Direction des Études et Synthèses Économiques

G 2013 / 12

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Document de travail

Institut National de la Statistique et des Études Économiques

INSTITUT NATIONAL DE LA STATISTIQUE ET DES ÉTUDES ÉCONOMIQUES

Série des documents de travail
de la Direction des Études et Synthèses Économiques

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10 OCTOBRE 2013

L'auteur remercie Pierre-André Chiappori, Pierre-Philippe Combes, Xavier D'Haultfoeuille, Eric Dubois, Meglena Jeleva, Guy Laroque, Claire Lelarge, David Martimort, Philippe Mongin, Corinne Prost, Bernard Salanié, Sandrine Spaeter, Eric Strobl, Yoshihiko Suzawa, et Bertrand Villeneuve pour leurs remarques et suggestions. L'auteur remercie Stephen Coate pour son éclairage sur les aides publiques. Ce travail a également bénéficié de commentaires de Lucie Calvet, Nicolas Grislain, Laurence Rioux, Corentin Trevien, Lionel Wilner et des participants à l'école d'été internationale de Belpasso sur l'économie des ressources et de l'environnement de 2011, au séminaire interne du laboratoire de microéconométrie du CREST, au séminaire de microéconomie théorie appliquée de Columbia University, à la 74ème conférence économique atlantique internationale, à la 20ème conférence annuelle de l'association européenne de l'économie des ressources et de l'environnement, au séminaire de la Chaire « Régulation et Risque Systémique » de l'Autorité de Contrôle Prudentiel et au 40ème séminaire du groupe européen des économistes du risques et de l'assurance. L'auteur remercie enfin Francis Roux et Christophe Michel pour leurs explications détaillées sur les données.

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Natural Disasters: Exposure and Underinsurance

Abstract

Insurance coverage against natural disasters remains low in many exposed areas. Limited insurance supply is commonly identified as a primary factor causing low insurance coverage. The French overseas departments provide an unusual combination of a well-developed natural disasters insurance supply in highly exposed regions. Indeed, the French natural disasters insurance system is guaranteed by the French government; first foreseen for continental France only, it was extended to overseas departments after Hurricane Hugo in 1989, in a state of emergency. This situation enables to analyze the determinants of insurance coverage on the demand side. Using unique household-level micro-data, I estimate a semi-structural model of insurance market which had not been empirically tested. The structural approach enables to show that underinsurance in the French overseas departments is neither due to perception biases nor to unaffordable insurance, but mainly to uninsurable housing and to anticipated assistance, which crowds out insurance. Individual insurance decision is impacted by neighbors' insurance choices via peer effects and via neighborhood eligibility for assistance.

Keywords: natural disasters, insurance, disaster aid, public assistance

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Catastrophes naturelles : exposition et sous-assurance

Résumé

La couverture assurantielle contre les catastrophes naturelles reste faible dans de nombreux pays pourtant fortement exposés, comme en Amérique Latine ou dans les Caraïbes. Une raison souvent invoquée pour expliquer cette faible couverture est la limitation de l'offre d'assurance. Les départements d'Outre-mer français présentent une situation rare d'offre d'assurance développée dans ces régions. En effet, le régime français d'assurance contre les catastrophes naturelles est garanti par l'Etat ; il était initialement prévu pour s'appliquer uniquement en métropole et a été étendu aux départements d'Outre-mer dans l'urgence, après l'ouragan Hugo en 1989. Cette situation permet d'analyser les déterminants de la demande d'assurance. Avec une base unique de données microéconomiques relatives aux assurés et aux non-assurés, j'estime un modèle théorique d'équilibre sur le marché de l'assurance habitation, assurance incluant obligatoirement la couverture des catastrophes naturelles. Cette approche structurelle me permet de mesurer les distorsions induites sur la tarification du risque de catastrophes naturelles et de montrer que la faible pénétration de l'assurance est due, non pas au prix de l'assurance ou aux biais de perception, mais au caractère inassurable de certains logements et à l'anticipation par les ménages d'une aide financière, qui se substitue à l'assurance. Je montre également que les décisions d'assurance de leurs voisins modifient les choix d'assurance des ménages, à la fois par des effets de pair et par l'éligibilité commune du quartier à des aides potentielles.

Mots-clés : catastrophes naturelles, assurance, aide aux victimes de catastrophes, aides publiques

Classification JEL : Q54, G22, H84, D12

1 Introduction

Natural disasters have had an important and growing impact on individual economies; over the last decades, associated damages have frequently reached several percents of GDP.[1] Up to now, the increasing cost of natural disasters is largely explained by the growing urbanization of risky areas (Barredo (2009), Bevere et al. (2011)). In the future, climate change could have a major additional impact (IPCC, 2007). Among the different strategies developed to manage natural risks, insurance as a coverage solution has taken a growing importance over the last thirty years. There is a macroeconomic value of risk transfer to insurance markets, since this transfer greatly facilitates economic recovery. Actually, the national output decrease subsequent to natural disasters is mainly driven by the uninsured losses (von Peter et al., 2012). As government is potentially the "insurer of last resort" after natural disasters, insurance coverage of public and private assets would enable countries to partially transfer catastrophic risk to private foreign actors via insurance mechanisms.[2]

However, risk transfer to insurance markets remains limited. Even if insured losses have significantly increased over time, they still represent a small fraction of economic losses (MunichRe, 2012). Indeed, insurance coverage remains low not only for public goods but also for firms' and households' possessions, even in developed countries.[3] In many developing countries and small island developing states, concurrence of exposure and underinsurance is striking (Cavallo and Noy (2009), Freeman et al. (2003), Pelling and Uitto (2001)). In particular, Latin America and the Caribbean are one of the more disaster-prone areas of the world (Borensztein et al. (2009), Heger et al. (2008), Rasmussen (2004)) and have the lowest levels of insurance cov-

[1]Natural Disasters. Counting the Cost. March 21st, 2011. *The Economist*.

[2]In almost all developing countries, insurers heavily rely on international reinsurance (Outreville, 2000). Local insurance companies can cede an important part of their risks to reinsurers, which are mainly foreign companies. For example, in the Caribbean, local insurers which cover households' and firms' possessions against natural disasters retain less than 20% of the amount they insure and cede the remaining portion to reinsurers (Pollner, 2000).

[3]For example, insurance coverage is low in the United States (Dixon et al. (2006), Kunreuther (1984)) or in many European countries (Maccaferri et al., 2012)).

erage (Borensztein et al., 2009).

Limited insurance supply is commonly identified as a primary factor causing low insurance coverage in hazard-prone regions of the world, including Latin America and the Caribbean. However the French overseas departments provide a rare natural experiment of a well-developed and regulated natural disasters insurance supply in Latin America, the Caribbean and other exposed small island countries.[4] The French natural disasters insurance system is guaranteed by the French government. This system was created in 1982 and was first foreseen to apply to continental land only. However, following Hurricane Hugo that devastated Guadeloupe in 1989, the government decided, in a state of emergency, to extend the natural disasters insurance system to the French overseas departments. This wide and regulated coverage supply enables to analyze the determinants of insurance coverage on the demand side, some of them being specific to developing countries, some of them also widely applying in developed countries.

The first and main contribution of this paper is to provide explanations on the demand side for underinsurance in disaster-prone areas and to measure and compare their magnitude. A structural approach enables to disentangle the different possible causes of underinsurance in the French overseas departments. I show that the two standard explanations, perception biases and insurance affordability, are precluded.[5] Actually, the two main explanations for the low insurance penetration rate are uninsurable housing and charity hazard. Uninsurable housing, namely the fact that dwellings are so little resilient to natural events that they can be considered as uninsurable by insurers, widely applies in Latin America, the Caribbean and many other developing countries. The impact of uninsurable housing on insurance demand, which is captured by using proxies for low-quality dwellings, is quanti-

[4]The French overseas departments include French Guiana (South America), Guadeloupe (Caribbean Sea), Martinique (Caribbean Sea) and Réunion (Indian Ocean). Mayotte (Indian Ocean) became a French overseas department in March 2011. As data were collected in 2006 in the French overseas departments, Mayotte is excluded from this empirical analysis.

[5]A companion paper draws first basic and robust qualitative conclusions (Calvet and Grislain-Letrémy, 2011).

fied and important. Charity hazard, that is the fact that assistance is a substitute for formal insurance and decreases demand for insurance, is a typical example of Samaritan's dilemma and concerns many developed and developing countries. The impact of charity hazard is shown thanks to the structural estimation, data on assistance being unavailable, and is also of important magnitude. Besides, I show that the neighbors' insurance choices impact the individual insurance decision via peer effects and via neighborhood eligibility for assistance, these two channels having comparable orders of magnitude. These results contribute to the growing literature about charity hazard (Petrolia et al. (2012), Landry and Jahan-Parvar (2011), Raschky and Weck-Hannemann (2007), Raschky et al. (2010)). Finally, I show that 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 households may not renew their insurance contracts once they have settled in.

The second contribution of this paper is to measure the impact of regulation on insurers' pricing behavior. The French government provides an unlimited guarantee to one reinsurer and regulates in return the scope and the price of natural disasters coverage. Beyond strict regulation, the attractive and unactuarial reinsurance policies offered by this reinsurer provide limited incentives for insurers to price natural risks in their insurance policies. Similar pricing distortions have been observed in other markets, for example in the retail electricity market (Joskow and Tirole, 2006) where intermediaries' pricing reflects their limited exposure and not the real price. Besides, as reinsurance policies limit insurers' exposure to natural risks, insurers also have limited incentives to acquire detailed information on their insured risk exposure (*ex ante* moral hazard) and to precisely assess damages (*ex post* moral hazard).

The third and last contribution consists in specifying and estimating a theoretical model of insurance derived from Abel (1986)'s, Pauly (1974)'s and Rothschild and Stiglitz (1976)'s works and which had not been previously tested. In this model, a supply equation explains the insurance premium; a demand equation explains the probability of purchasing insurance and takes into account the impact of insurance price on the decision to purchase insurance. Such an estimation of demand and supply has been performed on other markets such as the French labor market (Laroque and Salanié, 2002) but is new for an insurance market. A unique household-level micro-database combining detailed information about the insured and the uninsured has been built to estimate this model.

The paper is organized as follows. Section 2 illustrates exposure and underinsurance in Latin America and the Caribbean, presents commonly identified reasons on the insurance supply and demand sides and details the natural disasters insurance supply provided in the French overseas departments. Section 3 presents the theoretical model. Section 4 details the data and the empirical specification, identification and calibration of the model. Estimation results are commented in Section 5. Section 6 discusses the main reasons for uninsurance, that are uninsurable housing and charity hazard, and to what extent they apply in other developing and developed countries. Section 7 concludes.

