation to purchase home insurance. To my knowledge, no other insurance policy provides coverage for natural disasters.

**Insured value.** I have compared the insurance quotes, online or by phone, of the main insurance companies (including mutual ones). French insurers ask for the number of rooms and sometimes the living space to estimate the insured value for the building, which is not chosen by the insured. On the contrary, households can choose their insured value for contents (furniture and valuable items).

**Natural disasters.** After a natural event, the French government decides whether this event is a natural disaster and which periods and municipalities are concerned. The decision relies on the conclusions of an interministerial commission, which analyzes the phenomenon on the basis of scientific reports. Insured households can benefit from the insurance compensation only if an order is published for the event concerned.

**Insurance pricing.** The French law requires the natural disasters premium to be a fixed share of the home insurance premium: the premium for natural disasters amounts to 12% of the premium charged for other risks.\(^{10}\) But insurers are allowed to increase the home insurance premium (and therefore the natural disasters premium) with respect to the exposure to natural risks.

**Reinsurance policy.** However, the French government gives insurers little incentive to price natural risks. Indeed, the government provides an unlimited guarantee to one reinsurer,

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\(^9\)See French Insurance Code, section L. 125-1. Home insurance is an accessible product, as households can purchase a policy over the phone in approximately 20 minutes.

\(^{10}\)See French Insurance Code, sections L. 125-2 and A. 125-2. Actually, the premium for natural disasters equals 12% of the premium charged for other damages, excluding for example the premium for civil liability coverage. For the sake of simplicity, the model ignores this exclusion (Section 5).
the *Caisse Centrale de Réassurance* (CCR), which offers insurers an attractive and non-actuarially-based reinsurance policy and captures more than 90% of market share on the natural disasters reinsurance market.\textsuperscript{11} Insurers transfer half of their natural risks to the CCR, and for the remaining half, they are exposed up to a deductible which equals the sum of the collected premiums. In return, they pay 63.5% of their collected natural disasters premiums (51.5% to the CCR as the price of reinsurance policy and 12% to the government as a tax to fund prevention measures; see Appendix A.2 for a detailed presentation of the reinsurance policy offered by the CCR).

As modeled in Section 5, the potential loss and reinsurance premium paid by the insurer are affected only to a very limited extent by the exposure of its policyholders. Consequently insurance premiums only partially reflect risk exposure and insurers have little incentive to acquire detailed information on their insured risk exposure (ex ante moral hazard) and to assess damages precisely (ex post moral hazard).

**Insurance take-up rate.** Despite the supply of broad coverage for natural disasters at a regulated price, in 2006 only half of households living in the French overseas departments had purchased home insurance, which includes natural disasters coverage, for their primary residence (Appendix A.3). This take-up rate is higher than the rate observed in other exposed countries, but remains much lower than the rate observed in metropolitan France, where households are far less exposed to natural risks but almost all insured (Appendix A.3).

### 3 Data

In this section I present the unique household-level micro-database that I have built to explain underinsurance in the French overseas departments. The database combines information about insurance expenditure for the insured, risk exposure, and other economic variables for the insured and the uninsured. I have built it by matching the GASPAR database, which provides information about exposure to natural disasters at the municipal level, with the 2006 French Household Budget survey.

The GASPAR database, compiled by the French Ministry of Ecology, is the database

\textsuperscript{11}Private communication to the author.
to support the computer-aided management of administrative procedures relative to natural and technological risks. It specifies which of five hazards each municipality is exposed to, out of earthquakes, volcanic eruptions, hurricanes or cyclones, tsunamis or floods, and ground movements (Table 8). It also provides the number of disasters by hazard type in each municipality from 1990 (date of the enforcement of the system of natural disasters insurance in the French overseas departments) until the survey date.

The French Household Budget survey, managed by the French National Institute of Statistics and Economics Studies, is a comprehensive national survey of household expenditure, and in particular insurance expenditure. Regarding home insurance, households declare whether they have purchased home insurance and if so the premium paid. Neither the identity of the different insurers nor the type of company (mutual insurance company or not) is given.

The French Household Budget survey also provides information about the household itself (such as size, income and standard of living, and, for the reference person, gender, age and place of birth). Detailed information about housing is given. Uninsurable housing is characterized by the Inter-American Development Bank as dwellings built in no solid materials or without drinking water or drainage (IDB, 2000). Following this characterization, uninsurable housing is measured using information about dwelling quality. Interestingly, good-quality dwellings are on average built in more exposed areas, probably because risk exposure also provides positive amenities (river view, fertile ground).

The 2006 French Household Budget survey includes 3,134 households living in the French overseas departments. As the decision whether to purchase insurance or not depends on the insurance price, I exclude from the study the households insured by their relatives or their employer and any households which declare themselves insured but do not report their premium amount. I also exclude observations for which key variables (annual income, number of rooms) are missing. Out of the initial 3,134 households, 2,809 observations remain.

Data on losses and assistance are unavailable. Insurers do not provide information on losses. Regarding assistance, households in the French overseas departments can rely on substantial financial assistance from the government (French Senate, 2005), local authorities, non-governmental organizations or relatives after natural disasters. Households’ anticipation

\[12\] The household reference person is either the family reference person when there is one, or the oldest man, with priority to the oldest active person.
of financial assistance is difficult to quantify because of the numerous assistance channels. One of the main channels of governmental assistance to overseas France is the disaster relief fund for overseas areas. This compensation covers damages caused by natural disasters in the primary residence (including rebuilding); it is funded by budgetary credits.\textsuperscript{13} Detailed data on assistance provided by the disaster relief fund for overseas areas are unavailable.\textsuperscript{14}

Table 1 describes my sample. The average municipal exposure to natural risks is high but very varied: according to the GASPAR database, while municipalities are on average exposed to 4 distinct natural hazards, some are exposed to 5 hazards, and others to none. On average, 8 natural disasters have occurred since 1990; this number reaches 18 in some municipalities, whereas others have been spared. 48\% of households living in the French overseas departments had purchased home insurance, which includes coverage for natural disasters, for their primary residence in 2006. This insurance rate also varies considerably between municipalities: it reaches 92\% in some, whereas in others no one is insured. The average premium paid by insured households is €254, with premiums ranging from €20 to €2,000. Annual income ranges from €600 to €169,637 for an average of €22,694. 36\% of households are tenants; 13\% are homeowners with outstanding loans, the remainder own their home freehold. Many houses lack modern conveniences: 23\% are without hot water, 53\% without drainage, and 4\% without toilets inside the building. 3\% of houses are still under construction.

4 Model overview

I estimate a model of insurance supply and demand in the line of Pauly (1974) and Rothschild and Stiglitz (1976). I present here an overview of the model, its specification being detailed in the following section.

Risk structure. A dwelling suffers a loss $L_d$ caused by natural disasters with probability $p_d$. I assume that uninsured households receive assistance $A_d$ after a disaster. The net loss is thus $L_d - A_d$. Ordinary risks (such as theft, fire, explosion or water damage) cause a loss

\textsuperscript{13}See order of December 8, 2010 relative to the implementation of assistance by the disaster relief fund for overseas areas.

