Working paper

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Insurance against Natural Catastrophes

Balancing Actuarial Fairness and Social Solidarity

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Octobre 2020

PARI

PROGRAMME DE RECHERCHE
SUR L'APPRÉHENSION DES RISQUES
ET DES INCERTITUDES

Insurance against Natural Catastrophes
Balancing Actuarial Fairness and Social Solidarity

by

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October 2020

We wish to thank Wouter Botzen, Thierry Cohignac, Pierre François, Arnaud Goussebaille, Burrell Montz and Pierre Picard for discussions and feedbacks on a previous version of this text. Any remaining imprecision is our own.

Abstract

Natural disasters offer a special case for the study of private and public insurance mix. Indeed, the experience accumulated over the past decades has made it possible to transform poorly known hazards, long considered uninsurable, into risks that can be assessed with some precision. They exemplify however the limits of the risk-based premiums method, as it might imply unaffordability for some. The French scheme reflects such ideas and offers a wide coverage for moderate premiums to all, but is shaken by climate change: we show that some wealthier areas, that were not perceived as "at risk" in the past, have become exposed to submersion risk in the future. This singularly makes some well-off properties the potential main beneficiaries of a scheme that was historically thought to protect the worst-off. Acknowledging that some segmentation might become desirable, we examine several models for flood risk and the disparity in premiums they entail.

JEL: G22; Q54; Q58
Keywords: natural disasters; actuarial fairness; solidarity; climate change; flood; France

1 Introduction

1.1 Insurance against flood events

During the twentieth century, most Western countries have developed schemes to cope with natural catastrophes; these schemes vary depending on cultural, historical and natural contexts. But most involve a partnership between public and private insurance (Klein and Wang (2009)), and reflect two models of insurance. The first one is solidarity-based, with risk pooling within a mutual fund. In that case, the contributions are usually independent from the level of risk brought to the pool; those insurance schemes are also comprehensive, compulsory and state run[1]. A popular example, in another context, would be health insurance in most European countries, the UK and Canada, where the National Health System supplies a minimum standard level of coverage to all citizens, and is funded through taxation, that could be a percentage of the salary. Another example is given by Eugenie Short, vice-president of the Federal Reserve, "*the FDIC[2] charges a fixed premium for deposit insurance without regard to the riskiness of bank portfolios*" (in Short (1985)). The second one is personalized insurance, with risk-based valuation. In those models, risks are still pooled together, but contribution is the best estimate of so-called "*individual risks*". Such schemes are market based, contractual, and usually voluntary: insureds have a level of discretion over the coverage they want.

As concerns natural catastrophes, one finds at one end of the spectrum the Spanish State-owned insurance company, the Consorcio de Compensación de Seguros (CCS), that covers extraordinary risks for the market. The cover appears as an add-on to property damage products, themselves optional (Consorcio de Compensación de Seguros (2016)). The CCS also benefits from State-guarantee, although this has never happened in practice (Le Den et al. (2017)). Besides, the responsibility for prevention lies on the Spanish State alone, giving to the state an overall significant importance in the compensation mechanism.

At the other end of the spectrum are countries where public funds are not engaged at all, and where the sole logic of the market is involved. Germany is currently a good example; in 2002, a major flood occurred with significant damages to the economy. It was followed by an attempt to reform the (market only) system with the introduction of a compulsory cover through insurance companies, backed by a State-guarantee above a threshold. The initiative failed, since the German finance ministers refused to grant such a guarantee, due both to its estimated cost,

[1]In this article, we use *state* to designate a nation-based collective action, as in Scott (1998). The word *government*, as in Moss (2002), was considered, but we will use *state* as consistently as possible.

[2]The Federal Deposit Insurance Corporation (FDIC) is an independent agency created by the U.S. Congress to maintain stability and public confidence in the financial system.

and its principle (Schwarze and Wagner (2007)). Hence in Germany except for some recently implemented disaster relief aid (Surminski and Thieken (2017)), natural catastrophes continue to be covered by private insurance mechanisms alone. The take-up rate is low, yet following risk awareness campaigns it has increased from 19% in 2002 to 41% in 2018 (Surminski et al. (2020)).

The paradox however, exemplified here by Germany, is that even in countries where public intervention does not exist ex-ante, some ex-post fundings are usually observed (Jaffee and Russell (2013)). Indeed, when market only mechanisms are involved, the protection level via insurance remains low. But then, "*in the absence of adequate insurance, the burden of paying for losses falls largely on citizens, governments or aid organizations, with significant impact upon already straining government budgets, and economic and social hardship for those affected*" (Jarzabkowski et al. (2018); see also Jaffee and Russell (2013),Klein and Wang (2009)). In this paper we will consider the pros and cons of various pricing options, in order to enlighten the impact of risk based premiums on affordability.

1.2 The Data

In our empirical analysis, we used some French historical data with different granularity levels: (1) the lowest possible level is houses. We have data containing the prices of all houses sold and purchased from 2014 to 2018, with their exact location. We will be able to see if those houses are in risky areas, as defined officially (by PPRI and PPRL, , described in section 2.3). There are a bit more than 35 million houses in France.[3] (2) Houses belong to cities (also called *commune*), of various sizes. There are a bit more than 35 thousand cities in France. Since available claims data is at city level, risks can only be assessed at this level. (3) Cities belong to larger areas, called *départements*. There are 96 départements in metropolitan France. Instead of pooling the risks at the national level (as discussed in 2.1), we will consider a hierarchical model at the end of this article, with various aggregation levels, starting from cities, then départements, and finally, (4) the entire country.

A claim-based dataset was provided by CCR (*Caisse Centrale de Réassurance*), with 20 years of past experience (from 1995 to 2014), per city/commune (given by their zip code, that can be located). We had access to two variables: the total number of claims declared over 20 years, and the average cost of a single claim. Numbers were categorized, for instance for the number of claims over 20 years, 0, (0; 20], (20; 50], (50; 100], (100; 500] and over 500; for the average cost of individual claims (in 1,000 €) 0, (0; 2.5], (2.500; 5], (5; 10], (10; 20], and over 20. Using data at the level of cities does not reflect the heterogeneity of situations

[3]https://www.insee.fr/fr/statistiques/4263935

within them; since however we will argue that some pooling is necessary, and since prevention measures are taken at the city level, taking the city/commune as the unit of analysis does make sense. Population per city was added, as well as information about income and wealth[4] of inhabitants, and the number of housings[5]. Note that income and wealth of inhabitants are usually given per *consumption unit*, and they were extrapolated to have the income per household[6], using demographic data since insurance premiums are per household.

1.3 Agenda

We propose in this article to examine the French case, that stands somewhere in the middle on the axis of private/public involvement in the scheme for natural disasters protection. Section 2 shows how the French "*Régime d'Indemnisation des Catastrophes Naturelles*" (also called the "CatNat regime") tries to address issues of solidarity, prevention and responsibility: the flat rate and the unlimited state-guarantee given to the regime ensure solidarity. The principle of responsibility is expressed in the conditions for coverage (detailed below). But the regime is tackled by some as not encouraging responsible behaviors, nor prevention on the side of the insureds. This criticism becomes more acute as current data makes it possible to create risk-based premiums, that would displace the equilibrium towards more responsibility.

Studying the parameters that affect the *supply* of household coverage against catastrophes by insurers, Born and Klimaszewski-Blettner (2013) show that regulation has a negative impact. While the French market is highly regulated, its specific features ensure that, in Metropolitan France at least, the take up rate of catastrophe insurance is close to 100 percent. In this matter it benefits from its bundle with the basic property damage cover, the demand of which is not strongly price elastic (Grace et al. (2004)). This comfortable situation could be shaken by the introduction of risk-based premiums that would significantly increase the cost of insurance for some segments, hence reduce the take-up rate. Our study is thus focused on the possible impact on catastrophe risk insurance *demand* rather than supply, that would result from a shift towards more risk-based premiums.

In section 3, we use historical data of the French market to calculate the actuarial (or risk based) premiums in the specific case of flood. These premiums highlight the disparities between localities, and are compared to the current flat rate in part 3.1. They show how quickly the system would give unaffordable premiums to some of the insureds. Currently, premiums dedicated to cover against flood are a fixed

[4]from https://www.insee.fr/fr/statistiques/3126432

[5]from https://www.insee.fr/fr/statistiques/4171418?sommaire=4171436

[6]from https://www.insee.fr/fr/statistiques/1906666?sommaire=1906743

percentage of the total household premium, itself highly correlated to the value of the house (or the apartment), and the wealth of policyholders; it therefore does not reflect the risk of flood. We study in part 3.2 the correlation between wealth and risk. Using French mapping of risks and wealth, one can see that specific high risk areas are also among the most well-off. This leads to a paradox: while the scheme was conceived so as to provide a solidary protection to the worst-off, it might also imply a redistribution towards higher income areas.

This point might trigger a revision of the regime in the long run, the more so as the distortion is driven by climate risk. In section 4, we therefore compare various pricing scenarii to the one currently used in France. The current French model, with a unique premium rate is presented in part 4.1. Then, in part 4.2, we discuss spatial risk dispersion, since 15% of the households experience about 90% of the losses, over 20 years. In parts 4.3 and 4.4 we consider a model with two zones, one being more risky than the other. The difficult task here is to set the threshold between the two, especially because of some Will-Rogers effect among the two regions. And finally, in part 4.5 we consider a hierarchical, or credibility based model.