2 Exposure and underinsurance in Latin America and the Caribbean

In many developing countries (Cavallo and Noy (2009), Freeman et al. (2003)) and small island developing states (Pelling and Uitto, 2001), concurrence of exposure and underinsurance is striking. Especially, Latin America and the Caribbean are one of the more disaster-prone areas of the world (Borensztein et al. (2009), Heger et al. (2008), Rasmussen (2004)) and have suffered damages exceeding 50% of GDP (Table 1), while having the lowest levels of insurance coverage (Borensztein et al., 2009): less than 4% of losses were insured between 1985 and 1999, ranking them last among the regions of the world, with Asia (4%) and after Africa (9%) (Charvériat, 2000).[6] The insurance penetration rate, i.e. the percentage of insured economic agents, is particularly low among households (Charvériat, 2000). For example, in Mexico in 1998, less than 1% of houses had disaster insurance coverage (Kreimer et al., 1999); in Argentina, Ecuador and Brazil flood insurance penetration rate is also very low among individuals (Gaschen et al., 1998).

Table 1: Destructive impact of natural disasters in the Caribbean region

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

Notes: Heger et al. (2008).

2.1 Insurance supply

2.1.1 Limited insurance supply

Limited insurance supply is commonly identified as a primary factor causing low insurance coverage in hazard-prone regions of the world. Insurance supply is particularly limited in developing countries; microinsurance provides increasing but still partial coverage of loss to life, property and crop caused by natural disasters (see Mechler et al. (2006) for a review).[7] Restricted supply is mainly due to unavailable or unaffordable reinsurance and also to limited standardized information on risk exposure (Cavallo and Noy, 2009).

The case of Latin America and the Caribbean is again particularly striking. Coverage supply for governmental expenditures remains limited despite recent advances

[6] For example, in 1999, in the cases of the Vargas tragedy in Venezuela and of Quindio earthquake in Colombia, only 1.4% and 4.4% of total losses were insured, respectively (Charvériat, 2000).

[7] See also Barnett et al. (2008) for a review of index-based risk transfer products to cover natural damages to crops.

such as the creation of Caribbean Catastrophe Risk Insurance Facility in 2006 or the success of the Mexican government in the issuance of catastrophe bonds in 2006 (Borensztein et al., 2009) and in 2009 (WB, 2011).[8] Similarly, developments of insurance supply for households remain isolated,[9] and this insurance supply can be fragile. The example of Montserrat is particularly telling: in 1997, after several volcanic eruptions, insurance companies responsible for most policies entirely withdrew from the island (Analytica, 1997). Even when available, insurance premiums offered to households are high in Latin America and the Caribbean, because of the limited reinsurance supply (Auffret (2003), Charvériat (2000) and Evans (1996)).

2.1.2 The exception of the French overseas departments

The French overseas departments provide a rare natural experiment of a well-developed and regulated natural disasters insurance supply in Latin America, the Caribbean and other exposed small island countries.

As many countries located in the same areas, the French overseas departments are highly exposed to tsunamis, floods and ground movements;[10] Guadeloupe and Martinique are exposed to intense seismic activity;[11] each of the three islands is made of one active volcano (Grande Soufrière in Guadeloupe, Mount Pelée in Martinique, Piton de la Fournaise in Réunion) and is exposed to strong hurricanes or cyclones.[12]

[8]In the 1980s and the 1990s, Mexico, Colombia, Costa Rica, Nicaragua have also set up national natural disasters funds for uninsured regional or local infrastructures (Charvériat, 2000).

[9]In Brazil, the government-owned reinsurance institute largely contributes to develop the supply of floods reinsurance (Charvériat, 2000); in Puerto Rico, a reserve for catastrophe losses was created in 1994 to improve the availability and the affordability of catastrophe insurance (Charvériat (2000), Evans (1996)); in Manizales (Colombia), the city allows any resident to buy insurance to a private insurer through the municipal tax collection system (Fay and Wellenstein, 2005).

[10]Ground movements include all soil and subsoil movements (such as mudslides, rock and/or block falls, land collapses or subsidence, landslides, movements due to clayey soils).

[11]See the French earthquake map: http://www.planseisme.fr/IMG/jpg/Poster_alea_sismique_avril_2008-2.jpg. Major earthquakes occurred in Guadeloupe in 1843 and in Martinique in 1839. Earthquakes of smaller intensity can more frequently happen, such as Les Saintes (Guadeloupe) earthquake on November 21, 2004 and Martinique earthquake on November 29, 2007. According to scientists, a major earthquake is foreseen in each of these two islands in the very next decades.

[12]Hurricane Dean damaged Guadeloupe and Martinique on August 16, 2007; Cyclone Dina occurred in Réunion on January 22 and 23, 2002.

This is why collective prevention against natural disasters is highly developed in the French overseas departments.[13]

The French overseas departments were integrated into France as overseas departments in 1946 and are now integral parts of France. The French natural disasters insurance system was created in 1982 to institutionalize and coordinate numerous aid mechanisms that had lasted for centuries (Favier and Larhra, 2007). It applied first to continental land only; a specific insurance system was initially foreseen for the overseas departments. However, following Hurricane Hugo that devastated Guadeloupe in 1989, the government decided, in a state of emergency, to extend the natural disasters insurance system to the French overseas departments (Bidan, 2000).[14] Thus, since August 1, 1990 the French overseas departments have benefited from a well-developed and regulated supply of natural disasters insurance. Indeed, the government provides an unlimited guarantee to the French natural disasters insurance system and regulates in return the scope and the price of natural disasters coverage. Thus, the insurance system corresponds to a tax system: the government ultimately compensates insured damages caused by natural disasters and taxes the insured in return.[15]

Definition of natural disasters. Natural disasters are defined by the law as uninsurable natural hazards.[16] They can be earthquakes, volcanic eruptions, hurricanes, cyclones, tsunamis, floods or ground movements. In practice, after a natural event, the French government decides whether this event is a natural disaster and

[13]The very wide majority of municipalities have already undertaken or set up natural risks prevention plans. In Guadeloupe and Martinique, the government has set up additional measures in 2007 to improve seismic resilience to activity, especially the one of public infrastructure.

[14]At that time, the natural disasters insurance system was also extended to two self-governing territorial overseas collectivities of France, Mayotte and Saint Pierre and Miquelon. Mayotte became a French overseas department in March 2011 and so was not a department in 2006, when data were collected.

[15]The natural disasters insurance system also provides coverage to firms and local governments.

[16]Natural disasters are defined by the law as "uninsurable natural hazards mainly caused by abnormal intensity of a natural agent, when usual measures to prevent from these damages could not prevent their occurring or could not have been taken" (Insurance Code, section L. 125-1).

which periods and municipalities are concerned.[17] The decision relies on the conclusions of an interministerial commission, which analyzes the phenomenon on the basis of scientific reports. Storms (but neither hurricanes nor cyclones) and fire forests are considered as insurable risks; their coverage is not *de jure* but *de facto* included in home insurance and is not regulated.

Insured households. The coverage of dwellings against natural disasters is mandatorily included in comprehensive home insurance,[18] and this coverage is not provided by any other insurance policy to my knowledge. Insurers are not allowed to sell home insurance without this coverage, which guarantees that insurers do not select their clients. Similarly, households are not allowed to buy home insurance without this coverage. Recall that this system was first foreseen to apply to continental France only, where almost all households purchase home insurance. Thus, this mandatory inclusion initially guaranteed a large mutualization of natural risks over the country.

In practice, French insurers offer to households a coverage of their dwelling against several hazards (such as theft, fire, explosion, water damages or natural disasters), without letting them choose their insured value of the building; households can choose their insured value of furniture only.

Insurance pricing. The law imposes 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.[19] Insurers are allowed to increase the home insurance premium (and so the natural disasters premium) with respect to the exposure to natural risks.

[17] An order of the ministries of the Interior, of the Economy and of the Budget establishes whether an event is a natural disaster and determines the concerned periods, municipalities and hazards covered by the insurance system. Insured households and firms can benefit from the insurance compensation only if an order is published for the considered event.

[18] See Insurance Code, section L. 125-1. Home insurance policy is an accessible product, as it can be purchased by households on the phone in approximately 20 minutes.

[19] See Insurance Code, sections L. 125-2 and A. 125-2. The premium for natural disasters equals 12% of the premium charged for other damages only, excluding for example the premium of the coverage for civil liability. For the sake of simplicity, the model ignores this point (Section 3). See `http://www.ccr.fr` for more details.

Reinsurance policy. However, using reinsurance policies, the government provides limited incentives for insurers to price natural risks. Indeed, the government provides an unlimited guarantee to one reinsurer, the Caisse Centrale de Réassurance (CCR), which offers to insurers an attractive and unactuarial reinsurance policy and captures more than 90% of the market shares on the natural disasters reinsurance market.[20] Insurers transfer to CCR their natural risks (at the exception of a fixed deductible which equals the sum of their collected premiums); in counterpart, they pay to CCR a fixed share of their collected natural disasters premiums. As potential loss and reinsurance premium paid by the insurer depend on the exposure of his policyholders to a very limited extent, insurance premiums partially reflect risk exposure and insurers have limited incentives to acquire detailed information on their insured risk exposure (*ex ante* moral hazard) and to precisely assess damages (*ex post* moral hazard).

More precisely, the reinsurance policy offered by CCR is such that the insurer yields 50% of the sum of all the natural disasters premiums he has collected (over all policies) and 50% of his losses caused by natural disasters (over all policies) to CCR (quota-share contract).[21] So, the insurer keeps half of the premiums and covers half of the risks. On his remaining risks, he is exposed until a deductible, which equals the sum of the initially collected premiums (stop-loss contract) (Figure 1).[22] In 2006, the amount paid by insurers to CCR corresponded to 51.5% of the collected premiums (Mn-€670 over Bn-€1.3, Letrémy (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 portfolio in terms of professional risks and not household risks.[23]

Finally, insurers also have to give to the French government 12% of the collected

[20] Private communication to the author.

[21] Since 2000, insurers are not allowed to select which risks they cede to CCR (Erhard-Cassegrain et al., 2006).

[22] Each year the deductible is reassessed given the provision realized by the insurer.

[23] Private communication to the author.

premiums to fund prevention measures.[24] Thus, over the initially collected natural disasters premium, the insurer pays 63.5% of the premium, that is 51.5% to CCR and 12% to the government; in counterpart, the insurer is exposed until a deductible which equals the sum of the collected premiums.

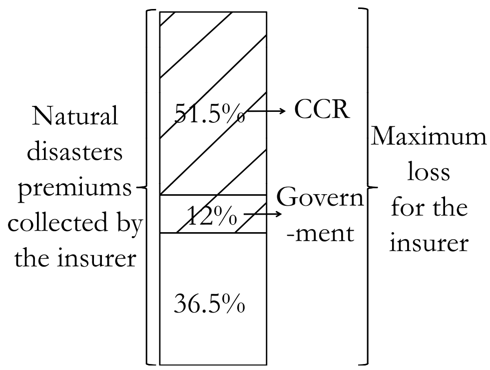

Figure 1: Reinsurance policy

This reinsurance policy is globally applied to all natural disasters policies offered by the insurer (home, firm and car insurance in continental land, overseas departments and territories). For the sake of simplicity, the theoretical model (Section 3) compares the premium of one home insurance policy with the additional expected coverage that it represents.