\textsuperscript{14}Annual aggregate statistics were only provided at departmental level by the French Ministry of Overseas.
Table 1: Descriptive statistics

<table>
<thead>
<tr>
<th></th>
<th>Percentage / mean</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of natural hazards</td>
<td>4</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Number of past natural disasters</td>
<td>8</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>Households insured for their primary residence</td>
<td>48%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insured households living in the same municipality</td>
<td>47%</td>
<td>0%</td>
<td>0.92%</td>
</tr>
<tr>
<td>Premium paid by the insured</td>
<td>€254</td>
<td>€20</td>
<td>€2,000</td>
</tr>
<tr>
<td>Annual income</td>
<td>€22,694</td>
<td>€600</td>
<td>-€169,637</td>
</tr>
<tr>
<td>Standard of living</td>
<td>€13,359</td>
<td>€407</td>
<td>€87,266</td>
</tr>
<tr>
<td>Number of rooms</td>
<td>4</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>Tenants</td>
<td>36%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Homeowners with outstanding loans</td>
<td>13%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Houses still under construction</td>
<td>3%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Houses without hot water</td>
<td>23%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Houses without drainage</td>
<td>53%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Houses without toilets inside the building</td>
<td>4%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reference person born in metropolitan France</td>
<td>10%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reference person born abroad</td>
<td>8%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age of the reference person</td>
<td>49</td>
<td>17</td>
<td>95</td>
</tr>
<tr>
<td>Gender of the reference person (female)</td>
<td>46%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: (*) These variables are built at the municipality level and are public information. (†) Are considered past disasters that have occurred in each municipality from the enforcement of the insurance system (1990) to the sampling date (2006). 2006 French Household Budget survey and GASPAR database. 2,809 observations.

$L_o$ with probability $p_o$. No assistance is provided to compensate damages caused by these individual risks.

For the sake of simplicity, losses caused by natural disasters and damages caused by ordinary risks are assumed to be independent events. As the product of the two probabilities $p_dp_o$ is negligible with respect to any of the two probabilities, there are indeed three states of nature for a household: a high loss $L_d - A_d$ with a low probability $p_d$, a low loss $L_o$ with a high probability $p_o$, and no loss with probability $1 - p_d - p_o$.

Households’ risk perception is potentially biased, and may differ from the accurate risk assessment performed by insurers for the probability of ordinary losses $\tilde{p}_o$, for the probability of natural disasters $\tilde{p}_d$ and for the losses $\tilde{L}_d$ caused by natural disasters. For the sake of simplicity, I assume that households have the same estimation of their ordinary losses $L_o$ as insurers.
Insurance policy. As households’ coverage choices are restricted to contents in France (Section 2), I assume that insurers offer a single, standard policy with full coverage. Therefore households either purchase home insurance ($\alpha = 1$) or not ($\alpha = 0$).

Supply equation. The supply equation explains the insurance premium offered by insurers. Insurance companies are assumed to be price takers. Insurance market competition and the risk neutrality of insurers imply that insurers’ expected profit is zero for each group of identical households (for what is observed by the insurers). As no information is provided on the insurer, only a zero expected profit for all insurers taken together can be considered.\(^\text{15}\)

Zero expected profit means that collected premiums equal expected losses caused by ordinary risks $EL_o$ and by natural disasters $EL_d$. I add a multiplicative constant $c$; this loading factor represents transaction costs (information search, negotiation, policy drafting, controls, claim disputes).

$$\pi = c(EL_o + EL_d).$$ \hspace{1cm} (1)

Demand equation. The demand equation explains the household’s probability of purchasing insurance. The decision whether to purchase insurance or not results from the comparison households make between their expected utilities with and without insurance. A household is assumed to be risk averse; his utility function $U(\cdot)$ is concave with respect to his wealth. He purchases insurance ($\alpha = 1$) if and only if his expected utility $EU$ is higher when he is insured ($\alpha = 1$) than when he is not ($\alpha = 0$).

$$\alpha = 1 \iff EU|_{\alpha=1} \geq EU|_{\alpha=0}. \hspace{1cm} (2)$$

Given full insurance at price $\pi$, the expected utility of the insured of wealth $W$ is

$$EU|_{\alpha=1} = U(W - \pi).$$ \hspace{1cm} (3)

\(^{15}\text{However, some characteristics of policy-holders could capture their choice of insurance company (and this way indirectly modify the premium, even if insurers may not measure them). For example, some insurance companies (mainly mutual ones) cover civil servants exclusively and are said to increase premiums with respect to risk exposure to a smaller extent than other companies. Here dummies for civil servants and other characteristics such as age or gender appear as non significant in the premium estimation.}\)
Given that the product of the two probabilities $\tilde{p}_d\tilde{p}_o$ is negligible, the expected utility of the uninsured of wealth $W$ is

$$EU|_{\alpha=0} = \tilde{p}_o U(W - L_o) + \tilde{p}_d U(W - \tilde{L}_d + \tilde{A}_d) + (1 - \tilde{p}_o - \tilde{p}_d)U(W).$$

$$= U(W) - \tilde{p}_o[U(W) - U(W - L_o)] - \tilde{p}_d[U(W) - U(W - \tilde{L}_d + \tilde{A}_d)].$$

(4)

The decision whether to purchase insurance or not depends on the insurance price. Thus, there is a link between the demand and supply equations, which are simultaneously estimated using maximum likelihood (see Appendix A.4 for the detailed calculation of maximum likelihood).

5 Model specification

I detail the specification of the model, for the supply side and then for the demand side.

5.1 Supply equation

Here I precisely model collected premiums and expected losses, as they both reflect the specific design of the French system of natural disasters insurance (Section 2). I then specify the functions of losses and probabilities and the error attached to the supply equation. I finally present the identification and calibration of risk parameters. Calibration is based on constraints on insurance pricing imposed by the French government and on values provided by the literature or insurers’ statistics. Robustness tests to the choice of these parameters are performed.

**Premiums.** The home insurance premium $\pi$ is the sum of the premium for natural disasters $\pi_d$ and the premium for other risks $\pi_o$. The premium for natural disasters $\pi_d$ amounts to $r = 0.12$ of the premium for other risks $\pi_o$ (Section 2).

$$\begin{align*}
\pi &= \pi_d + \pi_o, \\
\pi_d &= r\pi_o.
\end{align*}$$

$$\Rightarrow \pi = \frac{1 + r}{r} \pi_d. \quad (5)$$
Expected losses. Expected ordinary losses equal

$$EL_o = p_o L_o.$$  \hfill (6)

All insurers are assumed to be reinsured against natural disasters by the CCR, since the CCR captures more than 90% of market share in the natural disasters reinsurance market (Section 2). Expected losses caused by natural disasters are determined by the non-actuarially-based reinsurance policy offered by the CCR (Section 2). Insurers transfer half of their risks to the CCR, and for the remaining half, they are exposed up to a deductible, which equals the natural disaster premium. In return, they have to pay a fixed share $k = 0.635$ of the natural disaster premium.

$$EL_d = p_d \min\left(\pi_d, \frac{L_d}{2}\right) + k\pi_d,$$

$$= (p_d + k)\pi_d.$$ \hfill (8)

as $\pi_d < \frac{L_d}{2}$. Thus, supply equation 1 becomes

$$\pi = c(p_o L_o + (p_d + k)\pi_d),$$  \hfill (9)

$$= c p_o L_o + c(p_d + k)\frac{r}{1 + r}\pi,$$ \hfill (10)

$$\Rightarrow \log(\pi) = \log(cp_o L_o) - \log\left(1 - ck\frac{r}{1 + r} - cp_d\frac{r}{1 + r}\right).$$ \hfill (11)

Ordinary losses. Losses are not directly measured (Section 3). They depend on the value of the building and on the value of contents. As shown by the many insurance quotes I have compared, the building value is estimated by the insurers mainly from the number of rooms $N$. The insured value for contents (furniture and valuable items) is chosen by the insured; I estimate it using the standard of living $Y$.\textsuperscript{16} Losses also depend on occupancy status, since tenants, denoted by $O_t = 1$, bear only a fraction $(1 - \tau)$, $\tau \geq 0$, of the losses, the remaining

\textsuperscript{16}The standard of living is measured by the income per consumption unit. The first adult is worth one consumption unit; the second adult and each child older than 14 are worth 0.5; younger children are worth 0.3.
part of them being borne by their landlord. Thus, the ordinary loss $L_{oi}$ for household $i$ is

$$L_{oi} = lN_i^nY_i^y(1 - \tau O_{ti}), \quad \tau \geq 0,$$

where $l$ is a multiplicative constant and $n$ and $y$ are the elasticities of the loss with respect to the number of rooms and the standard of living, respectively.