2 Natural Catastrophes Insurance Schemes : the French case

2.1 At the Beginning : Solidarity, Founded on the Absence of Knowledge

Prior to the current system established in 1982, France benefited from a "*Secours Fund*", the aim of which was to provide urgency relief to natural catastrophe victims. These amounts were limited (up to 20% of the damage incurred) and, following large floods in 1981, unanimously judged inadequate. At the heart of the system, discussed and voted in 1982 by the Parliament, stood the principle of solidarity: some areas might be more exposed than others, however everybody is exposed in one way or another to some natural disaster[7]. Despite the principle of solidarity, the regime is not financed by tax; it is rather an additional compulsory premium added to each home insurance policy. It is not truly insurance either; indeed, the amount of the loading is decided by Parliament rather than insurance companies, as a flat percent of the home insurance premium. Besides, the additional premium covers damages defined as "natural catastrophe" via a special public commission, thus bypassing again the decision of insurance companies. We aim to show in

[7]The system covers most natural disasters, so geographic diversity increases the chance to face at least one specific risk in a given area. Nevertheless, in this article, we will not take into account this possible diversification, and focus only on flood risk, which is that largest one, in France.

this section that the system took shape within the assumption of the impossibility to "know" natural disasters: what kind of events to define as catastrophic, what amount of claims to expect, what zones to classify as high risk, all these elements were unknown at the time the regime was conceived.

In 1982, natural catastrophes were indeed neither precisely defined, nor their potential damage quantified. As stated earlier, these events were deemed "uninsurable." In the split between unmeasurable uncertainty and measurable risks (Knight (1985)), natural disasters were considered to always fall in the realm of unknown and inherently unknowable uncertainty. It is this lack of insurance coverage that the scheme came to fill. In this respect, a 1992 amendment confirms that it covers "*uninsurable*" events (Bidan and Cohignac (2017)), i.e. either statistically unknown, or systemic damages. In both cases, they cannot (temporarily or durably, respectively) be the object of classical insurance products. The tacit list of events covered by the regime is therefore changing over time, depending on insurance means and technological knowledge. For example, a windstorm cover was developed and became compulsory in the regular home insurance policy (and therefore excluded from the CatNat cover) in 1990; on the other hand, drought damages were added to the (informal) list of perils in 1989 (Bidan and Cohignac (2017)).

Besides the type of events, the overall cost was also unknown in 1982; during the parliamentary debates, the Economy Minister suggested a flat additional loading of about 5% on all home insurance policies, but he was tackled by other members of Parliament that claimed that the cost would be much higher. However, since in the absence of statistics nobody had a clear idea of the amounts at stake, they all agreed that "*the future will tell*"[8] (Barry (2020b)).

The additional loading (called "*surchage*", on both home insurance and own-damage auto policies) is thus voted by Parliament as a flat percentage of the basic premium. This flat loading reflects solidarity in a couple of ways:

- The loading (in percent) is the same whatever the area at stake: although a precise mapping of risk does not exist in 1982, the members of Parliament are well aware that specific areas are more exposed than others. However, the idea of adjusting the loading based on risk is rejected on two main grounds. First, the absence of a precise mapping would introduce some arbitrariness in the segmentation; second, for flood risk for instance, the exposure in one area might actually result from the absence or the impossibility of prevention measures in another area that does not bear the consequences. Hence the solidarity is a factual dependence of risk on collective behavior.

[8] In practice, the 5.5% appeared insufficient the next year and was raised to 9%. In 1999, the loading was raised again to its current level of 12%.

- The home insurance premium being correlated to the value of the house, it reflects indirectly the socio-economic level of the household. Hence the flat percentage means that more wealthy households contribute more in absolute terms than the less well-off, whatever their level of exposure. This implies some (unmeasured) redistribution of the burden towards the most well off.

- Since the cover is compulsory over all home insurance and auto own damage policies, and since these insurance products are widely bought, the system means both a very high level of protection for the population overall and, relatively, a low level of premium.

- Finally, a reinsurance with a public reinsurer that benefits from state guarantee, the Caisse Centrale de Réassurance (CCR), ensures the stability of the system and the solvency of insurance companies. In the worst-case scenario, the state (that also settles the premium level) will bear the cost.

The system as voted in 1982 is thus a mixed system of public and private interventions that reflects both the (absence of) knowledge on natural disasters and insurance mechanisms in 1982. The reliance on the insurance market together with flat premiums, for instance, was not perceived as contradictory; at the time, segmentation was not yet the rule of the game, and very few parameters were taken into account, whatever the product at stake (Barry (2020a)). Besides, the fairness as solidarity of flat contributions is often advanced by both practitioners (Frezal and Barry (2019), Lehtonen and Liukko (2011)) and members of Parliament. Finally, the implication of insurance companies is seen as a technical advantage for quick and efficient claims settlement.

Besides the solidarity principle firmly expressed in the dispositions above, measures are also taken to mitigate moral hazard. In order to ensure that the insureds are maintained as responsible agents, the cover is conditioned on a few elements, implying the responsibility of all the stakeholders:

- First is the responsibility of the State, that is in charge of implementing prevention measures. The Parliament indeed voted for the elaboration of a precise technical mapping (called Risk Exposition Plans (PER), later transformed into Risk Prevention Plans (PPR), see next section) aimed at delimiting buildable areas and reinforcing prevention measures when needed in already built ones.

- Second is the responsibility of the municipalities that negotiate with the state the contours of the plans, and might influence the latter so as to include more buildable areas than pure technical considerations would allow (see Dumas et al. (2005)).

- Finally, the responsibility of the insureds is maintained as the cover is conditioned on their buying home insurance and/or auto policies. Besides, the cover includes a deductible, first to avoid the congestion of the system with small claims, later to reflect and penalize recurring events, again as a signal for a better prevention (Dumas et al. (2005)).

2.2 Shaking the System with new Technologies

Starting in the 1980's, Baker and Simon (2002) notice that the social insurance paradigm, that posits solidarity as a primary goal is shaken by a new paradigm. Responsibility slowly takes precedence, implying a displacement of the notion of fairness as solidarity to fairness as the adjustment to individual risks. This paradigm shift, observable in all insurance products, is supported and enhanced by technological developments, the gathering of data, and the refinement of segmentation (Barry (2020a)). While the mix of public and private stakeholders in the French CatNat system was not an issue at inception, it is now exposed to a paradox; insurance companies have obtained over times the means to develop risk based models, including for natural disasters, that shake the possibility to maintain the flat solidarity loading, the more so as after state reinsurance, they continue to bare part of the risk.

According to Charpentier (2008), the first models for the analysis of climatic risks started to take shape at the end of the 1980's. More precisely, it is the especially catastrophic Andrew hurricane in 1992 that motivated the implementation of these models in insurance companies: "*even though catastrophe modeling technology was available to companies well before Hurricane Andrew, it took this event to convince companies that they should be using it*" as Clark (2002) explained.

Hence, insisting on the importance of information technologies, Kleindorfer and Kunreuther write in 1999 "*On the IT side, the development of faster and more powerful computers enables us to examine extremely complex phenomena in ways that were impossible even five years ago. Large databases can easily be stored and manipulated so that large-scale simulations of different disaster scenarios under alternative policy alternatives can now be undertaken. (. . .) A catastrophe model is the set of databases and computer programs designed to analyze the effect of different scenarios on hazard-prone areas. The information can be presented in the form of expected annual losses based on simulations run over a long period of time (e.g., ten thousand years) or the effect of specific events (e.g., worst-case scenarios)*" (see Kleindorfer and Kunreuther (1999)).

Symptomatically, while even the distribution of the total amount remained unknown in 1982, the new models aim at giving a risk assessment that goes down to the individual risk, based on building parameters and geolocation (Clark (2002)). Starting in the 2000's French insurers and reinsurers started to gather data and develop this kind of risk models for the French market, see (Quantin and Moncoulon (2012)). Hence natural disasters, once belonging to the realm of pure uncertainty, were being transformed into measurable risks. This recent knowledge leads however today to a paradox. Indeed, on the one hand it questions the possibility to maintain flat premiums over a country that is now mapped as variously exposed to risks; yet on the other hand, a precise adjustment to risks would mean that premiums become unaffordable to some.

The UK is here an example worth mentioning, since, until 2016, flood risks were covered via market mechanisms alone, with some level of segmentation freely chosen by insurers. An agreement between insurers and the state ensured the affordability of the premiums as long as the State would take the necessary preventive measures Haigh and Crabb (2014). The British regulator relied therefore on the efficiency of the market to establish premiums. But this was possible precisely because the granularity of knowledge was rough enough. In 2013, the Department for Environment, Food and Rural Affairs (Defra) warned however against a potential gap in flood cover due to the development of new technologies: *Premiums have been kept* affordable *through an informal cross subsidy, because customers at risk have not been differentiated from those not at risk,* as information on flood risk has been poor. With recent advances in flood mapping *insurers are increasingly able to set premiums more reflective of risk; this process has begun. Whilst ultimately, more risk-reflective premiums are economically efficient, if transition is too rapid those living at higher flood risk may face increases in premiums which are not compensated by reductions in other costs (e.g. mortgages). There is therefore a rationale to improve equity and reduce transitional costs*, Haigh and Crabb (2013).