Insurance penetration rate. Despite the supply of a wide coverage against natural disasters at a regulated price, in 2006 only half of households living in the French overseas departments have purchased home insurance, which includes coverage against natural disasters, for their main home (Table 2). This penetration rate is higher than the rate observed in other exposed countries, but remains much lower than the rate observed in continental France, where households are far less exposed to natural risks but almost all insured (Table 2).[25]

[24]See Environment Code, section L. 561-3.

[25]Indeed, we do not observe the adverse selection effect that would be typically expected: insurance subsidization for exposed households by the least exposed ones (living in continental France) could lead to a higher participation on the insurance market of exposed households (living in overseas departments). This adverse selection would mainly come not from the lack of information by insurers but from their limited incentive to use information because of reinsurance policies: as insurers bear a very limited part of losses caused by natural disasters, insurance premiums partially reflect natural risks and this way subsidies exposed households.

Table 2: Population, exposure to major natural risks and insurance penetration rate for main home in France in 2006

	French Guiana	Guadeloupe	Martinique	Réunion	Continental France
Population					
	205,954	400,736	397,732	781,962	61,399,733
Percentage of households exposed to natural hazards					
Earthquakes	0	100	100	55(⋆)	59(⋆)
Volcanic eruptions	0	30	100	65	0
Wind effects	0	100	100	100	8(⋆)
Tsunamis or floods	85(†)	84	100	100	21(†)
Grounds movements	70	100	100	100	19
Forest fires	0	0	0	100	19
Avalanches	0	0	0	0	1
Percentage of households insured for their main home					
	52	43	50	59	99

Notes: (⋆): Réunion and continental France are exposed to earthquake of small intensity; continental France is also exposed to wind effects of small intensity. (†): the tsunamis to which French Guiana and continental France are exposed are also of small intensity, but these two areas are exposed to floods of high intensity. Population census by the French National Institute of Statistics and Economics Studies (INSEE) in 2006; GASPAR database by the French Ministry of Ecology; French Household Budget survey by INSEE in 2006 (13,374 observations for percentage calculations).

2.2 Insurance demand

Several reasons may explain a low demand for natural disasters insurance: perception biases, unaffordable insurance, uninsurable housing, anticipated assistance, which crowds out insurance, and a vicious circle of underinsurance.

Insurance obligations. Purchasing home insurance is often required as 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 there is very little monitoring 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).[26] In the French overseas departments, purchas-

[26] This is also the case in the United States: banks or financial institutions can require the purchase of flood insurance to deliver a mortgage (Browne and Hoyt (2000), Office (1983)); there is

ing home insurance is also compulsory for tenants. According to my data, in 2006 only 67% tenants and 72% homeowners with outstanding loans are insured, whereas the overall insurance penetration rate is 48%.

Perceptions biases. Perception biases are often evoked to explain a low demand for coverage against extreme events. A wide literature deals with cognitive biases in the perception of extreme risks and their impact on demand for natural disasters insurance (see Tallon and Vergnaud (2007) for a review). For example, perception of low probabilities is reduced because of availability bias (Tversky and Kahneman, 1973), the "gambler's fallacy" following from a "belief in the law of small numbers" (Tversky and Kahneman, 1981),[27] the presence of a minimum threshold to look for information because of information cost (Kunreuther and Pauly, 2004) or the disability of comparing with ordinary risks (Kunreuther et al., 2001).

Insurance affordability. Another standard explanation is that insurance may be too expensive for overseas households. When insurance is available, insurance premiums offered to households are high in Latin America and the Caribbean (Auffret (2003), Charvériat (2000) and Evans (1996)). For example, in Mexico, premiums in earthquake-prone areas amount to 0.5% of the value of housing on an annual basis (Charvériat, 2000); in the Caribbean, rates for property insurance against disasters exceeded 1% of amount insured in the 1990s (Charvériat (2000), WB (1999)).

Even if insurance price is regulated in the French overseas departments, overseas households may not afford insurance, given that the median standard of living in the French overseas departments is almost 40% lower than in continental France (Michel et al., 2010).

very little monitoring of insurance renewal and many households do not renew their flood insurance policies (Kunreuther and Pauly, 2005).

[27] The belief in the law of small numbers is the belief that, once the dwelling has been damaged by a disaster, the probability of being touched again is lower.

Uninsurable housing. In developing countries, many dwellings are so little resilient to natural events that they can be considered as uninsurable by insurers. Uninsurable housing has a great magnitude in Latin America and the Caribbean. In Mexico, about 50% of total housing stock correspond to uninsurable houses, built with no solid materials or without access to potable water (Charvériat, 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 heterogenous quality represent 13% of dwellings in 2006 (Castéran and Ricroch, 2008) and are especially numerous in French Guiana. According to my data, the number of low-quality dwellings is significant and the insurance penetration rate is lower among their occupiers: this rate is 17% only among houses still in construction (which represent 3% of the sample), 15% among houses without hot water (23% of the sample), 34% among houses without drainage (53% of the sample) and 9% among houses without toilets inside the building (4% of the sample), whereas the overall insurance penetration rate is 48%.

All these low-quality dwellings are legal. A building permit, similar to the one existing in continental France or in other developed countries, is not required by law to build a house. Indeed, in the French overseas departments, the building property allows households to own the walls of their dwelling without owning the ground on which it is built. This is why more than 30% of individual dwellings in the French overseas departments have been built without a permit (DIREN (2005), Garnesson and Hecquet (2007), Olive and Riviere (2010)). Similarly, in the Caribbean region, building standards and location restrictions are either nonexistent or outdated and inadequate (Auffret, 2003). However, a building permit can be required by insurers as a condition for obtaining home insurance.

Uninsurable housing can be seen as a rational adaptation to exposure to natural disasters in low-income countries and an illustration of the poverty trap. Low-income households use these either nonexistent or outdated and inadequate building rights to build low-quality dwellings, that would be destroyed by an impending natural disaster. These households with few assets can be trapped this way in chronic low-quality dwelling. This phenomenon has been studied, especially in the field of small businesses and agriculture (Barnett et al., 2008). Within the French overseas departments, however, according to my data dwellings of good quality are on average built in more exposed areas, probably because of risk exposure also provides positive amenities (river sight, fertile ground).

Charity hazard. Assistance is a substitute for formal insurance and decreases demand for insurance. This phenomenon, called charity hazard, is a typical example of Samaritan's dilemma. Charity hazard has been formalized by several theoretical papers but only few empirical findings have been established in the case of natural disasters insurance (see Raschky et al. (2010) for a review).[28]

Charity hazard has an important magnitude in many developing countries (Gilbert, 2001), including Latin America and the Caribbean. Indeed, the Caribbean region largely depends on international assistance: the World Bank and the Inter-American Development Bank provide important and increasing assistance to victims of natural disasters (Auffret, 2003).

In the French overseas departments, after natural disasters, households can also rely on substantial financial assistance by government, local authorities, non-governmental organizations or relatives. Their anticipation of financial assistance is essentially based on their past experience and is difficult to quantify because of the numerous assistance channels. Official statements after natural disasters confirm that the uninsured can rely on an important compensation from the government (Senate, 2005).

[28] Charity hazard has been tested in health insurance (Herring (2005), Chernew et al. (2005), Brown and Finkelstein (2008)); first results suggest charity hazard in crop insurance in the United States (Deryugina and Kirwan, 2012).

Indeed, a main channel of governmental assistance to overseas France is the rescue fund for overseas. This compensation covers damages caused by natural disasters in the main home (including rebuilding); it is funded by budgetary credits.[29]

A vicious circle of uninsurance. Finally, underinsurance may reinforce itself for two main reasons. The first reason is similar to a peer effect. Social norms impact the decision to purchase insurance: individuals may decide to purchase insurance because they know others who did so; they may think that their relatives have similar preferences to them or have already spent the search costs of gathering information on risk, insurance or relief (Kunreuther and Pauly, 2005).

The second reason relies on the endogeneity of provided assistance and is this way linked to charity hazard. The neighbors' decision of uninsurance increases the neighborhood eligibility for assistance and so decreases the individual benefit of purchasing insurance. In other words, the more people are uninsured around one individual, the less he needs to purchase insurance since the political power of the uninsured grows. This mechanism is predicted by theory for many types of public aid: Arvan and Nickerson (2006) consider endogenous governmental compensation and show that an individual's purchase of insurance coverage creates negative externalities by diminishing neighborhood eligibility for such aid.[30]

3 Theoretical model

I estimate a semi-structural model of insurance supply and demand (Abel (1986), Pauly (1974), Rothschild and Stiglitz (1976)) within the French overseas departments. I detail here the theoretical specification of this model.

The supply equation explains the insurance premium offered by insurers. This price

[29] See order of December 8, 2010 relative to the implementation of help facility by the rescue fund for overseas.

[30] See Herring (2005) for illustration of endogenous availability of charity care for health.

conveys the nullity of the insurers' expected profit. Nullity of expected profit means that collected premiums equal expected losses. Both amounts, which reflect the specific design of the French natural disaster insurance system (Section 2), are here precisely modeled. Insurers are assumed to offer a unique standardized contract with full coverage.

The demand equation explains the household's probability of purchasing insurance. The quantity of purchased insurance results from the comparison by households between their expected utilities with and without insurance. The decision of whether to purchase insurance or not depends on the insurance price. I enrich this demand equation to precisely model the underlying determinants of insurance demand (Section 2).

3.1 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 damages) cause a loss 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 $p_d p_o$ is negligible with respect to any of the two probabilities, there are indeed three states of Nature: a high loss $L_d - A_d$ with a small probability p_d, a small loss L_o with an important probability p_o, and no loss with probability $1 - p_d - p_o$ (Figure 2).

Households may have a potentially biased risk assessment, different from the true ones (that are insurers' ones), for the probability of ordinary losses $\tilde{p}_o$, for the prob-

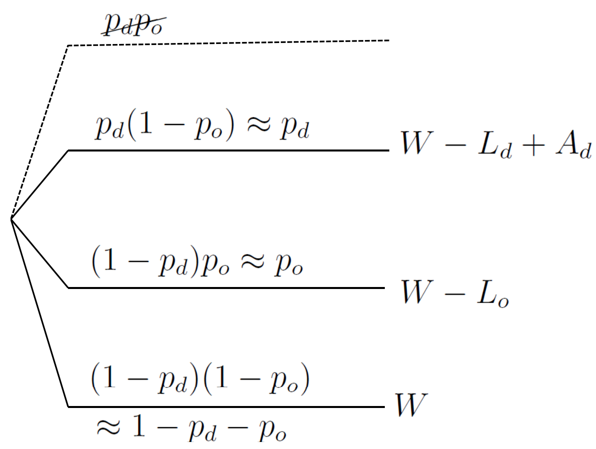

Figure 2: Risk structure

ability 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 than insurers.

3.2 Modeling the supply side

Insurance policy. As households' choices of coverage are restrained to furniture in France (Section 2), I assume that a unique standardized contract with full coverage is offered by insurers. Therefore households either purchase home insurance ($\alpha = 1$) or not ($\alpha = 0$).

Nullity of expected profit. Insurance companies are assumed to be price takers. Competition on insurance market and risk neutrality of insurers imply the nullity of the insurers' expected profit on each group of identical households (for what is observed by the insurers). Nullity of 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).