**Loss probabilities.** Insurers estimate the probability $p_d$ of natural disasters using information about physical hazards. Business practices indicate that French insurers use very basic information about natural risk exposure, likely because their financial exposure to natural risk is limited due to the reinsurance contract offered by the CCR (Section 2). I assume that the probability of natural disasters estimated by insurers for each household $i$ increases linearly with respect to the sum of hazards $R_i$ to which its municipality is exposed.

$$p_{di} = pR_i, \quad p \geq 0.$$

I have no specific information on the probability $p_o$ of ordinary losses, since I observe neither past ordinary losses nor other proxies for the probability of suffering these losses (Section 3).

**Error.** An error $\epsilon$ is attached to the supply equation. This error term is due to a potential assessment error made by the insurer. It is assumed to be normally distributed.

**Supply equation.** Using (11), (12) and (13) and given that $\alpha_i$ states whether the household $i$ purchases insurance or not, the supply equation becomes

$$
\begin{cases}
\text{if } \alpha_i = 1, & \log(\pi_i) = c_\pi + n \log(N_i) + y \log(Y_i) + \log(1 - \tau O_{ti}) \\
& - \log(1 - \kappa - \rho R_i) + \sigma \epsilon_i, \\
\text{if } \alpha_i = 0, & \pi_i = 0,
\end{cases}
$$

where $c_\pi = \log(cp_o l)$, $\rho = cpr/(1 + r)$ and $\kappa = ckr/(1 + r)$.

---

17Landlord is responsible for potential damages to contents in furnished dwellings, to the structure (walls, foundations) and for damages implying his liability (structural defects).
Identification and calibration of risk parameters. $c_{\pi}$, $\rho$, and $\kappa$ cannot be simultaneously identified. I estimate $c_{\pi}$ and $\rho$ and I calibrate $\kappa = \frac{ckr}{1 + r}$. $r = 0.12$ and $k = 0.635$ are imposed by the government and the CCR (Section 2). I calibrate loading factor $c$ using values provided by the literature: $c \approx 1.3$ (Gollier, 2003). Thus, I take $\kappa = \frac{ckr}{1 + r} \approx 0.088$. The significance and the sign of all estimated coefficients are robust when performed for $c \in \{1, 1.5\}$, that is for $\kappa \in \{0.068, 0.10\}$.

Estimation of $l$ is required to get ordinary losses $L_o$ (Equation 12), which also appear in the demand equation 2. Estimation of $c_{\pi} = \log(cp_ol)$ does not make it possible to simultaneously identify $p_o$ and $l$, even when considering that $c$ is already calibrated. As no proxy for the probability of ordinary losses $p_o$ is observed, I calibrate $p_o$ using statistics provided for metropolitan France: $p_o \approx 0.075$ (FFSA, 2006); the significance and the sign of all estimated coefficients are robust when performed for $p_o \in \{0.05, 0.5\}$.

5.2 Demand equation

Regarding the demand equation 2, I specify and calibrate the function of losses and the probability of ordinary losses, using values provided by insurers’ statistics. I then details the measurement of the different determinants of insurance demand. I present the performed tests for charity hazard, peer effects, and uninsurable housing. I specify how I control for insurance obligations. Insurance affordability, that is the impact of insurance price regarding household’s budget, is already captured by the comparison of the expected utilities with and without insurance. I also specify the selection bias and the error attached to the demand equation. I finally present the choices of utility function and of wealth measure. Robustness tests to the choice of each parameter are performed.

Losses and loss probabilities. Households are assumed to have the same estimation as insurers of their ordinary losses $L_o$. Due to the specificity of reinsurance policy, losses $\tilde{L}_d$ caused by natural disasters intervene in the demand equation only. These losses fundamen-

---

18In metropolitan France, between 2000 and 2004, home insurance statistics compiled by the French Federation of Insurance Companies show that the frequency of ordinary risks is around $p_o \approx 0.075$ (FFSA, 2006). Abroad, the probabilities of some of the ordinary risks are of the same order of magnitude. In Taiwan, the probability of fire occurrences in residential buildings per square meter of floor space is around 0.01 (Lin, 2005). In Long Beach (CA), the probability of burglary is around 0.019 for a house which has never been burglarized and reaches 0.59 after a first burglary (Short et al., 2009).
tally depend on the same dwelling characteristics as ordinary losses \( L_o \). For the sake of simplicity, I assume that, for every household \( i \),

\[
\bar{L}_{di} = \beta L_{oi}, \beta \geq 1. \tag{14}
\]

Because of this intrinsic link between ordinary losses and losses caused by natural disasters (that remains even in a nonproportional specification), the decrease in expected utility caused by ordinary losses, \( \tilde{p}_o[U(W) - U(W - L_o)] \), and the decrease in expected utility caused by natural disasters, \( \tilde{p}_d[U(W) - U(W - L_d + \tilde{A}_d)] \), are fundamentally linked and \((\tilde{p}_o, \tilde{p}_d, \beta)\) cannot be simultaneously identified. I favor the estimation of the natural disasters parameters, which makes it possible to capture charity hazard, and I calibrate \( \beta \) and \( \tilde{p}_o \).

I calibrate \( \beta \) using statistics provided by insurers: \( \beta = 15 \).\(^{20}\) As a sensitivity test, I have performed estimations for \( \beta \in \{10, 20\} \) and the significance and the sign of all estimated coefficients are robust to the choice of this parameter.\(^{21}\) Like in the supply equation, I calibrate the probability of ordinary losses: \( \tilde{p}_o = 0.075 \). The significance and the sign of all estimated coefficients are robust when performed for \( \tilde{p}_o \in \{0.05, 0.5\} \), while allowing \( \tilde{p}_o \) to be different from \( p_o \).

**Charity hazard.** As no proxy for expected assistance is observed (Section 3), I build a test for the presence of charity hazard based on the impact of past sinistrality. Indeed, past disasters have two opposite effects on households’ estimation of their exposure to natural disasters and so on their demand for insurance. On the one hand, the number \( S \) of past disasters increases households’ estimation of their probability \( \tilde{p}_d \) of suffering another disaster, which increases their insurance demand. On the other hand, past sinistrality can increase households’ expectation of receiving assistance \( \tilde{A}_d \), since their expectation is based on com-

\(^{19}\)Even once \( \beta \) is calibrated, \( \tilde{p}_o \) and a fixed part \( a \) in an affine function \( \tilde{p}_d(S) = a + bS \) are not simultaneously identified.

\(^{20}\)Home insurance statistics compiled by the French Federation of Insurers Companies show that the average damages caused by ordinary risks are around €1,200 (FFSA, 2006). Average damages caused by floods and ground movements for metropolitan households are around €7,500 and €15,000, respectively (Grislain-Letrémy and Peinturier, 2010). Thus, in metropolitan France the ratio of mean natural disaster losses over mean ordinary losses \( \bar{L}_d/\bar{L}_o \) ranges from 6.25 to 12.5. Given that natural disasters are more violent events in the French overseas departments, I take \( \beta = 15 \).