These considerations led to the establishment of a reinsurance pool in 2016, Flood Re, the aim of which is to maintain affordable flood insurance premium to all socio-economic segments, despite the capacity to know better actual risk levels.[9]

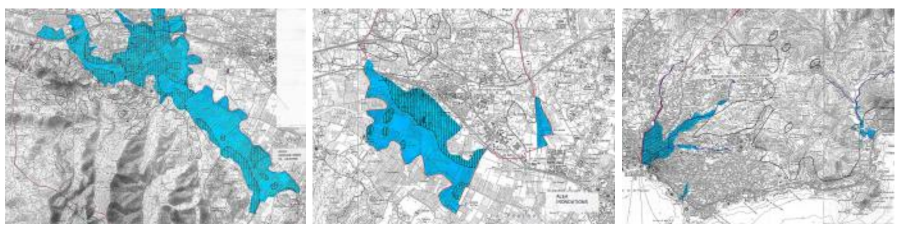
2.3 PPRI and PPRL, two different perils

As explained in Section 2.1, the French system relies on the mapping of risks by state agencies, so as to ensure proper construction zoning. Hence some knowledge of the risks was developed over the years, not for the sake of pricing, but for the elaboration of adequate levels of prevention. Today, the so-called *Floods Directive* is implemented through a PGRI (Management Plan for Inundation Risks), elaborated

[9]Flood Re is supposed to offer a transitory framework aimed at a return to market and risk-based premiums in 2039. However, premiums are supposed to be both risk-based and affordable in the long run thanks to public investments in flood defences and appropriate building regulation (FloodRe (2016)). As Golnaraghi et al. (2020) put it: "investments in risk reduction and prevention have significant implications for risk financing and the availability and affordability of insurance."

for each large-scale river basin. Several measures have been taken under two main plans: the PCS (Community Safety Plan) and the PPRI (Flood Risk Prevention Plan). The first plan concerns the emergency measures and actions in case of floods. It is based on the Hazard Study Document (*Etude de Dangers*) which is ordered by the municipality; the second concerns the adaptive and preventive measures taken by the municipality regarding its hazardous location. PPRI mention risk areas on maps. As shown on Figure 1, the blue zones exhibit higher risk of flood, with two distinct levels (see e.g. Díez-Herrero and Llorente-Isidro (2009) for an technical explaination about the construction of those zones). This risk is mainly associated with overflow risk, and is usually located nearby rivers.

Figure 1. PPRIs in Roquebrune-sur-Argens, Puget and Saint-Raphaël. The plain area (in blue) is the risky area.



For coastal flood, on the Atlantic zone, the Channel and the North Sea, those prevention plans are called PPRL (Coastal Risk Prevention Plan - see Figure 2 for visualization[10]). They display the infrastructures such as kinds of levees in place on the shore, and risk zones (with three distinct levels). Concerning PPRIs and PPRLs, they both aim to regulate urban development (by defining different constructible / non-constructible areas). One of the important differences between PPRI and PPRL is the taking into account of climate change for PPRL (based on sea level projections, in 2100, hence theoretically more constraining). PPRIs are thus related to well known historical *overflow risk* while PPRL are related to *coastal risk*, substantially increased recently with climate change, as discussed in Kulp and Strauss (2019).

3 Risk and Wealth

3.1 Fair Insurance Premiums

The shift of paradigm from solidarity to responsibility described by Baker and Simon (2002) is also accompanied, in the same period, by an evolution in the meaning

[10]via http://www.vendee.gouv.fr/approbation-du-pprl-de-la-baie-de-bourgneuf-vendee-a2200.html

Figure 2. PPRLs in Vendée. The dashed area is the risky area (the higher the density, the higher the risk). Note that existing dykes, for instance, are also mentioned.

of fairness. Barry (2020a) thus describes how American actuaries established in the 1980s a distinction between insurance and welfare: insurance should now strive to an "exact" calculation of risk, with no subsidies between groups of different risk levels, in contradiction with welfare, where considerations beyond the scope of risk might continue to be taken into account. Hence the notion of actuarial fairness is revised from a broad solidarity to the adjustment of premiums to individual risk profiles.

Incorporating the issue of moral hazard, this second model is usually seen as more efficient. Since agents bear the costs of their risk, they are indeed encouraged to behave responsibly and make choices that lower their exposure. From this perspective, risk-based premiums give the agent a signal of their exposure that is supposed to help them make sound decisions (Kousky and Kunreuther (2014)). In reverse, solidarity-based systems are tackled on this point: with no (financial) incentives to lower the risk and reduce vulnerabilities, they are taken to create moral hazards. Moreover, asking from lower risks to subsidize higher risks is here perceived as unfair.

But what kind of risks can one be considered to be responsible of? Higher risks are not necessarily responsible for their misfortune. Would it be fair, for someone seriously ill because of a disease that results from some bad luck, to pay a much higher insurance premium? For O'Neill (1997), one's genetic patrimony is a kind of genetic lottery, that could yield to actuarial unfairness if premiums do not compensate for - rather than reflect, higher risk. In order to maintain the responsibility principle with issues of fairness, one should thus take into account only those risks that result from individual *choices*. In the former example, a genetic disease should not be treated in the same manner as the practice of extreme sports. This concept of choice-sensitive fairness is also called luck-egalitarianism in justice theories (see e.g. Dworkin (2000), Cohen (1989), Rakowski (1991), or Arneson (2011)). In this approach, one should distinguish between outcomes due to brute luck from consequences of conscious choices - or option luck. A fair treatment consists in the neutralization of brute luck inequalities through subsidies. In natural disasters, localization is the main risk parameter. But should it be considered as brute or option luck? When prevention and risk reduction are not possible on an individual level but only collectively, as is the case for most flood prevention measures, the arguments for efficiency and responsibility are no longer valid since policyholders cannot make individual choices to lower their risk. Others argue that living in a flood prone area is a choice; as Rakowski (1991) puts it, "*if a citizen of a large and geographically diverse nation like the United States builds his house in a flood plain, or near the San Andreas fault, or in the heart of tornado country, then the risk of flood, earthquake, or crushing winds is one he chooses to bear, since those risks could be all but eliminated by living elsewhere*".

In the case of flood risk, the idea that risk based premium enhances responsibility and optimal choice by agents is not realized in practice: firstly, some studies on the United States and flood risk show that hazard mitigation might be a "*complement*" to insurance purchase rather than a substitute, pointing in fact to specific risk preferences as the explanatory variable for the choice to take prevention measures (Botzen et al. (2019)). This singularly limits the validity of the responsibility hypothesis that nurtures risk-based pricing. Secondly, the choice of leaving a risky area is complicated by income capacities, which blurs the distinction between brute and option luck. Studying the way populations adjust to hurricanes, Smith et al. (2006) show that higher income households can afford high risk areas and insurance to cover the exposure, whereas middle range income groups choose to avoid high risks and premium. The lowest segments actually choose the high risk because of the lower value of housing, but renounce buying insurance that is for them an unaffordable luxury (see also Viscusi (2006)). In countries (unlike France) where natural catastrophes insurance take up is low, the demand for insurance has also been studied, exhibiting a positive elasticity to income (Browne and Hoyt (2000); Grace et al. (2004); Michel-Kerjan (2010)). Botzen et al. (2019) similarly find on the United States that low income households are less likely to buy flood coverage than very high income, even in areas where it is mandatory.

The issue of responsible choice based on a signal given by risk-based premium is thus blurred by issues of affordability of insurance. In their study of the United States' National Flood Insurance Program (NFIP), Kousky and Kunreuther (2014) show that the tension between risk based premiums for flood insurance and their affordability for lower income groups led some legislators to step back from their commitment to risk-based pricing. [11] [12]

[11] For a historical description of the system with a focus on Florida see Michel- Kerjan and Kousky (2010)).

[12] Further studies led to a threshold of unaffordability when insurance premium exceeds 1 percent

3.2 Coastal vs. Overflow Risk

In order to illustrate the point discussed in the previous paragraph, we compare in this section the value of houses in risky and non risky zones of a given area. In the case of overflow risk (regulated by PPRIs), where risk is now well known and where new constructions are forbidden, prices of both apartments and houses are usually lower than in less risky parts of the city. If these risky areas are inhabited by lower socio-economic groups, then living there might not be a rational choice between options, but an economic necessity. In the case of coastal cities by contrast, where a PPRL is in place, one can see that houses and apartments at risks are usually more expensive than their counterparts in the lower risk zone. It can be explained by the fact that coastal properties enjoy a nice sea view and/or are at walking distance of the beach. In such cases, living in a high risk area is perceived as more valuable than not. This highlights that the "choice" to relocate might be highly correlated with financial capacities. But it also point to a pernicious effect: while the French system was designed to provide an affordable protection to all, the solidarity based premium might paradoxically turn in the next future to be beneficial to the most well-off. In Table 1, we can indeed see that in cities with coastal risk, that is increasing with climate change, the price of apartments or houses in risky areas is significantly higher than in non risky areas (+51% and +114% respectively in Vendée). [13]. We can observe that houses in risky areas can be much more expensive, as in Noirmoutier (+44%) or La Faute-sur-Mer (+700%).[14]

Table 1. Prices (€ per m^2) of houses sold (2014-2018) for Vendée - Western part of France, with PPRL (**coastal risk**). The *Difference* is the relative difference between average prices (per m^2) between the risky and the non-risky zones, either for apartments or houses.