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

Collected premiums and expected losses both reflect the specific design of the French natural disaster insurance system; they are here precisely modeled.

Premiums. The home insurance premium π is the sum of the premium for natural disasters π_d and the premium for other risks π_o. The premium for natural disasters π_d amounts to $r = 0.12$ of the premium for other risks π_o (Section 2).

$$\left.\begin{aligned} \pi &= \pi_d + \pi_o, \\ \pi_d &= r\pi_o. \end{aligned}\right\} \Rightarrow \pi = \frac{1+r}{r}\pi_d. \tag{2}$$

Expected losses. Expected ordinary losses equal

$$EL_o = p_o L_o. \tag{3}$$

All insurers are assumed to be reinsured against natural disasters by CCR, since CCR captures more than 90% of the market shares on the natural disasters reinsurance market (Section 2). Expected losses caused by natural disasters are determined by the unactuarial reinsurance policy offered by CCR (Section 2). The insurer is exposed until a deductible, which is the natural disaster premium. In counterpart, he has to pay a fixed share $k = 0.635$ of the natural disaster premium. Indeed, this share corresponds to the sum of the price of reinsurance policy and a tax to fund prevention measures (Section 2).

$$EL_d = p_d \min\left(\pi_d, \frac{L_d}{2}\right) + k\pi_d, \tag{4}$$

$$= (p_d + k)\pi_d. \tag{5}$$

as $\pi_d < \frac{L_d}{2}$.

The supply equation (1) becomes

$$\pi = c(EL_o + EL_d), \tag{6}$$
$$= c(p_o L_o + (p_d + k)\pi_d), \tag{7}$$
$$= cp_o L_o + c(p_d + k)\frac{r}{1+r}\pi. \tag{8}$$

Thus

$$\log(\pi) = \log(cp_o L_o) - \log\left(1 - ck\frac{r}{1+r} - cp_d\frac{r}{1+r}\right). \tag{9}$$

3.3 Modeling the demand side

Comparison of expected utilities. 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 ($\alpha = 0$).[31]

$$\alpha = 1 \Leftrightarrow EU|_{\alpha=1} \geq EU|_{\alpha=0}. \tag{10}$$

Given full insurance of price π, the expected utility of the insured is

$$EU|_{\alpha=1} = U(W - \pi). \tag{11}$$

The expected utility of the uninsured is

$$EU|_{\alpha=0} = \tilde{p}_o U(W - L_o) + \tilde{p}_d U(W - \tilde{L}_d + \tilde{A}_d) + (1 - \tilde{p}_o - \tilde{p}_d)U(W),$$
$$= U(W) - \tilde{p}_o[U(W) - U(W - L_o)] - \tilde{p}_d[U(W) - U(W - \tilde{L}_d + \tilde{A}_d)]. \tag{12}$$

I enrich the demand equation (10) to precisely model the underlying determinants of insurance demand (Section 2).

[31]The standard expected utility framework may not be the best appropriate to analyze the economic consequences of fat-tailed events (Weitzman, 2009); however Weitzman's alternatives may be less appropriate to study the purchase of catastrophe insurance.

Insurance obligations. Purchasing home insurance is compulsory for tenants and often required as a condition for obtaining a mortgage (Section 2). As many tenants and homeowners with outstanding loans remain uninsured (Section 2), proxies $\{O_k\}_k$ for occupancy status are added to control for these insurance obligations and to measure their impact.

Uninsurable housing. A significant number of houses are uninsurable buildings: they do not meet building standards or have been realized without building permit (Section 2). I enrich the demand equation (10) by adding proxies $\{H_k\}_k$ for uninsurable housing.

Peer effects. To test whether the more neighbors are insured, the higher the individual probability of purchasing insurance is, I add in the demand equation the expected penetration rate $E(Z_{\text{peer},i})$ of the group J_{peer} of peers to which the household i belongs:

$$E(Z_{\text{peer},i}) = \frac{\sum_{j \in J_{\text{peer}}, j \neq i} \alpha(j)}{\text{card}(J_{\text{peer}}) - 1}. \tag{13}$$

This model corresponds to a degenerated 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. This strategy is inspired by other papers studying peer effects, such as Hernández-Murillo and Sengupta (2012).

Neighborhood eligibility for assistance. The decision of purchasing insurance by one household depends on the decisions of others', not only via peer effects but via neighborhood eligibility for assistance. To test for its endogenous nature, anticipated assistance is assumed to depend on the expected penetration rate $E(Z_{\text{aid}})$ of the group J_{aid} for aid eligibility: $\tilde{A}_d(E(Z_{\text{aid}}))$.[32] This enables to test whether the percentage of insured households around one individual decreases his likelihood to get assistance after a disaster and so decreases the charity hazard effect.

[32] Again, this model corresponds to a degenerated Nash equilibrium.

The demand equation becomes

$$
\begin{aligned}
\alpha = 1 \Leftrightarrow & [U(W-\pi) - U(W)] + \tilde{p}_o[U(W) - U(W - L_o)] \\
& + \tilde{p}_d[U(W) - U(W - \tilde{L}_d + \tilde{A}_d(E(Z_{\text{aid}})))] + \sum_k o_k O_k \\
& + \sum_k h_k H_k + \delta E(Z_{\text{peer}}) \geq 0. \qquad (14)
\end{aligned}
$$

4 Data and model specification, identification and calibration

I present the unique household-level micro-database that has been built to estimate this theoretical model (Section 3). The empirical specification, which is fully parametric, is detailed. The identification and calibration of the model are discussed; all the performed robustness tests are exposed.

4.1 Data

The database combines information about insurance expenditure for the insured, risk exposure and other economic variables for the insured and the uninsured. It has been built by matching the 2006 French Household Budget survey with the GASPAR database, which presents information about exposure to natural disasters.

The French Household Budget survey, managed by the French National Institute of Statistics and Economics Studies (INSEE), is a comprehensive national survey on households' expenditures, and in particular insurance expenditures. Regarding home insurance, households declare whether they have purchased home insurance and if so the amount of the premium paid. Neither the identity of the different insurers nor the type of companies (mutual insurance company or not) are observed. Data on assistance are not available (Section 4).[33] The French Household Budget survey also provides information about the household himself (such as size, income and standard of living, and, for the reference person,[34] gender, age and place of birth). Detailed information about housing (such as occupancy status, dwelling quality, number of rooms) is given. However, no information on dwelling compliance with building standards and permits is provided. The 2006 French Household Budget survey comprises 3,134 households living in the French overseas departments.[35]

The GASPAR database, built by the French Ministry of Ecology, is the database of computer-aided management for administrative procedures relative to natural and technological risks. It specifies which hazard each municipality is exposed to, these five hazards being earthquakes, volcanic eruptions, hurricanes or cyclones, tsunamis or floods, and grounds movements.[36] It also provides the number of disasters by hazard type in each municipality from 1990 (date of the enforcement of the natural disasters insurance system in the French overseas departments) to the survey date.

As the decision of 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 all the other households who declare themselves as insured but do not report their premium amount. Over the initial 3,134 households, 2,860 observations remain. I then exclude 40 observations for which key variables (annual income, number of rooms) are missing and 11 for which the declared annual income is below €500. Finally, 2,809 observations remain.

[33] Even detailed data on assistance provided by the rescue fund for overseas are not available. Annual aggregate statistics at the departmental level only were provided by the French Ministry of Overseas.

[34] More often than not, the household reference person is the family reference person when there is one, or the oldest man, with priority to the oldest active person.

[35] In French Guiana, the sampling plan of the 2006 French Household Budget survey overrepresents the coastal area, which is more exposed to floods and tsunamis (Forgeot and Celma, 2009).

[36] It also specifies whether each municipality is exposed to forest fires, but this hazard is considered as insurable and therefore it is not considered as a natural disaster (Section 2). See Table 2 for the exposure of each French overseas department to these different natural hazards.

Table 3 describes my sample. The average municipal exposure to natural risks is high but very heterogenous: while municipalities are on average exposed to 4 distinct natural hazards, some are exposed to 5 hazards according to the GASPAR database, and others to none; on average, 8 natural disasters have occurred since 1990, this number reaching 18 in some municipalities, whereas others have been spared. 48% of households living in the French overseas departments have purchased home insurance, which includes the coverage against natural disasters, for their main home in 2006. This insurance rate also strongly varies among municipalities: it reaches 0.92% in some of them, whereas in others no one is insured. The premium paid by the insured is on average €254 and ranges from €20 to €2,000, reflecting important disparities among the sample population. Indeed, the 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 owning their home. While dwellings present 4 rooms on average, some present only 1, others 12. Many houses lack some modern conveniences: 23% are without hot water; 53% without drainage; 4% without toilets inside the building. 3% of houses are still in construction. Finally, the reference person is born in continental France and abroad in 10% and 8% of cases, respectively; she is a woman in 46% of households; her age varies between 17 and 95.

4.2 Specification, identification and calibration of the supply side

As no information is provided on the insurer, the nullity of the expected profit over all insurers confounded only can be considered.[37]

[37] 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 the 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.

Table 3: Descriptive statistics

	Percentage / mean	Minimum	Maximum
Number of natural hazards	4	0	5
Number of past natural disasters	8	0	18
Households insured for their main home	48%		
Insured households living in the same municipality	47%	0%	0.92%
Premium paid by the insured	€254	€20	€2,000
Annual income	€22,694	€600	€169,637
Standard of living	€13,359	€407	€87,266
Number of rooms	4	1	12
Tenants	36%		
Homebuyers	13%		
Houses still in construction	3%		
Houses without hot water	23%		
Houses without drainage	53%		
Houses without toilets inside the building	4%		
Reference person born in continental France	10%		
Reference person born abroad	8%		
Age of the reference person	49	17	95
Gender (woman) of the reference person	46%		

Notes: Are considered in the sum of natural hazards earthquakes, volcanic eruptions, wind effects, floods (including tsunamis) and ground movements. 2006 French Household Budget survey and GASPAR database. 2,809 observations.

Ordinary losses. Ordinary losses L_o depend on the dwelling characteristics. More precisely, they depend on the values of furniture and of the building. One proxy for the value of furniture (mainly jewels and furniture) is the standard of living Y, i.e. the income divided by the household's size.[38] One proxy for the value of the building is the number of rooms N. Losses also depend on occupancy status, since tenants, denoted by $O_t = 1$, do not bear all losses, a part of them being borne by their landlord.[39]

These effects are assumed to be multiplicative: the value of furniture in each room

[38]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.

[39]Landlord is responsible for potential damages to furniture in furnished dwellings, to the structure (walls, foundations) and for damages implying his liability (structural defects).

increases with respect to the standard of living Y, and the number of pieces of furniture increases with respect to the number of rooms N; last, tenants insure only a fraction $(1-\tau)$, $\tau \geq 0$ of the total value of the dwelling. l is a multiplicative constant. Thus, the ordinary loss L_{oi} for household i is

$$L_{oi} = lY_i^y N_i^n (1 - \tau O_{ti}), \ \tau \geq 0. \tag{15}$$

y and n are the elasticities of the loss with respect to the standard of living and the number of rooms, respectively.[40]

Loss probabilities. I have no specific information on p_o, since I do not observe past ordinary losses nor other proxies for the probability of suffering these losses.