\(^{21}\)Indeed, as the potential losses cannot exceed the wealth of the household, wealth determines the upper limit of the range of values for \( \beta \). For \( \beta = 20 \), the potential losses already exceed the wealth of 17 households. Estimations provide consistent orders of magnitudes: losses \( L_o \) are between €300 and €2,700 (for \( \beta = 15 \)).
pensation provided to them after past events. This effect would on the contrary decrease insurance demand. The weight $q_d(S)$ of the utility loss due to natural disasters “summarizes” these two impacts of the number $S$ of past disasters.\footnote{Simultaneous estimation of functional forms of $\tilde{p}_d$ and $A_d$ with respect to $S$ obtains non robust results, as it can lead either to positive values, as expected, or to a huge amount of assistance (beyond loss, i.e., $A_d > L_d$) that would make the utility decrease positive: households would gain in the case of natural disasters and then $\tilde{p}_d$ becomes negative to balance this effect.} For each household $i$,

$$EU|\alpha=0,i = U(W_i) - \tilde{p}_o[U(W_i) - U(W_i - L_o)] - q_d(S_i)[U(W_i) - U(W_i - \beta L_o)].$$

(15)

Thus, a test for the presence of a charity hazard effect can be based on the sign of $\partial q_d/\partial S$. If the second effect exceeds the first one, that is if the weight $q_d$ of the utility loss after a natural disasters decreases with respect to the number of past disasters ($\partial q_d/\partial S \leq 0$), then there is an important charity hazard effect. On the contrary $\partial q_d/\partial S > 0$ would be consistent with a small or null value of the charity hazard effect (see Appendix A.5 for a proper formalization). Perception bias or uncontrolled differences in risk aversion could not imply a negative sign of $\partial q_d/\partial S$ (see also Appendix A.5 for a discussion).

**Neighborhood eligibility for assistance.** The rate of insured households around an individual household can reduce the charity hazard effect, as it decreases the likelihood of obtaining assistance after a disaster. To test for this endogenous nature of anticipated assistance, I supplement the term that captures charity hazard with the expected take-up rate $E(Z_{aid,i})$ of the group $J_{aid}$ of joint eligibility for assistance. For each household $i$,

$$q_{di} = (q + \theta E(Z_{aid,i}))S_i,$$

where

$$E(Z_{aid,i}) = \frac{\sum_{j \in J_{aid}, j \neq i} \alpha(j)}{\text{card}(J_{aid}) - 1}.$$

(17)

If $q$ is negative then there is a charity hazard effect; if $\theta$ is positive then this effect is decreased by the rate of insured neighbors.

**Peer effects.** An individual household’s decision to purchase insurance can also be impacted by his neighbors’ decision via social norms. To test for the presence of peer effects, I...
add the expected take-up rate $E(Z_{\text{peer}})$ of the group $J_{\text{peer}}$ of peers to the demand equation.\textsuperscript{23}

Different definitions for the group $J_{\text{aid}}$ for joint eligibility and for the group $J_{\text{peer}}$ of peers have been tested by crossing the municipal level (which is the smallest geographical level that I observe) with any other observed household characteristic (such as age, gender, occupational groups, place of birth).

**Place of birth.** The place of birth can also explain the probability of purchasing insurance via an “initial peer effect”, since having grown up in a place where the vast majority of people are insured can increase the probability of purchasing insurance. As the home insurance take-up rate of metropolitan France is exceptionally high \citep{Grislain-Letrémyn_and_Peinturier_2010}, I test for the impact of the place of birth by adding the dummies $B_m$ and $B_a$ for households born in metropolitan France and abroad, respectively, to the demand equation.

**Uninsurable housing.** Following the characterization of uninsurable housing by the Inter-American Development Bank (IDB, 2000), I test for the impact of uninsurability by adding dummies for low-quality housing: a dummy $H_c$ for houses still under construction and three dummies for houses without modern conveniences (without hot water $H_w$, without drainage $H_d$, and without toilets inside the house $H_t$).

**Insurance obligations.** Dummies for tenants $O_t$ and for homeowners with outstanding loans $O_l$ are added to control for these insurance obligations and to measure their impact. Results are robust when tenants and homeowners with outstanding loans are excluded from the sample and also when the model is estimated for tenants only.\textsuperscript{24}

**Selection bias.** I add the term $\nu \epsilon$, where $\epsilon$ is the error attached to the insurance premium. This term allows for a selection bias, i.e., for correlation between unobserved heterogeneity factors that affect the insurance premium and the decision to purchase insurance.

\textsuperscript{23}Such a modeling of the impact of other households’ decision (via neighborhood eligibility for assistance or peer effects) corresponds to a special case of Nash equilibrium, where the decision of the group impacts the household's decision but where the reverse impact is negligible because of the size of each group.

\textsuperscript{24}An estimation for homeowners with outstanding loans only is not possible, as they are only 336 of them.
Another error $\eta$ is also attached to the decision to purchase insurance. It can be interpreted as an assessment error made by households. It is also assumed to be normally distributed. $\epsilon$ and $\eta$ are assumed to be independent, since possible correlation is taken into account by the selection bias term.

**Choice of utility function.** Utility function is a constant relative risk aversion $U(W) = W^{1-\lambda}/(1-\lambda)$, which is a reasonably good approximation of individual attitude toward risk in an expected utility setting (Chiappori and Salanié, 2008). Estimations are performed here under the assumption that utility is the log function, which is the limit case of $U(W) = W^{1-\lambda}/(1-\lambda)$ as $\lambda$ tends to 1. Results are robust when using $\lambda = 2$ or $\lambda = 3$.

**Choice of wealth measure.** The wealth measure used to perform estimations corresponds to households’ holdings. Indeed, households can lose almost all their possessions in the case of a natural disaster. For the sake of simplicity, I assume that the household’s observed annual income is constant over time until the death of the household’s reference person. His/her life expectancy is calculated by linear interpolation using French registry office statistics (Niel and Beaumel, 2010). The significance and the sign of all coefficients are robust to this modification: they are similar when using the holdings as defined here or the annual income. Results are robust when calculating the holdings with a discount rate of 4% until 30 years and 2% beyond as recommended by Gollier (2007), of 10% as recommended by Andersen et al. (2008), of 20%, or when uniformly multiplying annual income up to 100.

---

Estimation of risk aversion raises numerical problems. Indeed, risk aversion determines the orders of magnitude of the terms expressing the expected utility losses; and if the orders of magnitude of the variables in the demand equation strongly differ, the model may be wrongly estimated (coefficients corresponding to the negligible terms may appear as non significant). For example, in the case of the log function, I use $U(W) = c_U \log(W)$, with $c_U = 10$. Indeed, with $c_U = 1$ the terms expressing the expected utility losses would be too small by comparison to the other terms and the corresponding coefficients would be poorly estimated. The adequate value of $c_U$ would be different when using another value of risk aversion $\lambda$. 

---

---

25Estimation of risk aversion raises numerical problems. Indeed, risk aversion determines the orders of magnitude of the terms expressing the expected utility losses; and if the orders of magnitude of the variables in the demand equation strongly differ, the model may be wrongly estimated (coefficients corresponding to the negligible terms may appear as non significant). For example, in the case of the log function, I use $U(W) = c_U \log(W)$, with $c_U = 10$. Indeed, with $c_U = 1$ the terms expressing the expected utility losses would be too small by comparison to the other terms and the corresponding coefficients would be poorly estimated. The adequate value of $c_U$ would be different when using another value of risk aversion $\lambda$. 