			Average Price	Difference (%)	Maximum Price	Number	Proportion (%)
Vendée	Non risky	Apartments	4293		21840	329	9%
		Houses	2928		65909	2795	74%
	Risky	Apartments	3302	-23%	9773	39[15]	1%
		Houses	10253	+250%	71483	637	17%
Pays-Loire	Non risky	Apartments	4399		79913	8411	37%
		Houses	3019		75472	12678	55%
	Risky	Apartments	6784	+54%	68478	1001	4%
		Houses	3245	+7%	22895	765	3%

of income (Long (2018); see also National Research Council (2015)).

[13]The details for several cities are given in Table 9, in the Appendix

[14]The city of La Faute-sur-Mer became famous since 29 people died at the end of February 2010, because of the coastal flood caused by windstorm Xynthia.

Table 2. Prices (€ per m^2) of houses sold (2000-2020) for several départements in France, with PPRI (**overflow risk**, or **non-costal**).

			Average Price	Difference (%)	Maximum Price	Number	Proportion (%)
Var	Non risky	Apartments	5392			9874	53%
		Houses	5957			6913	37%
	Risky	Apartments	4190	-22%		1471	8%
		Houses	4172	-30%		226	1%
Haute Loire	Non risky	Apartments	2399		38333	3403	27%
		Houses	1314		20625	8857	69%
	Risky	Apartments	2163	-11%	28125	319	2%
		Houses	1247	-5%	7432	272	2%
Seine et Marne	Non risky	Apartments	6260		79710	82133	44%
		Houses	3356		79167	98824	53%
	Risky	Apartments	4333	-30%	40000	2177	1%
		Houses	2693	-20%	54096	1784	1%
Isère	Non risky	Apartments	4960		79800	27982	52%
		Houses	2429		69375	24600	45%
	Risky	Apartments	3252	-3%	35714	885	2%
		Houses	2543	+5%	14067	435	1%
Oise	Non risky	Apartments	6170		79963	24613	34%
		Houses	3126		78214	44737	62%
	Risky	Apartments	5725	-7%	50000	1385	2%
		Houses	2866	-8%	62184	1640	2%

For cities with non-coastal risk, prices of apartments or houses in risky areas is significantly lower than in non risky areas (-22% and -30% respectively in Var, -30% and -20% in Seine-et-Marne), as shown in Table 2. Again, details for several cities in Var are given in Table 10, in the Appendix. We can observe that houses and apartments in risky areas can be much less expensive, as in Gassin (-32%) or Roquebrune (-31%), as well as all cities listed.

3.3 Risk vs. Wealth

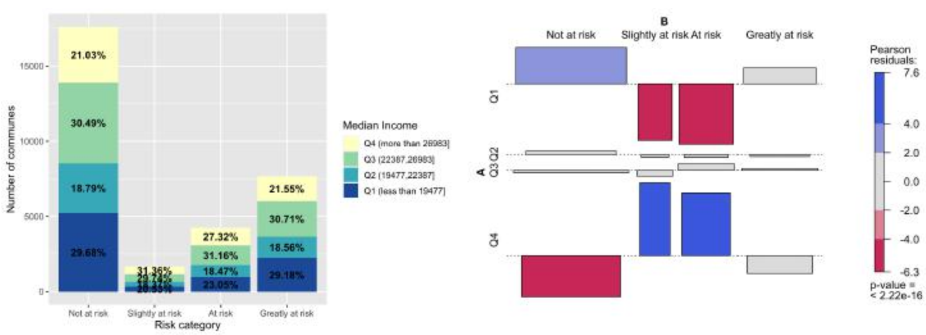
Living in a risky area is thus not necessarily a choice and the relative value of the property might be a good indication of whether it is a case of brute or option luck; low-income families may not have reasonable and acceptable alternatives than to live in riskier yet cheaper areas. While we will discuss in more detail the distribution of risks over the entire country in the next section, we briefly examine here the correlation between risk and wealth. Based on the cost of past flood events (over twenty years), communes are split into four groups: *not at risk*

[10]Only 39 apartments were sold over 5 years.

(56.47%), *slightly at risk* (5.36%), *at risk* (13.59%) and *greatly at risk* (24.58%). Similarly, we can use medium income per communes over the same period to create four categories, based on quartiles, from Q1 (lowest quartile, with median income below 19,477€) to Q4 (upper quartile, above 26,983€). Empirically, 28.17% of the French population live in a city in Q1, 18.66% in Q2, 30.56% in Q3 and 22.57% in Q4 (Since income quartiles are here per city, we cannot have 25% of the population in each group).

On Figure 3, on the left, we can visualize the distribution of communes according to their risk and their median income categories. Differences are small, but statistically significant. In Table 3, we have contingency tables associated with those two variables. First of all, cities that are *greatly at risk* are not more likely to be associated (neither positively nor negatively) to one level of wealth. Yet cities either *slightly at risk* or simply *at risk* tend to be positively associated with higher incomes (Q4) and negatively associated with lower income (Q1)[16]. This can mean that richer cities are closer to water-paths, rivers or seashores.

Figure 3. Distribution of communes, on the left, according to their median income (per quartile) and risk level (from *not at risk* to *greatly at risk*, from past history). On the right, Pearson's residuals from a chi's square test of independence (from Table 3).



Maps showing the spatial distribution of average annual costs (per city), this amount with respect to the average income, and the average price of house, and finally the value of the house with respect to the average income, can be visualized on Figures 6.3 and 10, in the Appendix.

[16]The chi'square statistics is here $Q = 214.04$, for 9 degrees of freedom, which corresponds to a p-value lower than $2 \cdot 10^{-16}$, which makes it hard to accept the independent assumption.

Table 3. Statistics about regions at risk, and median income, with a chi'square test of independent. Pearson's residuals (or square-roots of chi'square individual contributions) can be visualized on Figure 3.

	Observed				Expected (independent)			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
greatly at risk	2238	1423	2355	1653	2160.3	1431.6	2346.4	1730.7
at risk	977	783	1321	1158	1194.1	791.3	1296.9	956.6
slightly at risk	343	307	497	524	470.7	311.9	511.2	377.2
not at risk	5229	3310	5371	3705	4961.9	3288.2	5389.4	3975.4

4 Testing Various Pricing Scenarios in France

In the current French system, natural disasters (including flood risk) are covered by a loading on the regular household insurance premium (for personal insurance) and amounts to 12% of the premium. [17] But note that this contribution should cover against *all* natural catastrophes. According to CCR (2020), the 12% loading represents, on average, 21€ per home insurance contract. [18] The flood-premium represents 57% of the catastrophe surcharge, hence 6.8% of the home insurance premium (i.e. 6.8% is added to the standard home insurance premium to cover against flood risk) and on average 12€ per year. Thus, using a first order approximation, we might say that the flood-premium is a fixed percentage of the value of the house, or the wealth of households: the premium does not reflect risks, but takes into account financial capacities. In this section, we assess various pricing models while taking into account two facts: on the one hand, a pure risk-based premium or *choice-sensitive fairness* approach would not be fair, since bad luck is a mix between bad decision and brute luck. On the other hand, as illustrated by PPRLs, climate change is shifting areas at risk towards more well-off areas, thus threatening the flat loading to become an actual subsidy paid by the less well-off to the most well-off.

4.1 The Benchmark Solidarity Based Scenario

As explained above, the annual flood premium is, on average, 12.0€, or 6.86% of the household insurance premium. In the remainder of this paper, we will use the ratio of 6.86/12=0.5714 to convert premiums computed in € to premium rate (by multiplying by 0.5714). Hence a 100€ flood premium is equivalent to a premium loading of 57.14% on the home insurance pure premium, and a 175€ flood pure premium means a loading of 100%.

[17] it started at 5.5%, then jumped to 9% in 1985, and then to 12% in 2000

[18] We will mention here only household insurance, not commercial buildings.

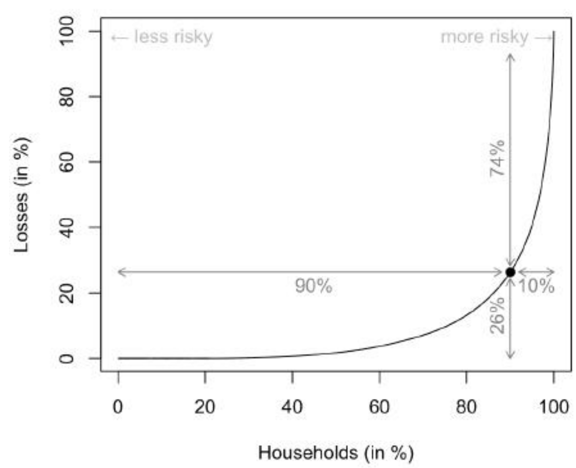
4.2 Spatial Risk Dispersion

Over the twenty years of data, 60% of the French cities (21,940) did not experience a single flood claim, indicating that flood risk is probably unbalanced over the country. Let x_i denote the total losses in city i, and p_i denote the population in that city. Assume that observations are ordered according to their average pure premium, then the Lorenz curve is the set of observations

$$\left(\frac{p_i}{\sum_j p_j}, \frac{x_i}{\sum_j x_j}\right),\ i = 1, \cdots, n,\ \text{when } \frac{x_1}{p_1} \leq \frac{x_2}{p_2} \leq \cdots \leq \frac{x_n}{p_n}.$$

On the x-axis, we have the proportion of households, sorted according to the relative risk of their city, and on the y axis, we have the proportion on the losses. Figure 4 shows the Lorenz curve of costs, per household. Note that data were at a city level, but we convert those to houses, since city sizes are quite heterogeneous[19].

