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Natural Disaster Insurance and the Equity-Efficiency Trade-Off

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Abstract

This article investigates the role of private insurance in the prevention and mitigation of natural disasters. We characterize the equity-efficiency trade-off faced by the policymakers under imperfect information about individual prevention costs. It is shown that a competitive insurance market with actuarial rate making and compensatory tax-subsidy transfers is likely to dominate regulated uniform insurance pricing rules or state-funded assistance schemes. The model illustrates how targeted tax cuts on insurance contracts can improve the incentives to prevention while compensating individuals with high prevention costs. The article highlights the complementarity between individual incentives through tax cuts and collective incentives through grants to the local jurisdictions where risk management plans are enforced.

Introduction

The last decades have witnessed the worlwide increasing frequency and intensity of weather-related disasters. Windstorms, typhoons, floods, landslides, and heatwaves were more and more frequent and we have experienced an upward trend in economic losses due to weather disasters, and an even stronger increase in insured losses.[1] These events may be the prelude to a still more critical evolution in the future insofar as

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[1] See Swiss Re (2006) on the trend toward higher catastrophe losses, and particularly on the increase in insured catastrophe losses. Swiss Re data show that the rise in insured losses is primarily driven by the natural catastrophes: while the claim burden due to natural disasters in the 1970s was just on US$3 billion per year, it rose to US$16 billion in the period 1987–2003, and in 2004 and 2005 it reached US$45 billion and US$78 billion, respectively, with claim burden from Hurricane Katrina expected to amount to US$45 billion. Insured losses are only the emerging part of the iceberg since there is practically no disaster insurance cover in the developing countries that have been severely affected by devastating natural catastrophes such as, in 2005, the earthquake in Kashmir and landslides and flooding trigerred by heavy monsoon rains in India. The increase in the burden of natural catastrophes jointly results from an increase in the number and in the severity of natural catastrophic events and from economic

climate change seems to play a major role in this evolution.[2] Minimizing the social cost of natural disasters should thus be ranked as a top priority in many industrialised countries and considered as an issue of the utmost importance for economic development and poverty reduction.

What can be the contribution of insurance to the management of natural hazards? In addition to risk pooling within a portfolio of insurance policies or risk spreading through reinsurance, cat bonds or other alternative risk transfer mechanisms, the insurance industry can help governments to create the right incentives for the mitigation of natural hazards. First, insurers may help assessing risks and providing information on risk exposure to individuals, corporations, and governments themselves. Insurers can also convey incentives for prevention through price signals. This may be done by charging risk-adjusted insurance premiums for property insurance or business interruption insurance in order to discourage the development of new housing or productive investment in hazard-prone areas or to incite property developers to comply with building codes. Likewise, insurers may offer crop insurance at affordable price for farming practices able to withstand climate instability (e.g., when farmers plant drought-resistant crop varieties).

However, using insurance pricing to mitigate natural disasters is not an easy task. First, individuals may prefer to rely on postdisaster assistance from governments or nongovernment organizations (NGOs) rather than paying an insurance premium to protect themselves against the consequences of natural hazards.[3] Second, property owners may not purchase disaster insurance because they underestimate their true loss probability.[4] Third, lower income consumers have difficulty affording insurance, and of course this obstacle is particularly important in developing countries. Fourth, because of adverse selection the burden may be concentrated on high-risk individuals, which makes it even heavier.

It is nevertheless particularly important to explore this path, since it uses the forces of economic incentives, which often prove to be much more effective and less costly than a command and control approach. Having said that, we face a fundamental

choices such as the growth in urban areas, the endogenous location choices of individuals and the changes in landuse.

[2] See Epstein and Mills (2005) and Association of British Insurers (ABI) (2006) on the extreme events and financial risks due to climate change.

[3] See Lewis and Nickerson (1989) and Coate (1995) on the economic incentives generated by public insurance for natural disasters.

[4] Kunreuther (1984, 1996) emphasizes the fact that individuals are reluctant to purchase flood insurance because they misperceive the flood peril. Browne and Hoyt (2000) study the determinants of the demand for flood insurance in the United States within the National Flood Insurance Program. They find that the number of flood insurance policies sold during the current period is positively correlated with flood losses during the prior period, which confirms that perceptions of the flood risk are an important determinant of insurance purchases. The learning ability of individuals facing flood risk thus seems to be limited. This may result either from bounded cognitive ability (i.e., finite memory) or from the fact that the flood risk is not stationary at the local level (e.g., when changes in regional development affect the delimination of flood plains) or at the global level because of climate change. In the same vein, see Chivers and Flores (2002).

problem. On the one hand, insurance may provide incentives by charging actuarial premiums. By doing so, insurers encourage the agents from the private sector to internalize the cost of natural disasters in their cost-benefit analysis—especially in the case of a new investment project. As we will see, insurance pricing may also indirectly incite communities (e.g., municipalities) to take adequate mitigation measures.[5] On the other hand, fairness issues are particularly relevant for natural disasters insurance pricing; indeed, many individuals are not in position to reduce their risk exposure at reasonable cost and for them insurance premiums are analogous to a lump sum tax, without any significant incentive effect.