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---
Estimated model. Finally, the estimated model is

\[
\begin{align*}
\alpha_i = 1 \iff & [U(W_i - \pi_i) - U(W_i)] + \tilde{p}_o[U(W_i) - U(W_i - L_{oi})] \\
+ [qS_i + \theta E(Z_{bild,i})S_i][U(W_i) - U(W_i - \beta L_{oi})] + \delta E(Z_{peer,i}) + b_m B_{di} + b_a B_{ai} \\
+ h_c H_{ci} + h_w H_{wi} + h_d H_{di} + h_t H_{ti} + c_i O_{ti} + o_i O_{li} + \nu \epsilon_i + \eta_i \geq 0, & \quad (18)
\end{align*}
\]

if \( \alpha_i = 1 \), \( \log(\pi_i) = c_{\pi} + n \log(N_i) + y \log(Y_i) + \log(1 - \tau O_{li}) \)

\[- \log(1 - \kappa - \rho R_i) + \sigma \epsilon_i, \quad (19)\]

if \( \alpha_i = 0 \), \( \pi_i = 0 \).

where errors \( \epsilon \) and \( \eta \) follow independent centered normal distributions with unit variance, \( c_{\pi} = \log(cp_o l) \) and \( \rho = cpr/(1 + r) \) are estimated parameters and \( \kappa = ckr/(1 + r) \), \( \tilde{p}_o \) and \( \beta \) are calibrated parameters. The utility function is \( U(\cdot) = c_U \log(\cdot) \) with \( c_U = 10 \).

5.3 Identifying variables

Identification requires the presence of variables that explain the probability of purchasing insurance but not the insurance premium.\(^{26}\) These identifying variables are the dummies for houses still under construction \((H_{c})\) and without drainage \((H_{d})\).\(^{27}\)

Interestingly, the economic meaning of these identifying variables is that houses still under construction or without drainage have a lower probability of being insured but, once a house is covered, the price of its coverage does not depend on these characteristics. Indeed, business practices indicate that most of the time insurers check building quality once a loss has occurred, before paying compensation. After a claim, the insurance adjuster checks the loss and the building quality. If he records that the dwelling quality is low, he either offers to raise the premium, or cancels the insurance contract and pays off the premiums received until then. For example, if the dwelling was still under construction before the loss, the insurance policy is canceled. This check and its consequences can easily be anticipated by

\(^{26}\)These dummies do not significantly explain the losses, even when considering that losses can be estimated differently by households and by insurers.

\(^{27}\)Houses still under construction and houses without drainage correspond to 3% and 53% of dwellings, respectively (Table 1). The model is overidentified, as identification requires one variable only to be excluded from the demand equation. Here, the two identifying variables are compatible: when only one of them is excluded from the premium, the remaining one is not significant in the premium equation and both variables are significant in the demand equation.
the concerned households, who will not buy insurance.\footnote{Information about business practices detailed in this paragraph has been provided to the author in private communications.}

6 Results

6.1 Supply

Insurance pricing. Table 2 presents the results of the estimation of the insurance premium (Equation 19). As expected, the insurance premium increases with respect to the number of rooms of the dwelling ($n > 0$) and the standard of living ($y > 0$), which explain the insured value. Besides, as tenants insure only a fraction of the total value of the dwelling, the insurance premium is lower for tenants ($\tau > 0$). The premium increases with respect to exposure to natural disasters ($\rho > 0$), confirming that insurers’ potential loss depends on the exposure of their policyholders, even if only to a very limited extent (Section 2).

Table 2: Estimation results: supply equation

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Estimate</th>
<th>Standard error</th>
<th>Pr &gt;</th>
<th>t value</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$c_\pi$</td>
<td>2.4</td>
<td>0.16</td>
<td>&lt;0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$n$</td>
<td>0.32</td>
<td>0.047</td>
<td>&lt;0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$y$</td>
<td>0.22</td>
<td>0.016</td>
<td>&lt;0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\tau$</td>
<td>0.29</td>
<td>0.027</td>
<td>&lt;0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\rho$</td>
<td>0.056</td>
<td>0.0068</td>
<td>&lt;0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma$</td>
<td>0.61</td>
<td>0.015</td>
<td>&lt;0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\kappa$</td>
<td>0.088</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: $\kappa = ckr/(1 + r)$ is calibrated at 0.088 (using $c = 1.3$, $k = 0.635$ and $r = 0.12$). 2006 French Household Budget survey and GASPAR database. 2,809 observations.

Insurance affordability. Some overseas households may not be able to afford insurance, as the median standard of living in the French overseas departments is almost 40% lower than in metropolitan France (Michel et al., 2010). To determine whether insurance is affordable for overseas households, the premiums offered to the uninsured are estimated using these coefficients.\footnote{These estimated coefficients (Table 2) correct the presence of a significant selection bias in Equation 18 (Table 4). In other words, this estimation takes into account the presence of unobserved heterogeneities}
The premiums offered to the uninsured are on average 9% lower than the premiums paid by the insured, mainly because the uninsured are poorer on average (Table 3). As the premium increases less than proportionally with respect to income \((y < 1, \text{Table 2})\), the budget weight (ratio of the premium over annual income) decreases with respect to income: the budget weight of the premium is therefore higher for the uninsured (the mean being 2.1%) than for the insured (1.4%), though it remains low (Table 3). This low budget weight of insurance premiums for the uninsured suggests that insurance premiums should not prevent them from purchasing insurance. To properly answer this question, an estimation of the price elasticity of insurance demand is performed below.

### Table 3: Home insurance: premium and budget weight

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Lower quartile</th>
<th>Median</th>
<th>Upper quartile</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Uninsured households</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Premium (2006 €)</td>
<td>231</td>
<td>187</td>
<td>236</td>
<td>274</td>
</tr>
<tr>
<td>Annual income (2006 €)</td>
<td>15,735</td>
<td>7,756</td>
<td>13,032</td>
<td>20,236</td>
</tr>
<tr>
<td>Budget weight</td>
<td>2.1%</td>
<td>1.2%</td>
<td>1.7%</td>
<td>2.6%</td>
</tr>
<tr>
<td><strong>Insured households</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Premium (2006 €)</td>
<td>254</td>
<td>118</td>
<td>180</td>
<td>300</td>
</tr>
<tr>
<td>Annual income (2006 €)</td>
<td>30,217</td>
<td>13,974</td>
<td>25,056</td>
<td>40,222</td>
</tr>
<tr>
<td>Budget weight</td>
<td>1.4%</td>
<td>0.5%</td>
<td>0.8%</td>
<td>1.4%</td>
</tr>
</tbody>
</table>

*Notes: 2006 French Household Budget survey and GASPAR database. 2,809 observations.*

### 6.2 Demand

Table 4 presents the estimation results for the demand equation (Equation 18). These results are commented and derived to quantify and compare the magnitude of demand determinants, in particular price and income elasticities of insurance demand.