Figure 4. Lorenz curve for the losses, with low risk are on the left of the x-axis, and high risk on the right of the axis: 10% of the households account for 73.6% of the losses.

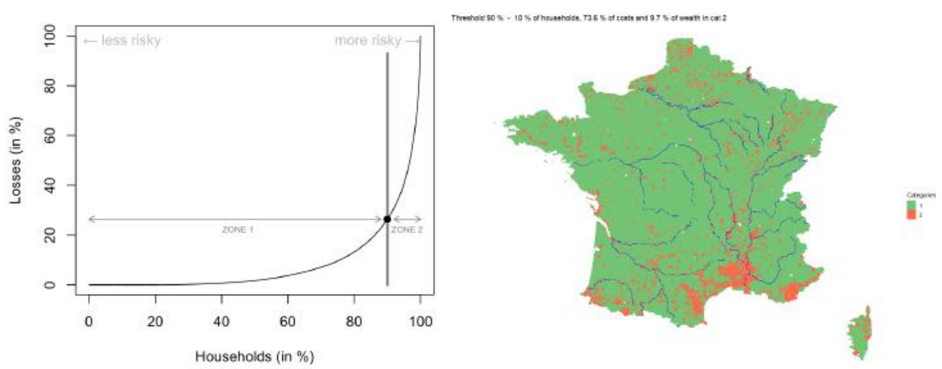


[19]The fact that 15% of the households are experiencing about 90% of the losses, over twenty years, is actually not unusual in insurance: if we assume that flood risk is uniform and centennial (each household has a 1% yearly chance to claim a loss), and that all risks are independent, then over twenty years 18.2% of the households will claim a lost at least once – if X has a binomial distribution $\mathcal{B}(n = 20, p = 1\%)$ (since we assure independence between years) then $\mathbb{P}(X = 0) = (1 - p)^n = 0.99^{20} = 81.79\%$. So 100% of the losses are related to 18.2% of the portfolio (and possibly 18.2% is the premium earned).

4.3 A Two-Zone Model

Instead of a flat rate for the flood-premium (at 6.86%, equivalent to 12€, on average), uniform over the whole country, a first step could be to consider a simple two-risk-category model, with some *less risky* (1) and *more risky* (2) zones. To distinguish between the two zones, we can use the Lorenz curve displayed in Figure 4. On the left, we have the less risky households and on the right, the more risky ones. Consider some arbitrary cutoff α (say $\alpha = 90\%$) so that cities of households on the right are in category (2), above α, while below, they will belong to category (1). On Figure 5, we use a cutoff value $\alpha = 90\%$: in the *more risk* category, we have $1 - \alpha = 10\%$ of the households, representing 9.7% of the wealth, and 73.6% of the losses. One can see that the high risk area thus defined is concentrated in South-East France.

Figure 5. The Two-Zone model, 90% of the households live in the least risky part (zone (1)) and 10% live in the most risky part (zone (2)).

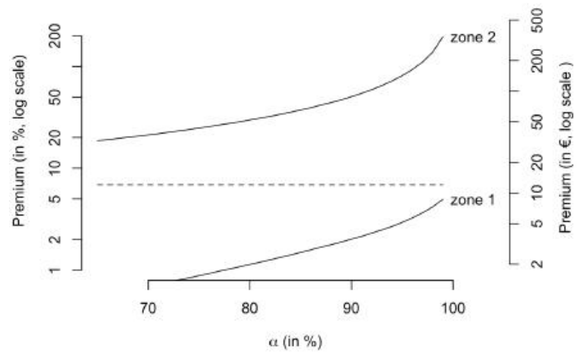


Recall that overall, the annual flood-premium is, on average, 12€ per household. When $\alpha = 90\%$, the average annual flood-premium $p_2(\alpha)$ becomes 88.5€ in the *more-risky* region (the interval is [24.39;152.56]). Such a premium reflects the fact that those 10% most risky areas represent 73.6% of the losses. Figure 6, illustrates the evolution of the flood-premium in each zone as function of α. For instance, when $\alpha = 80\%$, the flood-premium $p_2(\alpha)$ is 52€in the risky region (2). The largest value considered was close to 400€, per house. Note that National Research Council (2017) suggested, while discussing affordability of flood insurance cover, not to exceed 1% of the annual income, as a premium. For France, that would correspond to an annual premium of a bit more than 200€.

The higher the value of α, the higher the premium in *both* zones, which might seem surprising. But that is simply Will Rogers phenomenon (as called[20] in

[20]The Will Rogers phenomenon is obtained when moving an element from one set to another set

Figure 6. Premiums $p_1(\alpha)$ and $p_2(\alpha)$, in the two zones, where α is the % in zone 1.



Feinstein et al. (1985)). Heuristically, if we increase from α to $\alpha + \varepsilon$ (for some very small ε), the less risky city in zone 2 will become the more risky in zone 1, and will benefit from a drop in premium. In the risky zone, by removing the least risky, we increase the average risk (and the premium), while in the non risky zone, by adding the newly most risky city, we also increase the average risk. Interestingly, if we want premiums in the two regions to be as small as possible, Will Rogers phenomena means that it would be optimal to have α as small a possible, which means 0, and a unique solidarity-based premium. As discussed in Charpentier and Le Maux (2014) (using game theory arguments), if the risky zone is too small (large α), the ruin problem should be addressed, since risk mutualization is then hardly possible. So having a small α should be motivated by some diversification properties: having risks in different geographic areas is better from a risk management perspective.

4.4 A two-Zone model, with an upper limit

If the risky region is rather small, the premium asked in that region can be quite high. For instance, if the risky region (2) corresponds to 5% of the population, the average premium asked is 88.5€, which correspond to a 50% loading on the home insurance premium, on average. It is possible to introduce a capping to the high risk premium, that would be subsidized by the low risks. The cap can be in absolute euros amounts or in percent loading.

In Table 4, several upper limits (in amount and in percent) are considered, for individual premiums. The table illustrates the high sensitivity of the high risk

raises the average values of both sets. It is based on the quote, attributed to comedian Will Rogers, *when the Okies left Oklahoma and moved to California, they raised the average intelligence level in both states*.

Table 4. Premiums dedicated to flood risk, in a two-zone model, with proportions of the population α (in the less risky part) and $1-\alpha$ (in the more risky), where $\alpha = 98\%, 95\%, 90\%$ and 80%. In risky regions, premiums can be capped, with an upper bound that can be either in € (on top) in as percentage of the household premium (below). Premiums in various regions are expressed also either in € (on top) in as percentage of the household premium (below).

	Entire country	Two zone 2%	98%	Two zone 5%	95%	Two zone 10%	90%	Two zone 20%	80%
No restriction	12.0€	242.1€	7.3€	142.3€	5.1€	88.5€	3.5€	52.1€	2.0€
Capped Premium (200€)	12.0€	169.9€	8.7€	113.4€	6.7€	74.0€	5.1€	44.8€	3.8€
Capped Premium (120€)	12.0€	119.9€	9.8€	93.7€	7.7€	64.0€	6.2€	39.8€	5.0€
Capped Premium (80€)	12.0€	80.0€	10.6€	74.0€	8.7€	54.2€	7.0€	35.0€	26.1€
Capped Premium (40€)	12.0€	40.0€	11.4€	40.0€	10.5€	35.5€	9.3€	26.1€	8.5€
No restriction	6.8%	138.3%	4.2%	81.3%	2.9%	50.6%	2.0%	29.7%	1.1%
Capped Premium (100%)	6.8%	100.0%	5.0%	81.3%	4.2%	50.6%	2.0%	29.7%	1.1%
Capped Premium (75%)	6.8%	75.0%	5.5%	75.0%	3.3%	50.6%	2.0%	29.7%	1.1%
Capped Premium (50%)	6.8%	50.0%	6.0%	50.0%	4.6%	50.0%	2.0%	29.7%	1.1%
Capped Premium (25%)	6.8%	25.0%	6.5%	25.0%	5.9%	25.0%	4.9%	25.0%	2.3%

premium to both the level of α and the level of cap. The resulting premium in the lower risk by contrast is relatively stable, as the subsidies burden is spread over a relatively large part of the population.

On Figure 7, we can see the evolution of the premium, in each zone, as a function of α. On the left is $p(\alpha)$, and on the right is the capped version at 120€.

Figure 7. Premium $p(\alpha)$, capped so that premiums cannot exceed 120€.