Insurers estimate the probability of natural disasters using information about physical hazards. Business practices indicate that French insurers use very basic information about natural risk exposure, very likely because their financial exposure to natural risk is limited thanks to the reinsurance contract offered by CCR (Section 2); this is a typical case of *ex ante* moral hazard. I assume that the probability of natural disaster estimated by insurers for each household i linearly increases with respect to the sum of hazards R_i to which his municipality is exposed.[41]

$$\text{Insurers: } p_{di} = pR_i, \ p \geq 0. \tag{16}$$

Error. An error ϵ 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.

[40] Losses caused by natural disasters are not estimated in the supply equation, as potential loss and reinsurance premium paid by the insurer are not determined by these losses (Section 2).

[41] R is public information.

Using (9), (15) and (16), I get

$$\log(\pi_i) = \log(cp_o l) + y\log(Y_i) + n\log(N_i) + \log(1-\tau O_{ti}) - \log\left(1 - \frac{ckr}{1+r} - \frac{cpr}{1+r}R_i\right) + \sigma\epsilon,$$
$$= c_\pi + y\log(Y_i) + n\log(N_i) + \log(1-\tau O_{ti}) - \log(1-\kappa-\rho R_i) + \sigma\epsilon, \quad (17)$$

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

Identification and calibration of risk parameters. c_π, $1-\kappa$ and ρ cannot be simultaneously identified. I estimate c_π and ρ and I calibrate $\kappa = ckr/(1+r)$. $r = 0.12$ and $k = 0.635$ are imposed by the government and CCR (Section 2). I calibrate loading factor c using values provided by literature: $c \approx 1.3$ (Gollier, 2003). Thus, I take $\kappa = ckr/(1+r) \approx 0.088$. Estimations are performed for $c \in \{1, 1.5\}$, that is for $\kappa \in \{0.068, 0.10\}$.

Estimation of $c_\pi = \log(cp_o l)$ does not enable to simultaneously identify p_o and l (and c), even when considering that c is already calibrated. I calibrate p_o using statistics provided in continental France: $p_o \approx 0.075$ (FFSA, 2006);[42] estimations are performed for $p_o \in (0.05, 0.5)$. Risk parameter l is deduced from the estimated value of c_π.

Similarly, the risk parameter p will derive from the estimated value of $\rho = cpr/(1+r)$, given that c is calibrated and r is known.

Given that α_i states whether the household i purchases insurance or not, the supply

[42] In continental France, between 2000 and 2004, statistics by the French federation of insurance companies about home insurance 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 correspond to the same order of magnitude. In Taiwan, the probability of fire occurrences in residential buildings per m^2 of floor space is around 0.01 (Lin, 2005). In Long Beach (CA), the probability of burglary is around 1.9% for a house which has never been burglarized and reaches 59% after a first burglary (Short et al., 2009).

equation becomes

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

where $c_\pi = \log(cp_o l)$ and $\rho = cpr/(1+r)$ are estimated parameters and $\boldsymbol{\kappa} = ckr/(1+r)$ is calibrated.

4.3 Specification, identification and calibration of the demand side

Utility function and risk aversion. In an expected utility setting, constant relative risk aversion is a reasonably good approximation of individual attitude toward risk (Chiappori and Salanié, 2008). A constant relative risk aversion λ with respect to the income corresponds to the following utility function: $U(W) = W^{1-\lambda}/(1-\lambda)$. Literature has estimated different values for λ (Chiappori and Salanié, 2008). Estimations are here performed under the assumptions that utility is the log function, which is the limit case of $U(W) = W^{1-\lambda}/(1-\lambda)$ as λ tends to 1. Results are robust when using $\lambda = 2$ or $\lambda = 3$.[43]

Losses and loss probabilities. As households are assumed to have the same estimation as insurers of their ordinary losses L_o (Section 3), losses L_o are simultaneously estimated in the supply equation - but for the insured households only - and in the demand equation. On the contrary, losses $\tilde{L}_d$ intervene in the demand

[43]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 misestimated (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 with the other terms (Equation 14) and the corresponding coefficients would be poorly estimated. The adequate value of c_U would be different when using another value of risk aversion λ. Note that c_U and λ cannot be simultaneously identified.

equation only.[44] Losses $\tilde{L}_d$ caused by natural disasters fundamentally depend on the same dwelling characteristics than ordinary losses L_o. For the sake of simplicity, I assume that, for every household i,

$$\tilde{L}_{di} = \beta L_{oi}, \beta \geq 1. \tag{18}$$

Because of this intrinsic link between ordinary losses and losses caused by natural disasters (that remains even in a nonproportional specification), the utility decrease caused by ordinary losses, weighted by their occurrence probability, $\tilde{p}_o[U(W) - U(W - L_o)]$, and the utility decrease caused by natural disasters, weighted by their occurrence probability, $\tilde{p}_d[U(W) - U(W - L_d + \tilde{A}_d)]$, 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 enables to capture charity hazard, and I calibrate β and $\tilde{p}_o$.[45]

In continental France, the ratio of the mean natural disasters losses over the mean ordinary losses $\bar{L}_d/\bar{L}_o$ ranges from 6.25 to 12.5.[46] Knowing that natural disasters are more intense events in the French overseas departments, I take $\beta = 15$. As a sensitivity test, I have performed estimations for $\beta \in (10, 20)$ and significativeness and sign of all estimated coefficients are robust to the choice of this parameter.[47]

The probability of ordinary losses $\tilde{p}_o$, of which no proxies is observed. Section 5 presents the results under the assumptions that $\tilde{p}_o = 0.075$. Estimations are per-

[44]Losses caused by natural disasters are not estimated in the supply equation, as potential loss and reinsurance premium paid by the insurer are not determined by these losses (Section 2).

[45]Even once β is calibrated, $\tilde{p}_o$ and a fixed part a in an affine function $\tilde{p}_d(S) = a + bS$ are not simultaneously identified.

[46]In continental France, between 2000 and 2004, statistics by the French federation of insurers companies about home insurance show that the damages caused by ordinary risks are on average around €1,200 (FFSA, 2006). Damages caused by floods and ground movements for continental households are on average around €7,500 and €15,000, respectively (Grislain-Letrémy and Peinturier, 2010).

[47]Indeed, as the potential losses cannot exceed the wealth of the household, wealth determines the upper bound of the range of values for β. 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 $\beta = 15$).

formed for $\tilde{p}_o \in (0.05, 0.5)$, while allowing $\tilde{p}_o$ to be different from p_o. Significativeness and sign of all estimated coefficients are robust to the choice of these parameters.

Learning from past disasters. The number S of past disasters that have occurred in the municipality between the enforcement of the insurance system (1990) to the sampling date (2006) is public information. Past disasters have a double impact on households' estimation of their exposure to natural disasters. First, the number of past disasters increases households' estimation of their probability $\tilde{p}_d$ of suffering another disaster. Second, this number modifies households' expectation of receiving assistance, since their expectation is built on compensation provided to them after past events. Thus, households' expected assistance $\tilde{A}_d$ depends on number S of past disasters and on penetration rate $E(Z_{\text{aid}})$ of the group J_a of joint eligibility for assistance (Section 3): $\tilde{A}_d(S, E(Z_{\text{aid}}))$. Given that no proxy for expected assistance is observed (Section 4), capturing charity hazard requires to disentangle the two impacts of the number S of past disasters on insurance demand.

More formally, in the theoretical model,

$$\begin{aligned}\alpha = 1 \Leftrightarrow & [\log(W-\pi) - \log(W)] + \tilde{p}_o[\log(W) - \log(W - L_o)] \\ & + q_d(S, E(Z_{\text{aid}}))[\log(W) - \log(W - \beta L_o)] + \sum_k o_k O_k \\ & + \sum_k h_k H_k + \delta E(Z_{\text{peer}}) + \nu\epsilon + \eta \geq 0, \end{aligned} \tag{19}$$

where $q_d(S, E(Z_{\text{aid}}))$ "summarizes" the two impacts of past disasters, the one of the probability $\tilde{p}_d$ of natural disasters and the one on expected assistance $\tilde{A}_d$.[48] Indeed, as the number S of past disasters increases, insurance demand is modified by a premium increase and a utility loss. The premium increase effect (PIE) refers to the fact that an increase of insurance price (as risk and sinistrality are correlated) may reduce insurance demand. The utility loss effect (ULE) denotes the fact that the

[48]Simultaneous estimation of functional forms of $\tilde{p}_d$ and A_d with respect to S leads to 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.

anticipated loss of utility may also increase, which should on the contrary increase insurance demand. If anticipated assistance also increases with respect to the number of past disasters, this reduces the utility loss effect: this is the charity hazard effect (CHE). The sign of $\partial\alpha/\partial S$ is determined by the sign of

$$\underbrace{-\frac{\partial\pi}{\partial p_d}\frac{\partial p_d}{\partial S}\frac{dU}{dW}}_{\text{PIE}_{\leq 0}} \underbrace{\underbrace{-\frac{\partial\tilde{p}_d}{\partial S}(U(W-\tilde{L}_d+\tilde{A}_d(S))-U(W))}_{\text{ULE}_{\geq 0}} \underbrace{-\underbrace{\tilde{p}_d(S)}_{\geq 0}\underbrace{\frac{\partial\tilde{A}_d}{\partial S}}_{\geq 0}\underbrace{U'(W-\tilde{L}_d+\tilde{A}_d(S))}_{\geq 0}}_{\text{CHE}_{\leq 0}}}_{\text{ULE+CHE}=-\frac{\partial q_d}{\partial S}\text{UL}}. \tag{20}$$

As data on anticipated assistance are not available, the sum of ULE and CHE only can be identified. Thus, estimation reveals the existence of a charity hazard effect 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 $\frac{\partial q_d}{\partial S} > 0$, $|\text{CHE}| < \text{ULE}$ and this would be consistent with a small or null value of the charity hazard effect, CHE.

$$\frac{\partial q_d}{\partial S} \leq 0 \Leftrightarrow |\text{CHE}| \geq \text{ULE} \Rightarrow \frac{\partial\tilde{A}_d}{\partial S} \geq 0. \tag{21}$$

Indeed, a negative sign of $\partial q_d/\partial S$ would indicate that anticipated assistance by households increases with respect to the number S of past disasters that have occurred in the municipality (Equation 20). This would correspond to a cumulative effect in the anticipation of assistance: households living in municipalities where numerous disasters occurred have noticed the importance of assistance, probably more than the other households have; therefore they anticipate higher amounts of *ex post* aid.

Besides, to test for the endogenous nature of anticipated assistance (Section 3), the expected penetration rate $E(Z_{\text{aid}})$ of the group J_{aid} of joint eligibility for assistance is crossed with the charity hazard effect. Thus, for each household i,

$$q_{di} = (q + \theta E(Z_{\text{aid},i}))S_i. \tag{22}$$

A negative sign of q would indicate a charity hazard effect and a positive sign of θ would mean that the percentage of insured neighbors decreases this charity hazard effect, as it decreases the individual likelihood to get assistance after a disaster.