**Charity hazard.** The probability of purchasing insurance decreases with respect to the number of past disasters that have occurred in the municipality. As explained in Appendix that increase the probability of purchasing insurance and the insurance premium. These unobserved heterogeneities may be relative to risk aversion: households with higher risk aversion have a higher probability of purchasing insurance; their higher risk aversion may be partially measured by insurers and therefore reflected in their premium. Regarding residuals, using their estimated variance implies that residuals for the uninsured are assumed to have the same variance as those for the insured.
Table 4: Estimation results: demand equation

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Estimate</th>
<th>Standard error</th>
<th>Pr &gt;</th>
<th>t value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$q$</td>
<td>-0.065</td>
<td>0.011</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>$\theta$</td>
<td>0.095</td>
<td>0.020</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>$\delta$</td>
<td>0.67</td>
<td>0.13</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>$b_m$</td>
<td>0.77</td>
<td>0.11</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>$b_a$</td>
<td>-0.53</td>
<td>0.099</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>$h_c$</td>
<td>-0.71</td>
<td>0.23</td>
<td>0.0020</td>
<td></td>
</tr>
<tr>
<td>$h_w$</td>
<td>-0.85</td>
<td>0.076</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>$h_d$</td>
<td>-0.50</td>
<td>0.061</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>$h_t$</td>
<td>-0.70</td>
<td>0.20</td>
<td>0.00050</td>
<td></td>
</tr>
<tr>
<td>$o_t$</td>
<td>0.34</td>
<td>0.070</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>$o_l$</td>
<td>0.83</td>
<td>0.094</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>$\nu$</td>
<td>0.41</td>
<td>0.095</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>$\tilde{p}_o$</td>
<td>0.075</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\beta$</td>
<td>15</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: $\tilde{p}_o$ and $\beta$ are calibrated at 0.075 and 15, respectively. 2006 French Household Budget survey and GASPAR database. 2,809 observations.

A.5, the negative sign of $q$ likely indicates that households’ anticipation of assistance increases with respect to the number of past disasters that have occurred in the municipality. There is indeed a cumulative effect in the anticipation of assistance: households living in municipalities where numerous disasters have occurred are more aware than other households of the scope of assistance; therefore they anticipate higher amounts of ex post aid.

**Neighborhood eligibility for assistance.** The take-up rate in the group for aid eligibility decreases the charity hazard effect ($\theta > 0$), meaning that the percentage of insured households around one individual decreases his/her likelihood of obtaining assistance after a disaster. The effect of neighborhood eligibility for assistance is significant at the municipal level, suggesting that there is no favoritism towards households sharing one of the observed characteristics. This effect is of small magnitude (Table 5).

**Peer effects.** The take-up rate in the neighborhood directly increases the individual probability of purchasing insurance ($\delta > 0$). Peer effects are also significant at the municipal level. They are of important magnitude. Indeed, assuming that 3 out of 4 households living in the municipality were insured, if peer effects only were at stake, the individual probability
of purchasing insurance would reach 0.65 (Table 5).

Both external effects of neighbors’ decision to purchase insurance (based on aid eligibility or peer effects) remain significant when considering one without the other.

Place of birth. Households whose reference person is born in metropolitan France have a higher probability of purchasing insurance \( (b_m > 0) \), whereas those born abroad have a lower probability of purchasing insurance \( (b_a < 0) \). This result suggests that having grown up in a place where the vast majority of people are insured increases the probability of being insured. This “initial peer effect” is also of considerable magnitude. If all households were born in metropolitan France, the percentage of insured households would go from 48% to 71%. On the contrary, if all households were born abroad, the percentage of insured households would drop from 48% to 29% (Table 5).

Uninsurable housing. As expected, households living in a house under construction or without modern conveniences have a lower probability of purchasing insurance \( (h_c, h_w, h_d, h_t < 0) \). In practice, insurers check building quality once a loss has occurred, before paying compensation. This check can easily be anticipated by the households living in low-quality dwellings and likely deters them from buying insurance. The impact of uninsurable housing is of important magnitude: if all households were living in a house still under construction, the percentage of insured households would drop from 48% to 19%; if all dwellings were houses without hot water, the insurance take-up rate would drop to 13%; if they were living in a house without drainage, this rate would drop to 36%; if all dwellings were houses without toilets inside the building, this rate would drop to 19% (Table 5).

Insurance obligations. Tenants, and homeowners with outstanding loans even more so, have a higher probability of purchasing insurance than homeowners \( (o_t > o_t > 0) \). This result shows that the existing constraints relative to insurance purchase are operant. Moreover, they have an important impact: if all households were tenants, the percentage of insured households would go from 48% to 60% (Table 5); if all households were homeowners with outstanding loans, the percentage of insured households would reach 72% (Table 5).
Table 5: Impact of some determinants of insurance demand

<table>
<thead>
<tr>
<th>Assumption</th>
<th>Percentage of insured households</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Municipal insurance rate</strong></td>
<td></td>
</tr>
<tr>
<td>Municipal insurance rate = 75%</td>
<td></td>
</tr>
<tr>
<td>via aid eligibility only</td>
<td>0.49 (*)</td>
</tr>
<tr>
<td>via peer effects only</td>
<td>0.65 (*)</td>
</tr>
<tr>
<td><strong>Place of birth</strong></td>
<td></td>
</tr>
<tr>
<td>$B_m = 1$</td>
<td>71%</td>
</tr>
<tr>
<td>$B_a = 1$</td>
<td>29%</td>
</tr>
<tr>
<td><strong>Uninsurable housing</strong></td>
<td></td>
</tr>
<tr>
<td>$H_c = 1$</td>
<td>19%</td>
</tr>
<tr>
<td>$H_w = 1$</td>
<td>13%</td>
</tr>
<tr>
<td>$H_d = 1$</td>
<td>36%</td>
</tr>
<tr>
<td>$H_t = 1$</td>
<td>19%</td>
</tr>
<tr>
<td><strong>Insurance obligations</strong></td>
<td></td>
</tr>
<tr>
<td>$O_t = 1$</td>
<td>60%</td>
</tr>
<tr>
<td>$O_l = 1$</td>
<td>72%</td>
</tr>
</tbody>
</table>

Notes: the initial percentage of insured households is 48%. (*) Here is given the individual probability of purchasing insurance. 2006 French Household Budget survey and GASPAR database. 2,809 observations.

**Price elasticity of insurance demand.** The elasticity of insurance demand with respect to the premium is $-5 \cdot 10^{-4}$, which is far lower than results found by other studies for home and flood insurance (Table 6). This is partly due to the fact that the premium is negligible with respect to households’ holdings. However, even when the model is estimated using annual income as wealth, the price elasticity of insurance demand remains of comparable low magnitude. Indeed, when the premium increases by 50%, the number of households that are willing to purchase insurance decreases by only 0.2% or 1.4%, when the model is estimated using wealth or annual income, respectively. This small price elasticity is mainly due to the subsidized natural disasters coverage provided by home insurance. This result confirms that, in the French overseas departments, households are not deterred from purchasing insurance by its price.

**Income elasticity of insurance demand.** The elasticity of insurance demand with respect to income can also be calculated and its order of magnitude is consistent with other studies (Table 6). The income elasticity of insurance demand equals 0.10 or 0.03, when the
model is estimated using wealth or annual income, respectively. Its positive sign confirms that the insured are wealthier on average than the uninsured (Table 3). Income elasticity of insurance demand may be positive or negative. Indeed, two opposite effects come into play. On the one hand, theory predicts that while absolute risk aversion decreases with respect to income, demand for insurance also decreases with respect to income (Schlesinger, 2000). On the other hand, wealthier households may buy more expensive houses, thereby exposing themselves to higher potential losses and increasing their need for coverage (Cleeton and Zellner, 1993). The positive sign of income elasticity means that the latter effect outstrips the former.