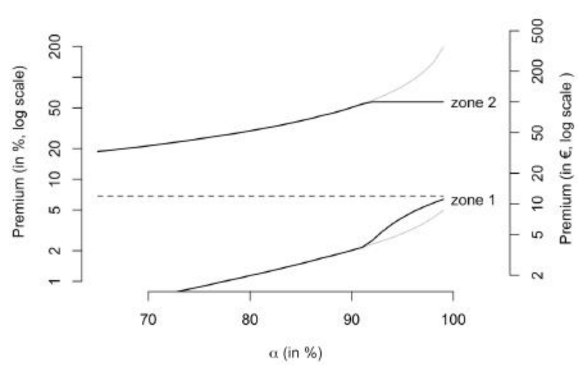


Table 5. Comparing premiums, in percent of the household premium, in nine cities, in Var, Pays-de-Loire and Vendée.

		Uniform			Two-Zone Model		
		Country	Region	City	$\alpha = 95\%$	$\alpha = 90\%$	$\alpha = 80\%$
Var	Frejus	12.0€	30.6€	15.7€	5.1€	3.5€	52.1€
	Grimaud	12.0€	30.6€	84.3€	142.3€	88.5€	52.1€
	Puget	12.0€	30.6€	133.0€	142.3€	88.5€	52.1€
Pays Loire	Assérac	12.0€	3.6€	6.7€	5.1€	3.5€	2.0€
	Mesquer	12.0€	3.6€	10.2€	5.1€	3.5€	2.0€
	Le Croisic	12.0€	3.6€	25.9€	5.1€	88.5€	52.1€
Vendée	Talmont-Saint-Hilaire	12.0€	10.7€	4.8€	5.1€	3.5€	2.0€
	Noirmoutier-en-l'Île	12.0€	10.7€	8.5€	5.1€	3.5€	2.0€
	La Faute-sur-Mer	12.0€	10.7€	275.1€	142.3€	88.5€	52.1€

Table 6. Comparing premiums, in €, in nine cities, in Var, Pays-de-Loire and Vendée.

		Uniform			Two-Zone Model		
		Country	Region	City	$\alpha = 95\%$	$\alpha = 90\%$	$\alpha = 80\%$
Var	Fréjus	6.9%	17.5%	9%	2.9%	2.0%	29.8 %
	Grimaud	6.9%	17.5%	48.2%	81.3%	50.6%	29.8 %
	Puget-sur-Argens	6.9%	17.5%	76.1%	81.3%	50.6%	29.8 %
Pays Loire	Assérac	6.9%	2%	3.8%	2.9%	2.0%	1.1 %
	Mesquer	6.9%	2%	5.8%	2.9%	2.0%	1.1 %
	Le Croisic	6.9%	2%	14.8%	2.9%	50.6%	29.8 %
Vendée	Talmont-Saint-Hilaire	6.9%	6.1%	2.7%	2.9%	2.0%	1.5 %
	Noirmoutier-en-l'Île	6.9%	6.1%	4.9%	2.9%	2.0%	1.1 %
	La Faute-sur-Mer	6.9%	6.1%	157.2%	81.3%	50.6%	29.8 %

4.5 Hierarchical Models

As discussed previously, solidarity-based insurance schemes are criticized because they yield moral hazard, but so are market-based risk-sensitive insurance schemes, in a sense, since they might remove incentives for *collective* action to mitigate flood hazards. In order to avoid such collective moral hazard and further mitigate and spread the risk-based premium, we consider in this section some hierarchical models, where solidarity is local, before aggregating at a country level. This could be seen as a hierarchical credibility model (as in Bühlmann (1967), Bühlmann (1969))

Let $\overline{x}_{i:j}$ denote the historical average yearly loss in city i and region j, $w_{i:j}$ the total wealth in that city, and $n_{i:j}$ the number of households. An actuarially fair premium for that city would be $p_{i:j}$ such that $p_{i:j} \cdot n_{i:j} = \overline{x}_{i:j}$. An actuarially fair premium for region j would be p_j such that

$$p_j \cdot \sum_i n_{i:j} = \sum_i \overline{x}_{i:j}$$

A hierarchical premium, with rate β would be

$$p_{i:j}(\beta) = \beta \cdot p_{i:j} + (1-\beta) \cdot p_j$$

More generally, one can also consider some nation-based solidarity, first, so that

$$p_{i:j}(\beta,\gamma) = \gamma p + (1-\gamma)\big[\beta \cdot p_{i:j} + (1-\beta) \cdot p_j\big]$$

where p is the average premium on the entiere dataset. For instance, in Fréjus (Var), the premium is, in €,

$$p_{\text{Fréjus:Var}}(\beta,\gamma) = \gamma 12.0 + (1-\gamma)\big[\beta \cdot 15.8 + (1-\beta) \cdot 30.6\big]$$

or

$$p^{\%}_{\text{Fréjus:Var}}(\beta,\gamma) = \gamma 6.85 + (1-\gamma)\big[\beta \cdot 9.00 + (1-\beta) \cdot 17.46\big]$$

On Figure 9, we can see that the variance of premiums increases with β, and decreases with α, as intuited. Nevertheless, if instead of looking at the variability, we look at a high quantile (which would make sense since we cannot have a too high premium in a given city), we can see that the evolution with β is not monotonic. We can see that the 99% quantile is minimal when $\beta = 25\%$.

Figure 9. Evolution of the variance of the premiums on the left, and the 99% quantile on the right, for the premium $p(\beta,\gamma)$ in the hierarchical model, as a function of β, for various γ.

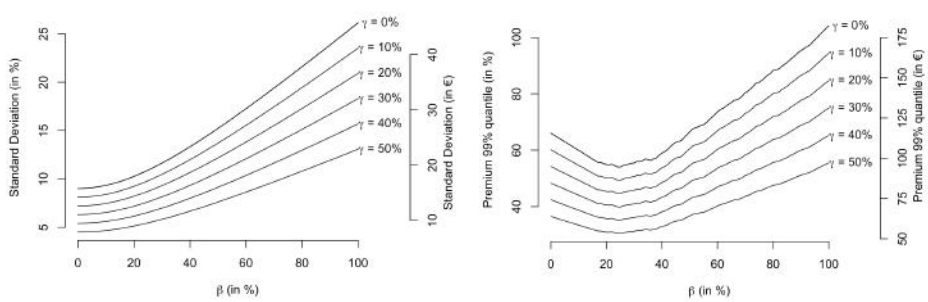


Table 7. Comparing premiums in nine cities, values in % of the household premium, with a hierachical model, γ is the share of national solidarity, $(1-\gamma)\beta$ is the share of city-based solidarity. Those values can be visualized on Figure 8.

		Uniform (γ,β) $(1,0)$ Country	$(0,0)$ Region	$(0,1)$ City	Hierarchical Model $\gamma=0\%$ $\beta=10\%$	$\beta=20\%$	$\beta=50\%$
Var	Fréjus	6.9%	17.5%	9.0%	9.5%	8.8%	7.6 %
	Grimaud	6.9%	17.5%	48.2%	11.8%	14.4%	18.8 %
	Puget-sur-Argens	6.9%	17.5%	76.1%	13.3%	18.4%	26.7 %
Pays Loire	Assérac	6.9%	2.0%	3.8%	1.2%	1.4%	1.7 %
	Mesquer	6.9%	2.0%	5.8%	1.4%	1.7%	2.2 %
	Le Croisic	6.9%	2.0%	14.8%	1.9%	3.0%	4.8 %
Vendée	Talmont-Saint-Hilaire	6.9%	6.1%	2.7%	3.3%	3%	2.5 %
	Noirmoutier-en-l'Île	6.9%	6.1%	4.9%	3.4%	3.3%	3.1 %
	La Faute-sur-Mer	6.9%	6.1%	157.2%	12.1%	25.1%	46.7 %

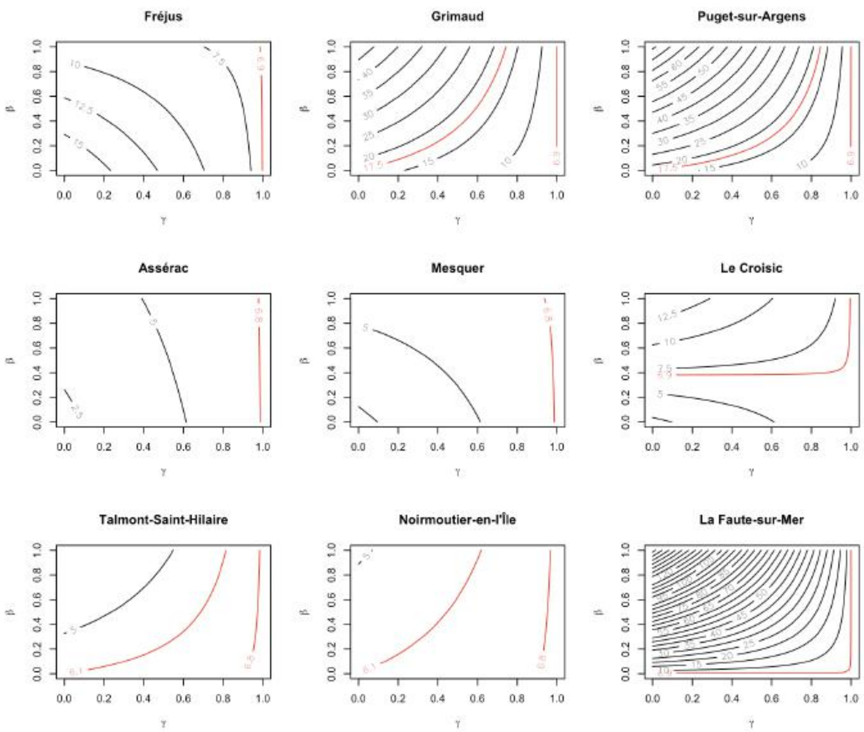
		Hierarchical Model $\gamma=20\%$ $\beta=10\%$	$\beta=20\%$	$\beta=50\%$	Hierarchical Model $\gamma=40\%$ $\beta=10\%$	$\beta=20\%$	$\beta=50\%$
Var	Fréjus	14.7%	13.7%	12%	12.7%	12.0%	10.7 %
	Grimaud	17.8%	21.5%	27.7%	15.1%	17.8%	22.5 %
	Puget-sur-Argens	20.1%	27.1%	38.8%	16.8%	22.0%	30.8 %
Pays Loire	Assérac	3.2%	3.4%	3.7%	4.1%	4.2%	4.5 %
	Mesquer	3.3%	3.8%	4.5%	4.2%	4.5%	5.1 %
	Le Croisic	4.0%	5.6%	8.1%	4.7%	5.9%	7.8 %
Vendée	Talmont-Saint-Hilaire	6%	5.6%	4.9%	6.2%	5.9%	5.4 %
	Noirmoutier-en-l'Île	6.2%	6.0%	5.8%	6.3%	6.2%	6.0 %
	La Faute-sur-Mer	18.3%	36.5%	66.7%	15.5%	29.1%	51.7 %