Let us check that no other phenomenon could imply a negative sign of q. First, perception bias could decrease $\partial \tilde{p}_d / \partial S$ and therefore the demand for insurance (Section 2) but not imply a negative sign for the estimated coefficient $\partial q_d / \partial S$: even in the presence of perception bias, the perceived utility loss would still increases with respect to the number S of past disasters, even when considering the belief in the law of small numbers. This belief consists in considering that once a dwelling has been damaged by a disaster, the probability of being struck again is lower (Tversky and Kahneman, 1981). Households may have this belief after one unique disaster, but likely not after having been struck several times, which is the case as they have suffered in average 8 disasters since 1990 (Table 3). Second, a negative sign of q could derive from uncontrolled differences in risk aversion. In other words, one cannot exclude for now that more exposed households do not purchase insurance because they have a lower risk aversion.[49] However, data show that households who live in more exposed areas are presumed to be actually more risk averse (Table 4): they are older, the proportion of women among them is higher.[50] Besides, among households who live in more exposed areas, the proportions of people either born in continental land (who could be used to managing risk differently), or who purchase automobile insurance - with a limited or an extended coverage -[51] are not significantly higher.[52]

[49]Heterogeneities in wealth or in dwelling quality are already taken into account in the demand equation. The location choice of wealthy households is not significantly correlated with risk exposure; dwellings of good quality are on average built in more exposed areas (Section 2).

[50]Levin et al. (1988), Powell and Ansic (1997), Halek and Eisenhauer (2001) and Jianakoplos and Bernasek (1998) show that women are more risk averse than men. Morin and Suarez (1983), Palsson (1996) show that the risk aversion increases with respect to the age; however, cohort effects may complicate the impact of age on risk aversion (Brown (1990), Jianakoplos and Bernasek (1998)). Besides, risk aversion depends on contextual framework (Schubert et al. (1999)).

[51]Third-party insurance only is mandatory for automobiles. Only 1.5% of households own a car without this coverage.

[52]These statistics also confirm that supply accessibility is not lower for exposed households. Indeed, difficulties in terms of supply accessibility are especially limited for home insurance, as households can purchase a home insurance policy on the phone in approximately 20 minutes.

Table 4: Self-selection on housing market: correlation between proxies for risk aversion and the number of past disasters in the municipality

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

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

Adverse selection because of insurance pricing? On the contrary, if $q \geq 0$, it can be tested whether there is adverse selection, that is whether

$$\text{ULE} + \text{CHE} \geq |\text{PIE}|, \tag{23}$$

i.e. whether $\partial\alpha/\partial S \geq 0$. Insurance subsidization for exposed households by the least exposed ones could lead to an extensive adverse selection, that is to a higher participation, on the insurance market, of exposed households. Here, adverse selection would mainly come not from the lack of information by insurers but from their limited incentive to use information because of reinsurance policies (Section 2): as insurers bear a very limited part of losses caused by natural disasters, insurance premiums only partially reflect natural risks and this way subsidies exposed households.

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.[53] Results are robust when tenants and homeowners with outstanding loans are excluded from the sample and also when the model is estimated either on tenants only.[54]

[53]Monitoring of insurance renewal may be partly realized in public housing. Unfortunately, information about public housing is not available.

[54]An estimation on homeowners with outstanding loans only is not possible, as they are 336 only.

Uninsurable housing. Data provide information about dwelling quality, but not about dwelling compliance with building standards or permits (Section 4). The Inter-American Development Bank defines insurable housing market as housing built by solid materials and with potable water and drainage (IDB, 2000). Here I control for uninsurability by adding dummies for low dwelling quality: a dummy H_c for houses still in 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).

Groups of peers and of joint eligibility for assistance. Different definitions for the group J_{peer} of peers and for the group J_{aid} for joint eligibility 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).[55]

The place of birth can also explain the probability of purchasing insurance via an "initial peer effect". Indeed, as insurance penetration rate of continental France is exceptionally high (Grislain-Letrémy and Peinturier, 2010), having grown up in a place where a wide majority of people are insured can increase the probability of purchasing insurance. This is why dummies B_{cl} and B_a for households born in continental France and abroad, respectively are added to the demand equation.

Wealth. The wealth 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 observed income w earned by the household during the year is constant over time until the death of the reference person inside the household. I denote by A the age of the reference person in the household and E his life expectancy, which is calculated by linear interpolation using registry office statistics (Niel and Beaumel, 2010). I use here the discount rates

[55] When the geographical level is the municipality, the geographical impact is implicitly assumed to be uniform across municipalities, as there are too many municipalities to allow for different coefficients between municipalities.

recommended by Gollier (2007), that is $r_1 = 4\%$ until 30 years and $r_2 = 2\%$ beyond. Thus, I get

$$W = \sum_{0 \leq t \leq E-A} \frac{w}{(1+r_1)^t} \qquad \text{if } E - A \leq 30, \tag{24}$$

$$= \sum_{0 \leq t \leq 30} \frac{w}{(1+r_1)^t} + \sum_{31 \leq t \leq E-A} \frac{w}{(1+r_1)^{31}(1+r_2)^{t-31}} \text{ otherwise.} \tag{25}$$

This corresponds to a multiplication of the annual income by a factor that depends on the age of the reference person: it varies from 6 for the 95-year-old people to 24 for the 17-year-old ones, with an average of 18. Sign and significativeness of all coefficients are robust to this modification: they are similar when using the holdings as here defined or the annual income. They are even robust when uniformly multiplying annual income until to 100.[56]

Selection bias. I add the term $\nu\epsilon$, where ϵ 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.

Error. Another error η 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. ϵ and η are assumed to be independent, since possible correlation is taken into account by the selection bias term.

[56]Indeed, at the first order, the constant by which income is multiplied can be factorized in the terms implying income (Equation 26). Thus, its presence mainly modifies the order of magnitude of the coefficients of these terms.

Finally, the estimated model is

$$\begin{cases} \alpha_i = 1 \Leftrightarrow [\log(W_i - \pi_i) - \log(W_i)] + \tilde{\boldsymbol{p}}_{\boldsymbol{o}}[\log(W_i) - \log(W_i - L_{oi})] \\ \qquad +[qS_i + \theta E(Z_{\text{aid},i})S_i][\log(W_i) - \log(W_i - \boldsymbol{\beta} L_{oi})] + o_t O_{ti} + o_l O_{li} \\ \qquad +h_c H_{ci} + h_w H_{wi} + h_d H_{di} + h_t H_{ti} + \delta E(Z_{\text{peer},i}) + b_{cl} B_{cli} + b_a B_{ai} + \nu \epsilon_i + \eta_i \geq 0, \quad (26) \\ \text{if } \alpha_i = 1, \log(\pi_i) = c_\pi + y \log(Y_i) + n \log(N_i) + \log(1 - \tau O_{ti}) \\ \qquad - \log(1 - \boldsymbol{\kappa} - \rho R_i) + \sigma \epsilon_i, \quad (27) \\ \text{if } \alpha_i = 0, \pi_i = 0. \end{cases}$$

where errors ϵ and η follow independent centered normal distributions with unit variance, $c_\pi = \log(cp_o l)$ and $\rho = cpr/(1+r)$ are estimated parameters and $\boldsymbol{\kappa} = ckr/(1+r)$, $\tilde{\boldsymbol{p}}_{\boldsymbol{o}}$ and $\boldsymbol{\beta}$ are calibrated parameters.

Identifying variables. Identification requires the presence of variables that explain the probability of purchasing insurance but not the insurance premium. These identifying variables are the dummies for houses still in construction (H_c) and without drainage (H_d).[57] Economically, it means that houses still in construction and without drainage have a lower probability of being insured (because they are likely uninsurable) but, once a house is covered, the price of its coverage does not depend on these characteristics.

The model is overidentified, as identification requires to exclude one variable only from the demand equation. The two identifying variables are here compatible: when only one of the two is excluded from the premium, the remaining one is not significant in the premium equation and both variables are significant in the demand equation.

[57] Houses still in construction and houses without drainage correspond to 3% and 53% of dwellings, respectively (Table 3). These dummies (as dummies for houses without hot water or toilets inside the dwelling) do not significantly explain the losses, even when considering that losses can be differently estimated by households and by insurers.

5 Results

Estimation is based on maximum likelihood and is detailed in Appendix A.

5.1 Supply

Insurance pricing. Table 5 presents the results of the estimation of the insurance premium (Equation 27). As expected, the insurance premium increases with respect to the standard of living ($y > 0$) and the number of rooms of the dwelling ($n > 0$), which are proxies for the insured value (furniture and building values). 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 the exposure to natural disasters ($\rho > 0$), confirming that the potential loss of the insurer depends on the exposure of his policyholders, even if it is to a very limited extent (Section 2).

Table 5: Estimation results: supply equation

Coefficient	Estimate	Standard error	Pr > |t value|
c_π	2.4	0.16	<0.0001
y	0.22	0.016	<0.0001
n	0.32	0.047	<0.0001
τ	0.29	0.027	<0.0001
ρ	0.056	0.0068	<0.0001
σ	0.61	0.015	<0.0001
$\boldsymbol{\kappa}$	0.088	0	

Notes: $\boldsymbol{\kappa} = ckr/(1+r)$ 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 afford insurance, as the median standard of living in the French overseas departments is almost 40% lower than the one in continental France (Michel et al., 2010). To determine whether insurance is affordable for overseas households, the premiums offered to the uninsured are here estimated. These premiums can be estimated using these coefficients.[58]

The premiums offered to the uninsured are on average 9% below the premiums paid by the insured, mainly because the uninsured are on average poorer (Table 6).[59] As the premium increases less than proportionally with respect to the income ($y < 1$, Table 5), the budget weight (ratio of the premium over the annual income) decreases with respect to the income: the budget weight of the premium is so higher for the uninsured (the mean being 2.1%) than for the insured (1.4%), while remaining limited (Table 6). This limited budget weight of insurance premium for the uninsured suggests that insurance premiums should not prevent them from purchasing insurance. Answering properly that question requires estimation of insurance demand and in particular of the elasticity of insurance demand with respect to the premium.

Table 6: Home insurance: premium and budget weight

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

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

[58]These estimated coefficients (Table 5) correct the presence of a significant selection bias in Equation 26 (Table 7). In other words, this estimation takes into account the presence of unobserved heterogeneities 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 to purchase insurance; their higher risk aversion may be partially measured by insurers and so reflected in their premium. Regarding residuals, using their estimated variance implies that residuals for the uninsured are assumed to have the same variance than the ones for the insured.

[59]The elasticity of demand with respect to the income is estimated in Section 5.2.

5.2 Demand

Table 7 presents the estimation results for the demand equation (Equation 26). These results are now precisely commented and derived to quantify and compare the magnitude of demand determinants.