Table 6: Price and income elasticities of demand for home and flood insurance

<table>
<thead>
<tr>
<th>Line of insurance and place</th>
<th>Definition of demand</th>
<th>Price elasticity</th>
<th>Income elasticity</th>
<th>Citation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Home insurance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>French overseas departments</td>
<td>(PP)</td>
<td>$-5 \cdot 10^{-4}$</td>
<td>0.10</td>
<td>Current study</td>
</tr>
<tr>
<td>Florida</td>
<td>(FA)</td>
<td>-1.08</td>
<td>0.06</td>
<td>Grace et al.</td>
</tr>
<tr>
<td>New York</td>
<td>(FA)</td>
<td>-0.86</td>
<td>-0.03</td>
<td>(2004)</td>
</tr>
<tr>
<td><strong>National flood insurance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>United States</td>
<td>(PP)</td>
<td>-0.11</td>
<td>1.40</td>
<td>Browne and Hoyt</td>
</tr>
<tr>
<td>United States</td>
<td>(FA)</td>
<td>-1.00</td>
<td>1.51</td>
<td>(2000)</td>
</tr>
</tbody>
</table>

Notes: insurance demand is defined either by the percentage of the population that has purchased policies (PP) or by the face amount of coverage (FA).

7 Conclusion

This paper studies the reasons for low insurance coverage against natural disasters in Latin America and the Caribbean. Reduced availability or unaffordability of insurance are commonly identified as primary causal factors. The French overseas departments provide a rare example of a well-developed supply of natural disasters insurance in these highly exposed regions. This broad and regulated supply makes it possible to analyze the determinants of insurance coverage on the demand side.

I show that uninsurable housing and also likely charity hazard explain the low demand for

\[ \phi_a + \eta > 1 \]

where \(\phi_a\) is the elasticity of relative risk aversion to initial income and \(\eta\) is the elasticity of the amount of risk with respect to initial income.
insurance. The price of the subsidized insurance offered in the French overseas departments does not significantly contribute to decrease insurance demand, as confirmed by the low price elasticity of insurance demand. Furthermore, neighbors’ insurance choices impact individuals’ decision to purchase insurance decision through peer effects and, to a lesser extent, through neighborhood eligibility for assistance. Finally, I show that the existing insurance obligations are operant but do not guarantee that targeted households are insured, as these households may not renew their insurance policies once they have settled in.

On the supply side, results illustrate the great impact of regulation on insurers’ pricing behavior. The French government provides an unlimited guarantee to one reinsurer and, in return, regulates the scope and the price of natural disaster coverage. Beyond strict regulation, the attractive, non-actuarially-based reinsurance policies offered by this reinsurer provide little incentive for insurers to price natural risks in their insurance policies. Similar pricing distortions have been observed in other markets; in the retail electricity market for example, intermediaries’ pricing reflects their limited exposure and not the real price (Joskow and Tirole, 2006).

References


A Appendices

A.1 Exposure to natural disasters of the Caribbean region

Table 7: Destructive impact of natural disasters in the Caribbean region

<table>
<thead>
<tr>
<th>Country</th>
<th>Time</th>
<th>Event</th>
<th>Damages (% of GDP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>St Lucia</td>
<td>1988</td>
<td>Hurricane Gilbert</td>
<td>365</td>
</tr>
<tr>
<td>Grenada</td>
<td>2004</td>
<td>Hurricane Ivan</td>
<td>203</td>
</tr>
<tr>
<td>Dominica</td>
<td>1979</td>
<td>Hurricanes David and Fredrick</td>
<td>101</td>
</tr>
<tr>
<td>St Kitts and Nevis</td>
<td>1995</td>
<td>Hurricane Luis</td>
<td>85</td>
</tr>
<tr>
<td>St Lucia</td>
<td>1980</td>
<td>Hurricane Allen</td>
<td>66</td>
</tr>
<tr>
<td>Antigua and Barbuda</td>
<td>1995</td>
<td>Hurricane Luis</td>
<td>61</td>
</tr>
<tr>
<td>Guyana</td>
<td>2005</td>
<td>Floods</td>
<td>59</td>
</tr>
</tbody>
</table>

Notes: Heger et al. (2008).

A.2 Reinsurance policy

The reinsurance policy offered by the CCR is such that the insurer yields 50% of the sum of all the natural disasters premiums it has collected (over all policies) and 50% of its losses caused by natural disasters (over all policies) to the CCR (quota-share contract). So, the insurer keeps half of the premiums and covers half of the risks. For its remaining risks, it is exposed up to a deductible, which equals the sum of the initially collected premiums (stop-loss contract). The deductible is reassessed each year according to the reserve constituted by the insurer. In 2006, the amount paid by insurers to the CCR corresponded to 51.5% of the collected premiums (€670 million over €1.3 billion, Letremy (2009)), that is 50% as the price of the quota-share policy and 1.5% as the price of the stop-loss policy. In practice, the stop-loss price depends on the composition of the insurer’s portfolio in terms of professional risks and not household risks (private communication to the author). Besides, insurers also have to give the French government 12% of the collected premiums to fund prevention measures (see French Environment Code, section L. 561-3). Thus, over the initially collected natural disasters premium, the insurer pays 63.5% of the premium, that is 51.5% to the CCR and 12% to the government.

This reinsurance policy is applied to the whole set of natural disasters policies offered by the insurer overall (home, firm, and car insurance in metropolitan France, overseas departments and territories). For the sake of simplicity, the model compares the premium of one home insurance policy with the additional expected coverage that it represents (Section 5).
A.3 Exposure and underinsurance in the French overseas departments

Table 8: Population, exposure to major natural risks and home insurance take-up rate for primary residences in France in 2006

<table>
<thead>
<tr>
<th></th>
<th>French Guiana</th>
<th>Guadeloupe</th>
<th>Martinique</th>
<th>Réunion</th>
<th>Metropolitan France</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>205,954</td>
<td>400,736</td>
<td>397,732</td>
<td>781,962</td>
<td>61,399,733</td>
</tr>
<tr>
<td>Percentage of households exposed to natural hazards</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Earthquakes</td>
<td>0</td>
<td>100</td>
<td>100</td>
<td>55(*)</td>
<td>59(*)</td>
</tr>
<tr>
<td>Volcanic eruptions</td>
<td>0</td>
<td>30</td>
<td>100</td>
<td>65</td>
<td>0</td>
</tr>
<tr>
<td>Wind effects</td>
<td>0</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>8(*)</td>
</tr>
<tr>
<td>Tsunamis and floods</td>
<td>85(†)</td>
<td>84</td>
<td>100</td>
<td>100</td>
<td>21(†)</td>
</tr>
<tr>
<td>Ground movements</td>
<td>70</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>19</td>
</tr>
<tr>
<td>Forest fires</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>19</td>
</tr>
<tr>
<td>Avalanches</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Percentage of households insured for their primary residence</td>
<td>52</td>
<td>43</td>
<td>50</td>
<td>59</td>
<td>99</td>
</tr>
</tbody>
</table>

Notes: (*) Réunion and metropolitan France are exposed to low intensity earthquakes; metropolitan France is also exposed to low intensity wind effects. (†) French Guiana and metropolitan France are exposed to low intensity tsunamis but to high intensity floods. Population census in 2006; GASPAR database by the French Ministry of Ecology; 2006 French Household Budget survey (13,374 observations for percentage calculations).

A.4 Calculation of the model likelihood

Estimation is based on maximum log-likelihood. The calculation of the likelihood is detailed hereafter.