5 Conclusion

Fairness in insurance is an evolving concept. In a study on motor insurance, Meyers and Van Hoyweghen (2018) claim that the shift from static pricing based on classification to behavior-based pricing is accompanied by a shift in the meaning of fairness: in the first scheme, fairness is expressed as solidarity within the group (the class of insureds), whereas in the second one fairness results from making the driver responsible for his rate: those who want to pay less for their insurance need "only" change their driving behaviour (fairness as an adjustment to individual risk, supposedly here dependent on individual choices).

Would it be possible to adopt a similar approach in natural disasters and switch from the paradigm of solidarity to that of responsibility? On the one hand, data is now available in France to produce risk-based premiums, with classical economic logic leading to interpret the absence of premium modulation as a disincentive to caution. Thus a 2005 survey mission notes that "*by its very nature, the CatNat*

Figure 8. Iso-premiums $p(\beta, \gamma)$ (in percent) for nine cities, for different values of γ and β. The vertical line of the right ($\gamma = 1$) corresponds to the benchmark case, with $p = 6.8\%$.



scheme may have a disempowering effect on policyholders who do not bear the economic consequences of a risky location from the point of view of the risk incurred", while adding, symptomatically, "*it is however very difficult to objectively assess such an effect*," Dumas et al. (2005). On the other hand, experiences in this direction in the UK and the US have led regulators to step back from purely risk-based premiums in order to maintain affordable premiums for the less well-off. Moreover, the driver's behavioral impact on risk is not easily transposable to natural disasters, living in a risky area being not always a choice.

Our analysis of property prices shows however a more nuanced picture. In well-known overflow risks areas prices are indeed lower than in the non-risky parts of the same city, indicating that economic agents have integrated the non-desirability associated with flood exposure. In that case, the inhabitants usually do not live there out of choice and the current flat surcharge is appropriate to compensate for both wealth and risk inequalities. Yet in areas exposed to coastal risks and impacted

Table 8. Comparing premiums in nine cities, values in €, with a hierachical model, γ is the share of national solidarity, $(1-\gamma)\beta$ is the share of city-based solidarity.

		Uniform (γ,β) $(1,0)$ Country	$(0,0)$ Region	$(0,1)$ City	Hierarchical Model $\gamma=0\%$ $\beta=10\%$	$\beta=20\%$	$\beta=50\%$
Var	Frejus	12.0€	30.6€	15.8€	29.1€	26.9€	23.2€
	Grimaud	12.0€	30.6€	84.4€	36.0€	44.1€	57.5€
	Puget sur Argens	12.0€	30.6€	133.2€	40.9€	56.2€	81.9€
Pays Loire	Assérac	12.0€	3.6€	6.7€	3.9€	4.4€	5.2€
	Mesquer	12.0€	3.6€	10.2€	4.3€	5.2€	6.9€
	Le Croisic	12.0€	3.6€	25.9€	5.8€	9.2€	14.8€
Vendée	Talmont-Saint-Hilaire	12.0€	10.7€	4.8€	10.1€	9.2€	7.8€
	Noirmoutier-en-l'Île	12.0€	10.7€	8.5€	10.5€	10.1€	9.6€
	La Faute-sur-Mer	12.0€	10.7€	275.1€	37.1€	76.8€	142.9€

		Hierarchical Model $\gamma=20\%$ $\beta=10\%$	$\beta=20\%$	$\beta=50\%$	Hierarchical Model $\gamma=40\%$ $\beta=10\%$	$\beta=20\%$	$\beta=50\%$
Var	Fréjus	25.7€	23.9€	21€	22.3€	20.9€	18.7 €
	Grimaud	31.2€	37.6€	48.4€	26.4€	31.2€	39.3 €
	Puget-sur-Argens	35.1€	47.4€	67.9€	29.3€	38.5€	53.9 €
Pays Loire	Assérac	5.5€	5.9€	6.5€	7.1€	7.4€	7.9 €
	Mesquer	5.8€	6.6€	7.9€	7.4€	8.0€	8.9 €
	Le Croisic	7.1€	9.7€	14.2€	8.3€	10.3€	13.7 €
Vendée	Talmont-Saint-Hilaire	10.5€	9.8€	8.6€	10.9€	10.3€	9.4 €
	Noirmoutier-en-l'Île	10.8€	10.5€	10.1€	11.1€	10.9€	10.6 €
	La Faute-sur-Mer	32.1€	63.8€	116.7€	27.1€	50.9€	90.5 €

by climate change, the economic fairness of the French regime is challenged, since risky areas are usually also the more expensive ones, and they currently benefit from a surcharge that does not reflect risk exposure. While climate risk has recently been added to the mapping of risks via the PPRLs, its impact on the current equilibrium of the regime might thus push towards some reform.

In an attempt to introduce some risk-based dimension in the pricing, a couple of models have been checked. They exhibit the great disparity of geographical situations: premium loadings very quickly become significantly higher than the flat existing scheme. Thus, natural disasters can only be financed collectively, either at the national level, as is currently the case, or some regional one. Paradoxically, the almost universal territorial coverage - that is one of the strengths of the French system when compared to other European systems (Le Den et al. (2017))-, actually provides an argument against segmentation. Indeed, in markets where the natural disasters insurance penetration rate is low, anti-selection is likely and engages to introduce modulated premiums, not as an incentive to modify behaviors but as a necessity to maintain the financial soundness of the system (Hudson et al. (2017)). Conversely, in a regime with a very broad base as in the French case, premiums do not seem to be the best way to encourage prevention, let alone to modify "risky settlements". From this standpoint, behavioural economics applied to insurance (e.g. Baker and Siegelman (2013)) show that financial incentives via deductibles and premiums do not work: individuals do not react in the expected way to these signals. Moreover, as argued here, modulation could well exclude the weakest socio-economic strata. If implemented, segmentation should therefore target specific high risk and high property value areas.

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6 Appendix

6.1 Prices of houses and apartments in cities with PPRL (coastal risk) in Vendée and Loire-Atlantique

Table 9. Prices (€ per m^2) of houses sold (2000-2020) for several cities in Pays de la Loire and Vendée - Western part of France, with PPRL (coastal risk). The *Difference* is the relative difference between average prices (per m^2) between the risky and the non-risky zones, either for apartments or houses.

			Average Price	Difference (%)	Maximum Price	Number	Proportion (%)
Overall[21]	**Non risky**	**Apartments**	**4395**		**79933**	**8740**	**33%**
		Houses	**3002**		**75471**	**15473**	**58%**
	Risky	**Apartments**	**6653**	**+51%**	**68478**	**1040**	**4%**
		Houses	**6429**	**+114%**	**71482**	**1402**	**5%**
La Faute sur Mer	Non risky	Apartments	4420		10000	22	3%
		Houses	2035		14666	432	59%
	Risky	Apartments	3065	-31%	7352	13	2%
		Houses	16529	+712%	71482	267	36%
La Guittière	Non Risky	Apartments	4577		21840	211	13%
		Houses	2405		19111	1427	86%
	Risky	Apartments	2394	-48%	3725	9	1%
		Houses	1709	-29%	3913	21	1%
Le Croisic	Non risky	Apartments	4416		79913	7886	44%
		Houses	3067		75471	8566	47%
	Risky	Apartments	6841	+55%	68478	981	5%
		Houses	3262	+6%	22894	693	4%
Moutiers en Betz	Non risky	Apartments	4222		61933	449	14%
		Houses	2996		43253	2675	84%
	Risky	Apartments	4127	-2%	10735	18	1%
		Houses	2929	-2%	6345	51	2%
Noirmoutier	Non risky	Apartments	3638		18010	96	7%
		Houses	4136		65909	936	67%
	Risky	Apartments	3964	+9%	9772	17	1%
		Houses	5966	+44%	32331	349	25%
Pont d'armes	Non risky	Apartments	3659		17543	76	5%
		Houses	2772		31481	1437	94%
	Risky	Apartments	2244	-39%	2420	2	0%
		Houses	3434	+24%	6972	21	1%

[15]For the two departements, Vendée and Pays-de-Loire.