Table 7: Estimation results: demand equation

Coefficient	Estimate	Standard error	Pr > |t value|
o_t	0.34	0.070	<0.0001
o_l	0.83	0.094	<0.0001
h_c	-0.71	0.23	0.0020
h_w	-0.85	0.076	<0.0001
h_d	-0.50	0.061	<0.0001
h_t	-0.70	0.20	0.00050
q	-0.065	0.011	<0.0001
θ	0.095	0.020	<0.0001
δ	0.67	0.13	<0.0001
b_{cl}	0.77	0.11	<0.0001
b_a	-0.53	0.099	<0.0001
ν	0.41	0.095	<0.0001
$\tilde{\boldsymbol{p}}_{\boldsymbol{o}}$	0.075	0	
$\boldsymbol{\beta}$	15	0	

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

Small elasticity of insurance demand with respect to premium. The elasticity of insurance demand with respect to the premium can be calculated from these results. The elasticity of insurance demand with respect to the premium is $-5 \cdot 10^{-4}$, which is far smaller than results found by other studies for home and flood insurance (Table 8).[60] When the premium increases by 50%, the number of households who are willing to purchase insurance decreases by only 0.2%. This small price elasticity is due to the subsidized natural disasters coverage provided by home insurance. This result confirms that overseas households are not deterred from purchasing insurance by its price.

[60] This is not due to the fact that the premium is negligible with respect to households' holdings. Indeed, even when the model is estimated using annual income as wealth, the price elasticity of insurance demand remains low ($-5 \cdot 10^{-2}$).

Income elasticity of insurance demand. The elasticity of insurance demand with respect to the income can also be calculated and its order of magnitude is consistent with other studies (Table 8).[61] The income elasticity of insurance demand equals 0.10. Its positive sign confirms that the insured are on average richer than the uninsured (Table 6). Income elasticity of insurance demand may be positive or negative. Indeed, two opposite effects are at stake. On the one hand, theory predicts that, if the absolute risk aversion decreases with respect to the income, the demand for insurance also decreases with respect to the income (Schlesinger, 2000). On the other hand, wealthier households may buy costlier houses, exposing themselves this way to higher potential losses and increasing their need of coverage (Cleeton and Zellner, 1993).[62] Here a third effect is probably also at stake. Low income households likely benefit from more assistance after natural disasters,[63] which decreases insurance demand from low-income households. The positive sign of income elasticity means that the last two effects exceed the first one.

Table 8: Price and income elasticities of demand for home and flood insurance

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

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

Insurance obligations. Tenants and even more homeowners with outstanding loans have a higher probability of purchasing insurance than homeowners ($o_l > o_t >$

[61] Given that wealth is proportional to income (Section 4), elasticities with respect to wealth or to income are identical.

[62] Cleeton and Zellner (1993) show that the income elasticity of insurance demand is positive if $\phi_a + \eta > 1$, where ϕ_a is the elasticity of relative risk aversion to initial income and η is the elasticity of the amount of risk with respect to the initial income.

[63] For example financial assistance by the rescue fund for overseas decreases with respect to the income.

0). This result shows that the existing constraints relative to insurance purchase are operant. Besides, they have an important impact: if all households were tenants, the percentage of insured households would go from 48% (Table 3) to 60% (Table 9); if all households were homeowners with outstanding loans, the percentage of insured households would reach 72% (Table 9).[64]

Uninsurable housing. As expected, households living in a house in construction or without modern conveniences have a smaller probability of purchasing insurance ($h_c, h_w, h_d, h_t > 0$). In practice, insurers can control building quality and permit, either before selling the contract or once a loss has occurred before paying compensation. In any case, this control can be easily anticipated by households. The impact of uninsurable housing is important: if all households were living in a house still in construction, the percentage of insured households would go from 48% down to 19%; if all dwellings were houses without hot water, the insurance penetration rate would go down to 13%; if they were living in a house without drainage, this rate would go down to 36%; if all dwellings were houses without toilets inside the building, this rate would go down to 19% (Table 9).

Table 9: Impact of uninsurable housing and insurance obligations on insurance demand

Assumption	Percentage of insured households
$O_t = 1$	60%
$O_l = 1$	72%
$H_c = 1$	19%
$H_w = 1$	13%
$H_d = 1$	36%
$H_t = 1$	19%

Notes: the initial percentage of insured households is 48%. 2006 French Household Budget survey and GASPAR database. 2,809 observations.

[64] Purchasing home insurance is also required as a condition for obtaining a mortgage in the United States (Browne and Hoyt (2000), Kunreuther and Pauly (2006)) (Section 2). Browne and Hoyt (2000) show that the number of mortgages per capita in the United States is negatively related to the number of policies purchased per capita, likely because the level of mortgages captures wealth and income effects.

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 Section 4, the negative sign of q reveals the presence of charity hazard that outweighs the utility loss effect, and means that anticipated assistance by households 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 occurred have noticed the importance of assistance, probably more than the other households have; therefore they anticipate higher amounts of *ex post* aid.

A vicious circle of uninsurance. The penetration rate in the neighborhood increases the individual probability of purchasing insurance ($\delta > 0$), which reveals peer effects: the more neighbors are insured, the higher is the individual probability of purchasing insurance. This peer effect is significant at the municipal level, but not when defining the group of peers as households sharing same observed characteristics inside a municipality.

Besides, the penetration rate in the group for aid eligibility decreases the charity hazard effect ($\theta > 0$): the percentage of insured households around one individual decreases his likelihood to get assistance after a disaster. The relevant group for aid eligibility is also the municipality ($J_{\text{aid}} = J_{\text{peer}}$). This suggests that there is no favoritism towards households sharing one of the observed characteristics.[65]

Assuming that 3 over 4 households living in the municipality were insured, if there were peer effects only, the individual probability of purchasing insurance would reach 0.65; if the endogenous nature of assistance only was at stake, this probability would reach 0.49 (Table 10).

The place of birth explains the probability of purchasing insurance when this characteristic is simply added to the demand equation. Indeed, all things being equal,

[65] The two external effects of neighbors' insurance decision (based on peer effect or aid eligibility) remain significant when considering one without the other.

Table 10: Impact of the municipal insurance rate

Assumption	Individual probability of purchasing insurance
Municipal insurance rate = 75%	
via peer effects only	0.65
via aid eligibility only	0.49

Notes: the initial probability of purcahsing insurance is 0.48. 2006 French Household Budget survey and GASPAR database. 2,809 observations.

households whose reference person is born in continental France have a higher probability of purchasing insurance ($b_{cl} > 0$), whereas households born abroad have a lower probability of purchasing insurance ($b_a < 0$). This result suggests that having grown up in a place where a wide majority of people are insured increases the probability of being insured. This "initial peer effect" has also an important magnitude. If all households were born in continental 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 go from 48% down to 29% (Table 11).

Table 11: Impact of the place of birth on insurance demand

Assumption	Percentage of insured households
$B_{cl} = 1$	71%
$B_a = 1$	29%

Notes: the initial percentage of insured households is 48%. 2006 French Household Budget survey and GASPAR database. 2,809 observations.

Therefore households are not deterred from purchasing insurance by relatively high insurance premiums but by assistance provided after disasters; uninsurable housing also decreases the probability of being insured. My findings also suggest that the neighbors' insurance choices impact the individual insurance decision via peer effects and via neighborhood eligibility for assistance.

6 Discussion

The French overseas departments provide a rare natural experiment of a well-developed natural disasters insurance supply in Latin America, the Caribbean and other exposed small island countries. The determinants of insurance coverage on the demand side are uninsurable housing, which mainly applies in developing countries, and charity hazard, which also widely applies in developed countries. These two phenomena are here precisely discussed.

6.1 Uninsurable housing

Uninsurable housing widely applies in developing countries (Gilbert, 2001) and is well-documented in Latin America and the Caribbean (Section 2). Many developing countries (located in Africa, Asia and Pacific region, Europe or Middle East) benefit from some aids by the World Bank specifically dedicated to dwellings repair or rebuilding (Gilbert, 2001). These reconstruction projects often include an improvement of dwelling quality (introduction or use of earthquake resistant materials and designs, training of local masons, carpenters and artisans) (Gilbert, 2001). In the French overseas departments, building aid is already in place (Tjibaou, 2004).[66] This housing policy contributes to the decrease of uninsurable housing (Table 12). This may probably partly explain why the penetration rate has been progressively increasing (except in French Guiana, where uninsurable housing remains especially important) since 1995 (Table 13), since the impact of uninsurable housing on insurance demand is important (Section 5, Table 9).

6.2 Charity hazard

Charity hazard has an important magnitude in many developing countries (Gilbert, 2001) and among them the Caribbean region (Section 2); some aids, for example

[66] Furthermore, recent legal evolutions enable homeowners of squalid dwellings with neither right nor title to be compensated if public operations require their dwelling to be demolished. See law n^{0}2011-725 of June 23, 2011 relative to informal housing districts and fight against bad housing on overseas departments and regions.

Table 12: Evolution of dwelling quality in the French overseas departments

Share of (%) in 1999 / in 2007	Permanent structures	Dwellings in wood	Traditional huts	Makeshift dwellings
French Guiana	68.0 / 73.0	16.8 / 16.4	10.3 / 6.5	4.8 / 4.2
Guadeloupe	74.8 / 89.6	10.1 / 5.5	12.6 / 3.6	2.5 / 1.2
Martinique	88.5 / 93.7	5.3 / 3.6	4.4 / 1.1	1.8 / 1.7
Réunion	73.7 / 86.2	10.3 / 4.2	14.0 / 8.5	2.1 / 1.1

Notes: Main homes only are considered. Dwelling can be a house or an apartment. Population census by INSEE in 1999 and 2007.

Table 13: Evolution of home insurance penetration rate in the French overseas departments

(%)	1995	2001	2006
French Guiana	47	38	52
Guadeloupe	29	32	44
Martinique	39	41	50
Réunion	29	45	59

Notes: French Household Budget survey by INSEE in 1995, 2001 and 2006. 2 922 observations in 1995, 3 302 in 2001, 3 134 in 2006.

ones from the World Bank, are specifically dedicated to dwellings repair or rebuilding in developing countries (Gilbert, 2001). Charity hazard is also at stake in developed countries (see Raschky and Weck-Hannemann (2007) for a review).

Many European countries (Austria, Czech Republic, Germany, Italy, Poland, Slovakia) combine public assistance and private insurance with a low penetration rate (Maccaferri et al., 2012).[67] For example, in Canada, public assistance is also developed (through the Disaster Financial Assistance Arrangements and local funds created by some provinces) and Canadian households do not distinguish between public aids and compensations provided by insurers (Dumas et al., 2005). In Germany and in Italy, insurance is private and governmental assistance to flood victims is provided on an ad hoc basis; less than 10% of German households and about 5%

[67]In all these countries that combine public assistance and private insurance, it is difficult to determine the causality between the development of public assistance and the low penetration rate of private insurance: was demand for private insurance reduced because of public aid? Or was assistance initially developed to make up for a limited private insurance supply?

of Italian buildings are insured against floods (Bouwer et al. (2007), Schwarze and Wagner (2007)). These few examples illustrate differences in the institutional design of governmental relief programs between countries. This design - actually more its transparency than the coverage magnitude - significantly determines the demand for private natural hazard insurance (Raschky et al., 2010).