By denoting

\[ Z_\alpha = \bar{p}_o [c_U \log(W_i) - c_U \log(W_i - L_{oi})] + [q S_i + \theta E(Z_{iid,i}) S_i] [c_U \log(W_i) - c_U \log(W_i - \beta L_{oi})] \]

\[ + \delta E(Z_{peer}) + b_m B_m + b_a B_a + h_e H_e + h_w H_w + h_d H_d + h_H H_t + a_o O_t + a_l O_l, \]

\[ Z_\pi = c_\pi + n \log(N) + y \log(Y) + \log(1 - \tau O_t) - \log(1 - \kappa - \rho R), \]

the estimated model (Equations 18 and 19) becomes

\[ \begin{cases} 
\alpha = 1 & \iff [c_U \log(W - \pi) - c_U \log(W)] + Z_\alpha + \nu \epsilon + \eta \geq 0, \\
\text{if } \alpha = 1, & \log(\pi) = Z_\pi + \sigma \epsilon, \\
\text{if } \alpha = 0, & \pi = 0.
\end{cases} \]

The probability density function of centered normal distribution with unit variance is denoted \( \varphi(\cdot) \) and the cumulative density function is denoted by \( \Phi(\cdot) \).

For an insured household that pays a premium \( \pi \), using the symmetry of the normal
distribution, the probability of purchasing insurance is

\[ Pr\left( \eta \geq -\left( c_U \log \left( 1 - \frac{\pi}{W} \right) + Z_\alpha + \nu \epsilon \right) \right) = \Phi \left( c_U \log \left( 1 - \frac{\pi}{W} \right) + Z_\alpha + \nu \epsilon \right), \tag{24} \]

and the hazard is \( \epsilon = (\log(\pi) - Z_\pi) / \sigma \) with probability \( 1 / \sigma \cdot \varphi \left( (\log(\pi) - Z_\pi) / \sigma \right). \) Thus, for an insured household that pays a premium \( \pi, \) the likelihood function is

\[ \frac{1}{\sigma} \varphi \left( \frac{\log(\pi) - Z_\pi}{\sigma} \right) \Phi \left( c_U \log \left( 1 - \frac{\pi}{W} \right) + Z_\alpha + \nu \frac{\log(\pi) - Z_\pi}{\sigma} \right), \tag{25} \]

For an uninsured household, the premium is not observed. Thus, the expected value of the probability of not purchasing insurance is

\[ 1 - \int_{\mathbb{R}} \Phi \left( c_U \log \left( 1 - \frac{\exp(Z_\pi + \sigma \epsilon)}{W} \right) + Z_\alpha + \nu \epsilon \right) \varphi(\epsilon) d\epsilon. \tag{26} \]

Following Laroque and Salanié (2002)'s method to approximate such an integral, I denote by \( \epsilon_i \) the \( i \)-th \( m \)-quantile (\( \Phi(\epsilon_i) = i/m \)) and calculate \( \bar{\epsilon}_i \), the average normal-weighted point in each interval \([\epsilon_i, \epsilon_{i+1}]\). As \( x \varphi(x) = -\varphi'(x) \),

\[ \bar{\epsilon}_i = \frac{\int_{\epsilon_i}^{\epsilon_{i+1}} x \varphi(x) dx}{\Phi(\epsilon_{i+1}) - \Phi(\epsilon_i)} = m \left[ \varphi(\epsilon_i) - \varphi(\epsilon_{i+1}) \right], \tag{27} \]

and the integral can be approximated by

\[ \int_{\mathbb{R}} F(\epsilon) \varphi(\epsilon) d\epsilon \approx \frac{1}{m} \sum_{i=0}^{m-1} F(\bar{\epsilon}_i). \tag{28} \]

Results are presented here for \( m = 10 \); they are robust when using \( m = 20 \).

A.5 Testing for the presence of charity hazard

Given that no data for expected assistance is provided (Section 3), I build a test for the presence of charity hazard based on the impact of past sinistrality. The idea consists in disentangling the two opposite effects of the number \( S \) of past disasters on the expected utility of the uninsured. As stated by Equation 4,

\[ EU_{|a=0} = U(W) - \bar{p}_o[U(W) - U(W - L_0)] - \bar{p}_d(S)[U(W) - U(W - \tilde{L}_d + \tilde{A}_d(S))]. \tag{29} \]

On the one hand, the number \( S \) of past disasters raises the anticipated probability of natural disasters \( \tilde{p}_d(S) \), which increases the anticipated loss of utility. This is the utility loss effect (ULE), which decreases the expected utility of the uninsured (and increases insurance demand). On the other hand, the number \( S \) of past disasters increases the anticipation of as-
asistance $\tilde{A}_d(S)$. This is the charity hazard effect (CHE), which increases the expected utility of the uninsured (and decreases insurance demand). The sign of $\partial EU|_{\alpha=0}/\partial S$ is determined by the sign of

$$\text{ULE} + \text{CHE} = \frac{\partial \tilde{p}_d}{\partial S} \left( \frac{U(W - \tilde{L}_d + \tilde{A}_d(S)) - U(W)}{UL \leq 0} \right) + \tilde{p}_d(S) \frac{\partial \tilde{A}_d}{\partial S} \left( \frac{U'(W - \tilde{L}_d + \tilde{A}_d(S))}{\text{ULE} \leq 0} \right) \gtrless 0,$$

$$= \frac{\partial q_d}{\partial S} \text{UL} \leq 0.$$

As data on assistance are unavailable, only the sum of ULE and CHE can be identified. Thus, the presence of a charity hazard effect can be detected only if it exceeds the utility loss effect, i.e., only if $\text{CHE} \geq |\text{ULE}|$, that is only if $\frac{\partial q_d}{\partial S} \leq 0$. If on the contrary $\frac{\partial q_d}{\partial S} > 0$, then $\text{CHE} < |\text{ULE}|$, which would be consistent with a small or null value of the charity hazard effect.

$$\frac{\partial q_d}{\partial S} \leq 0 \Leftrightarrow \text{CHE} \geq |\text{ULE}| \Rightarrow \frac{\partial \tilde{A}_d}{\partial S} \geq 0. \quad (30)$$

A negative sign of $\frac{\partial q_d}{\partial S}$ indicates that households’ anticipation of assistance increases with respect to the number $S$ of past disasters that have occurred in the municipality.

Let us check that no other phenomenon could imply a negative sign of $\frac{\partial q_d}{\partial S}$. Perception biases could decrease the perception of extreme risks and consequently the demand for insurance. Could some perception biases imply that the perceived utility loss decreases with respect to the number $S$ of past disasters? One perception bias could have such an impact. The belief in the law of small numbers states that when their dwelling has been damaged by a first disaster, households may consider that the probability of being struck again is lower. But households may not hold this belief after having been struck several times, as is the case here - they have suffered 8 disasters on average since 1990 (Table 1).

A negative sign of $q$ could derive from uncontrolled differences in risk aversion. Indeed, one cannot exclude for now that more exposed households do not purchase insurance because they have a lower risk aversion. Risk aversion increases with respect to age (Palsson, 1996) and is higher among women (Halek and Eisenhauer, 2001). Data show that households living in more exposed areas are presumed to be actually more (and not less) risk averse (Table 9): they are older, the proportion of women among them is higher. Besides, among households living in more exposed areas, the proportions of people either born in metropolitan France (who could be used to managing risk differently), or who purchase automobile insurance - with limited or extended coverage - are not significantly higher.
Table 9: Self-selection on housing market: correlation between proxies for risk aversion and the number of past disasters in the municipality

| Factor                                      | Correlation value | Pr > |r|   |
|---------------------------------------------|-------------------|------|-----|
| Age of the reference person                 | 0.060             | 0.0015|
| Gender (female) of the reference person     | 0.068             | 0.0003|
| Place of birth (metropolitan France) of the reference person | -0.0032         | 0.86 |
| Insured automobile                          | -0.0053           | 0.78 |
| Comprehensive automobile coverage           | 0.029             | 0.13 |

Notes: Only third-party insurance is mandatory for automobiles. Only 1.5% of households own a car without this coverage. 2006 French Household Budget survey and GASPAR database. 2,809 observations.