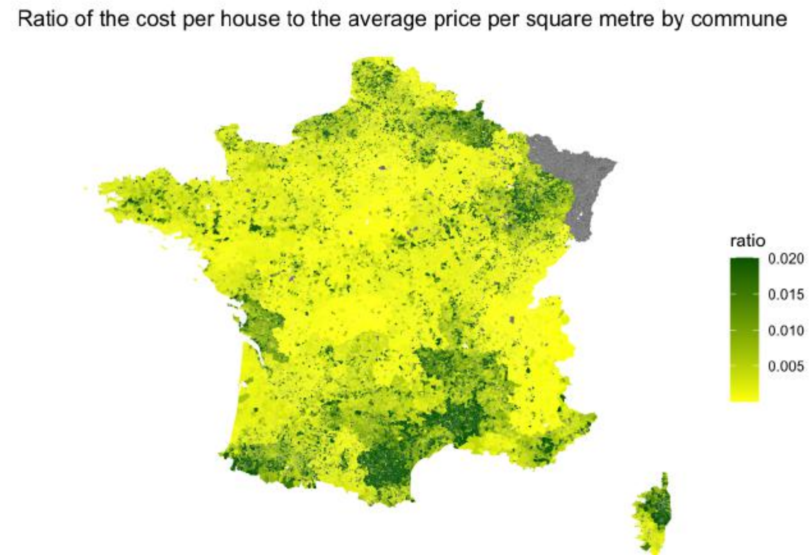
6.2 Prices of houses and apartments in cities with PPRI (overflow risk) in Var

Table 10. Prices (€ per m^2) of houses sold (2000-2020) for several *cities* in the Var departement, in France, with PPRI (overflow coastal).

			Average Price	Difference (%)	Maximum Price	Number	Proportion (%)
Overall	**Non risky**	**Apartments**	**5392**		**75000**	**9874**	**53%**
		Houses	**5957**		**78750**	**6913**	**37%**
	Risky	**Apartments**	**4190**	**-22%**	**39394**	**1471**	**8%**
		Houses	**4172**	**-30%**	**44750**	**226**	**1%**
Gassin	Non risky	Apartments	9550		75000	108	24%
		Houses	10371		78750	320	71%
	Risky	Apartments	6191	-35%	12500	22	5%
		Houses	7558	-27%	7558	1	0%
St Maxime	Non risky	Apartments	5931		50802	1113	46%
		Houses	7492		75292	927	38%
	Risky	Apartments	5013	-15%	34230	377	16%
		Houses	5407	-28%	9756	14	1%
Roquebrune	Non risky	Apartments	7845		71000	811	35%
		Houses	4867		45493	1369	59%
	Risky	Apartments	4953	-37%	23810	54	2%
		Houses	3634	-25%	14720	80	3%
Puget	Non risky	Apartments	5122		29909	226	41%
		Houses	3859		26667	293	53%
	Risky	Apartments	3594	-30%	5269	8	1%
		Houses	2910	-25%	10773	29	5%
Grimaud	Non risky	Apartments	6987		62481	430	35%
		Houses	9516		66216	740	6%
	Risky	Apartments	4766	-32%	12683	40	3%
		Houses	6167	-35%	44750	28	2%
Fréjus	Non risky	Apartments	4818		69762	4066	71%
		Houses	4424		76993	1492	26%
	Risky	Apartments	3564	-26%	21111	171	3%
		Houses	3967	-10%	22277	26	0%
St Raphaël	Non risky	Apartments	4966		66713	3120	54%
		Houses	5350		59135	1772	31%
	Risky	Apartments	3798	-24%	39394	797	14%
		Houses	4348	-19%	14778	48	1%

6.3 The geography of wealth and risk

Figure 10. Top: Ratio of total cost per house over the average price of house, per m^2, per city. Average price of house is here taken as an indicator of wealth. Darker areas are relatively more exposed in terms of economic burden to flood losses. Down: Ratio of average cost per city over median income in the city. The center of France is here darker because of low median income rather than flood exposure.



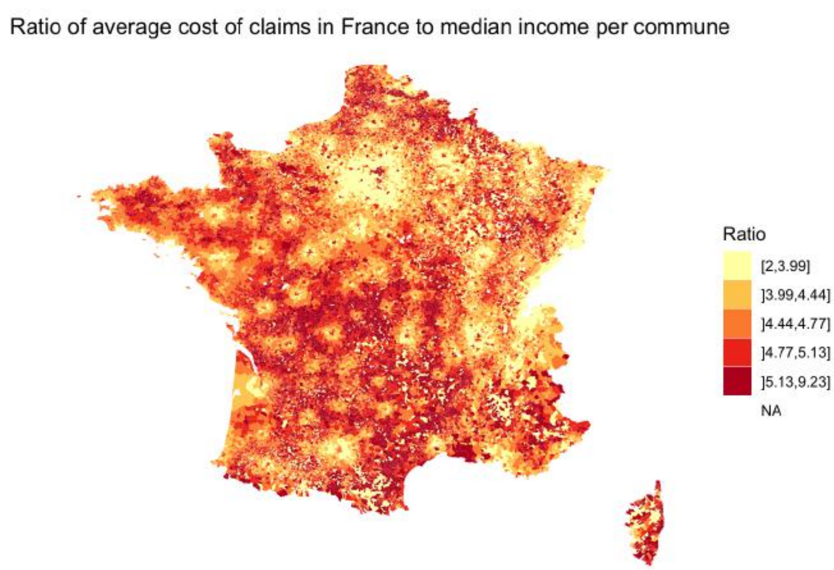
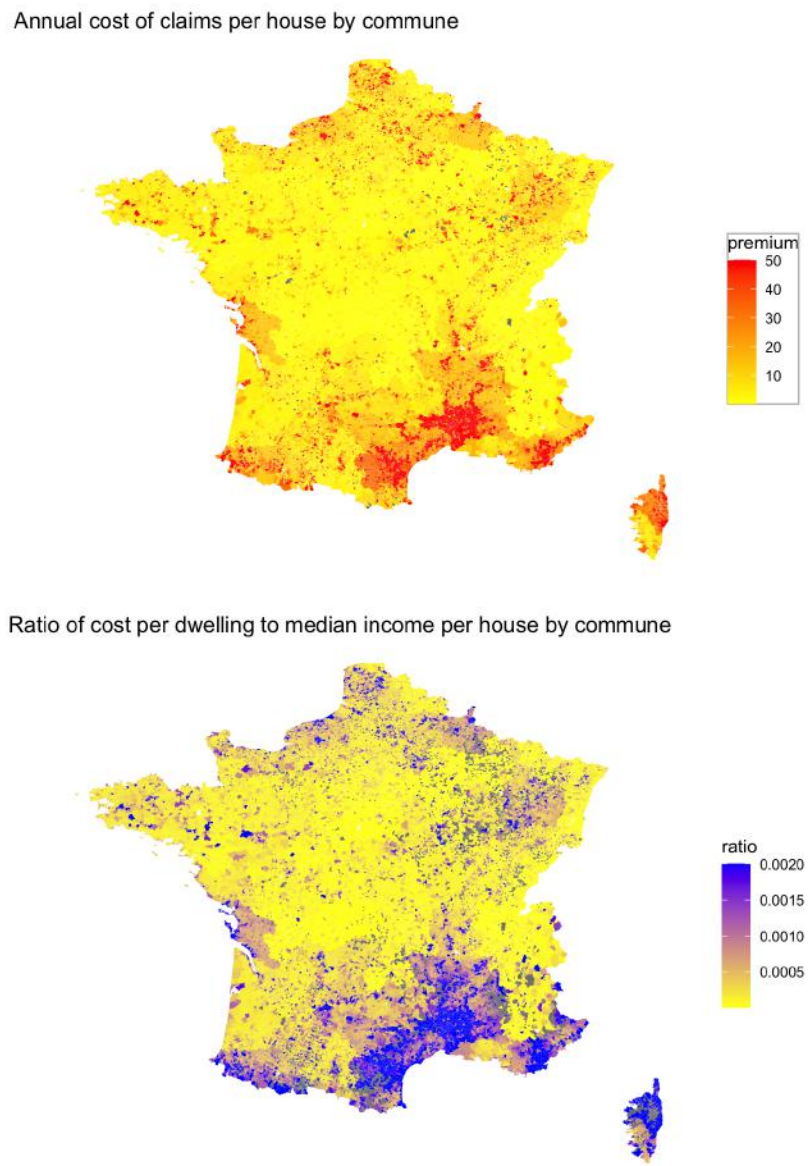


Figure 11. Top: Annual cost of claims per house, per city (in €).
Down: Ratio of total cost per house over median income per city.



Down: Ratio of total cost per house over median income per city.
Down: Ratio of total cost per house over median income per city.

PARI

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Dans ce cadre, la chaire PARI bénéficie de ressources apportées par Addactis, la CCR, Generali, Groupama, la MGEN et Thélem.

Elle est co-portée par **Pierre François,** chercheur au CNRS, doyen de l'Ecole Doctorale de Sciences Po et **Laurence Barry,** chercheur à Datastorm, la filiale de valorisation de la recherche de l'ENSAE.

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