Charity hazard may also occur in developed countries where public assistance co-exists with public insurance. In the United States, flood insurance is offered by the Federal State and is purchased by a minority of households (Dixon et al. (2006), Kunreuther (1984)).[68] Before Hurricane Katrina, Browne and Hoyt (2000) and Kunreuther and Pauly (2006) show that a key explanation for the low demand for natural disasters insurance from American households is their biased risk perception and not charity hazard.[69] After Hurricane Katrina, Bush administration committed to provide billions of dollars in disaster relief to victims; this may have induced expectation of Federal assistance (Kunreuther and Pauly, 2005). Petrolia et al. (2012) show that the decision to purchase a flood policy is positively correlated with the eligibility for disaster assistance.

To what extent is charity hazard an issue? After all, as recalled by Raschky and Weck-Hannemann (2007), a catastrophe fund is *de facto* a "mandatory insurance". Indeed, one can argue that public assistance is not that much different from insurance subsidy: public assistance is a cross-subsidization from less exposed tax-payers to more exposed ones; similarly, insurance subsidy is a cross-subsidization from less exposed insured households to more exposed ones. This comparison is especially relevant for countries where insurance pricing implies insurance subsidy, such as France or the United States. Indeed, in France, the natural disasters pre-

[68]In the United States, flood insurance, which is offered by the Federal State to households, is purchased by around half of the single-family homes living in special flood hazard areas - i.e. zones with a 100-year recurrence interval for flood - and by only 1% of single-family homes outside (Dixon et al., 2006).

[69]For example, Browne and Hoyt (2000) test the presence of charity hazard and find a positive correlation between governmental aid and flood insurance purchase - and not a negative one. Their interpretation is that flood exposure may increase both governmental aid and insurance purchase.

mium is a fixed share of the home insurance premium (Section 2). In the United States, flood insurance is actuarial with subvention of specific risks and 22% of flood insurance policies are subsidized (Hayes and Neal, 2009).

Coate (1995) answers this very precise objection: compensation provided by insurance is defined *ex ante*, whereas compensation provided by aid is often defined *ex post*. This main difference has two important consequences, both underlined by Coate (1995).

First, *ex post* assistance is likely to be inefficient. There are two main reasons to expect that people who provide assistance will not choose the optimal level of assistance. The first reason is that assistance may rely on approximate loss assessment or even on discretionary decisions. In the United States, half of disaster payments by the Federal Emergency Management Agency are politically motivated (Garrett and Sobel, 2003).[70] The second reason is that the uninsured can free-ride, since natural disasters assistance is provided via different channels. To that respect, the assistance providers themselves can consider that the level of assistance is not optimal.

Second, providing *ex post* assistance reduces self-responsibility and gives no incentive for prevention. It does not refrain households from living in exposed areas or from building vulnerable houses, while these choices increase future losses and so future assistance provided by the whole society. Certainly, insurance subsidy also reduces self-responsibility, but this subsidy can be made temporary or combined with other incentives for prevention. For example, in the United States, this subsidy is temporary: flood insurance is provided at subsidized rates until the completion of the community's flood rate map. In France, this subsidy goes with incentives for prevention: the natural disasters insurance deductible increases with respect to the

[70]Similarly, in Pakistan, after the 2001 flood in Islamabad and Rawalpindi, public support checks were mainly distributed to family members and political supporters of local councilors who coordinate governmental assistance (Mustafa, 2003).

number of past disasters that have occurred in the municipality;[71] increasing the premium with respect to the risk exposure could also be considered.[72] Efficiency of such insurance policies clearly requires that the most exposed households had purchased insurance.

A third argument can be added to Coate (1995)'s ones: public assistance may distort the fiscal system and so redistribution between the rich and the poor. For example, in the United States, after Hurricane Andrew in 1992, assistance to the rich was funded by the poor, as Federal assistance was counterbalanced by a reduction of social budget (Favier and Pfister, 2007). On the contrary, in the French overseas departments, low income households benefit from more assistance after natural disasters (for example via the rescue fund for overseas). Actually this precisely contributes to explain why the uninsured are the poor in these departments (Subsection 5.2).

7 Conclusion

This paper studies the reasons for underinsurance against natural disasters in highly exposed areas. Limited insurance supply is commonly identified as a primary factor causing low insurance coverage in exposed areas. The French overseas departments provide a rare situation of a well-developed natural disasters insurance supply in highly exposed regions. Indeed, the French natural disasters insurance system is guaranteed by the French government; first foreseen for continental France only, it was extended to overseas departments after Hurricane Hugo in 1989, in a state of emergency. This natural experiment enables to analyze the determinants of insurance coverage on the demand side.

[71] The natural disasters insurance deductible paid by individuals is fixed by the government and can increase in municipalities which suffered several natural disasters and made however no risk prevention plan (Insurance Code, section L. 125-1, annex I). As the very wide majority of the municipalities in the French overseas departments have already undertaken or set up such plans (Section 2), this rule has a negligible impact in these departments.

[72] For now, increasing the premium with respect to the risk exposure is considered for insurance of firms' or local authorities' buildings only, not for home insurance. See http://www.senat.fr/leg/pjl11-491.html.

Using unique household-level micro-data about the insured and the uninsured, I estimate a semi-structural model of equilibrium on insurance market which had not been empirically tested. The structural approach enables to measure distortions on natural risk pricing due to insurance supply regulation and to disentangle the different possible causes of underinsurance on the demand side. I show that underinsurance in the French overseas departments is neither due to perception biases nor to unaffordable insurance, but mainly to uninsurable housing and to anticipated assistance, which crowds out insurance. Besides, the neighbors' insurance choices impact the individual insurance decision via peer effects and via neighborhood eligibility for assistance. Finally, I show that 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 targeted households to be insured, as they may not renew their insurance contracts once they have settled in.

There are two substantive lessons that one learns from this analysis. First, the main reasons for the low demand for insurance coverage against natural disasters in exposed areas are uninsurable housing, which mainly applies in developing countries, and charity hazard, which also widely applies in developed countries. Second, and consequently, these findings suggest that the development of an affordable supply of natural disasters coverage would probably increase the insurance penetration rate in disaster-prone areas, but would unlikely imply a wide majority of insured households not only because the social equilibrium of uninsurance has to be broken, but also because of charity hazard and, in developing countries, because of uninsurable housing. Thus, the development of a natural disasters coverage supply in disaster-prone areas (either via governmental initiatives or via microinsurance) would unlikely ensure the ability of governments to massively transfer catastrophic risk via coverage mechanisms if it does not go with a policy reducing charity hazard and, in developing countries, uninsurable housing.

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A Appendix

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

Recall that the estimated model is

$$\begin{cases} \alpha_i = 1 \Leftrightarrow [\log(W_i - \pi_i) - \log(W_i)] + \tilde{\boldsymbol{p}}_{\boldsymbol{o}}[\log(W_i) - \log(W_i - L_{oi})] \\ \qquad +[qS_i + \theta E(Z_{\text{aid},i})S_i][\log(W_i) - \log(W_i - \boldsymbol{\beta} L_{oi})] + o_t O_{ti} + o_l O_{li} \\ \qquad +h_c H_{ci} + h_w H_{wi} + h_d H_{di} + h_t H_{ti} + \delta E(Z_{\text{peer},i}) + b_{cl} B_{cli} + b_a B_{ai} + \nu \epsilon_i + \eta_i \geq 0, & (28) \\ \text{if } \alpha_i = 1, \log(\pi_i) = c_\pi + y\log(Y_i) + n\log(N_i) + \log(1 - \tau O_{ti}) \\ \qquad - \log(1 - \boldsymbol{\kappa} - \rho R_i) + \sigma \epsilon_i, & (29) \\ \text{if } \alpha_i = 0, \pi_i = 0. \end{cases}$$

where $\boldsymbol{\kappa}$ is a calibrated parameter. I denote

$$Z_\alpha = \tilde{\boldsymbol{p}}_{\boldsymbol{o}}[\log(W_i) - \log(W_i - L_{oi})] + [qS_i + \theta E(Z_{\text{aid},i})S_i][\log(W_i) - \log(W_i - \boldsymbol{\beta} L_{oi})]$$
$$+ o_t O_t + o_l O_l + h_c H_c + h_w H_w + h_d H_d + h_t H_t + \delta E(Z_{\text{peer}}) + b_{cl} B_{cl} + b_a B_a, \quad (30)$$
$$Z_\pi = c_\pi + y\log(Y) + n\log(N) + \log(1 - \tau O_t) - \log(1 - \boldsymbol{\kappa} - \rho R). \quad (31)$$

Besides, 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 who pays a premium π, the probability of purchasing insurance can be directly calculated using (19). Using the symmetry of the normal distribution, I get

$$Pr\left(\eta \geq -(\log\left(1 - \frac{\pi}{W}\right) + Z_\alpha + \nu\epsilon)\right) = \Phi\left(\log\left(1 - \frac{\pi}{W}\right) + Z_\alpha + \nu\epsilon\right), \quad (32)$$

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 who pays a premium π, the likelihood function is

$$\frac{1}{\sigma}\varphi\left(\frac{\log(\pi)-Z_\pi}{\sigma}\right)\Phi\left(\log\left(1-\frac{\pi}{W}\right)+Z_\alpha+\nu\frac{\log(\pi)-Z_\pi}{\sigma}\right), \tag{33}$$

For an uninsured household, the premium is not observed. Thus, the expected value of the probability of not purchasing insurance is[73]

$$1-\int_{\mathbb{R}}\underbrace{\Phi\left(\log\left(1-\frac{\exp(Z_\pi+\sigma\epsilon)}{W}\right)+Z_\alpha+\nu\epsilon\right)}_{F(\epsilon)}\varphi(\epsilon)d\epsilon. \tag{34}$$

I use the method exposed by Laroque and Salanié (2002) to approximate the integral that appears in the likelihood.[74] Following their estimation method, I denote by ϵ_i the ith 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 $x\varphi(x)=-\varphi'(x)$,

$$\bar{\epsilon}_i=\frac{\int_{\epsilon_i}^{\epsilon_{i+1}}x\varphi(x)dx}{\Phi(\epsilon_{i+1})-\Phi(\epsilon_i)}=m\Big[\varphi(\epsilon_i)-\varphi(\epsilon_{i+1})\Big], \tag{35}$$

and the integral can be approximated by

$$\int_{\mathbb{R}}F(\epsilon)\varphi(\epsilon)d\epsilon\approx\frac{1}{m}\sum_{i=0}^{m-1}F(\bar{\epsilon}_i). \tag{36}$$

Results are here presented for $m=10$; they are robust when using $m=20$.

[73]The likelihood function for the uninsured takes into account the fact that the selection bias $\nu\epsilon$ and the estimated premium for the uninsured both depend on the error term ϵ (Equation 34).

[74]Laroque and Salanié (2002) explain the wage and the participation decision on labor market, taking into account the fact that the decision to work depends on the wage. Their estimation is based on maximum likelihood and requires the approximation of a similar integral.

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