Hence, incentives come into conflict with equity (or fairness). Providing incentives to prevention and mitigation militates in favor of actuarial insurance pricing, but competitive insurance may be a too heavy burden for the ones who live and work in vulnerable situation without any possibility of reducing their risk exposure at a reasonable cost.

The trade-off between equity and efficiency is the heart of the matter and we will analyze this dilemma in what follows. We will focus attention on the risk prevention at the individual level by inhabitants of risk-prone areas and at the collective level by local authorities in the form of risk management plans. The starting point is a simple model of a regulated insurance market drawn from Latruffe and Picard (2005). In this model, the inhabitants of a country are initially living either in high- or low-risk areas. All those living in a high-risk area may make individual prevention decisions by moving to a low-risk zone and they possess private information about their prevention costs.[6] The insurance market is supposed to be competitive but the government may either levy taxes on insurance contracts or subsidize these contracts according to the risk exposure. In this very simple model, individuals make a prevention decision if the corresponding decrease in insurance premium is larger than the prevention cost. Individual prevention thus requires that taxes and subsidies (or regulatory constraints prohibiting categorical discrimination) do not fully annihilate the risk-based categorization by insurers. In this model, more differentiation in insurance pricing (i.e., lower compensatory taxes and subsidies) makes prevention more advantageous to inhabitants.

We will also consider the risk prevention at a collective level by focusing on the actions by local authorities in the form of risk management plans (e.g., flood plain management ordinances to reduce future flood damages). These plans affect the likelihood of suffering a natural disaster and they are a determining factor of the actuarial premiums charged by property insurers. It is assumed that the central government has imper-

[5] The incentive properties of insurance pricing is weakened if municipalities wait for the regional or national government to pay for the *ex post* costs of natural disasters. This adverse effect of government aid is lessened if the national government can commit on financial assistance rules (thereby disconnecting its aid from the postdisaster ressources privately secured by municipalities through insurance mechanisms or local taxes) rather than affecting grants in a discretionary way.

[6] The equity-efficiency trade-off exists insofar as prevention and mitigation costs are unknown or at least imperfectly known to the government. If these costs were perfectly verifiable, then tailor-made incentive mechanisms could be designed to compensate the individuals who have to pay large premiums because they cannot reduce their risk exposure.

fect information on the cost of local risk management plans as well as on individual prevention costs. Taxes and subsidies distort the choice made by local authorities as they do for individual prevention choices. The outcome is only a second-best Pareto-optimum although it is improved by incentive contracts between local governments and the central government.[7]

The model will highlight the synergy between the incentives to individual and collective prevention. On the one hand, a decrease in taxes and subsidies on insurance contracts reduces the distortions in the individuals' attitude toward risk, but it also stimulates the risk prevention by communities. On the other hand, local risk management plans reduce the burden of subsidies paid in high-risk areas and they increase the tax receipts in low-risk areas, hence a surplus and possible additional tax cuts by the central government.

The background of the present article may be found in the wide-ranging literature in which the equity and efficiency issues of insurance pricing regulation have been investigated over the past years. An important issue in this literature is whether government-imposed restrictions on rate classification are the source of inefficiency in insurance markets. The starting point of these reflections may be found in the debates on the social costs of community rating in health insurance initiated in the economic litterature by Arrow (1963) and Pauly (1970). The emphasis of these debates is put on the distortions in health insurance choices induced by the restrictions on rate classification—see in particular, Browne and Frees (2004) and Buchmueller and DiNardo (2002). The same issue is also relevant for many other insurance markets such as the automobile insurance market—see Harrington and Doerpinghaus (1993)—or the annuity market—see Finkelstein, Poterba, and Rothschild (2006).

The theoretical basis of these analysis may be found in the literature on risk classification in insurance markets.[8] This literature mainly puts the emphasis on the relationship between the social value of insurance rate classification and the informational structure of the environment in which this classification takes place. In particular, in an asymmetric information setting where applicants for insurance (but not insurers) have perfect information about their loss probabilities, then one may expand the set of incentive compatible allocations by allowing insurers to categorize individuals based upon observable characteristics (such as age, gender, or occupation) or consumption choices that are correlated with risk—see Crocker and Snow (1986) and Bond and Crocker (1991). Risk classification then entails an efficiency gain. Risk classification may also interfere with the decision of individuals to look for information about their

[7] These dual contractual relationships beween insurers and insureds on one side and between local communities and the federal government on the other side are the core of the National Flood Insurance Program (NFIP) established by the U.S. Congress in 1968 and managed by the Federal Emergency Management Agency (FEMA). See FEMA (2006). The NFIP includes a Community Rating System (CRS), which is a voluntary incentive program that encourages community flood plain management activities that exceed the minimum NFIP requirements from 5 percent to 45 percent for participating communities. In a very abstract way, the model of the section "Prevention by Communities" may be viewed as a theoretical schematization of this system.

[8] See Crocker and Snow (2000) for a survey.

own risk (think of genetic testing) and, as studied by Doherty and Posey (1998), it stimulates their risk prevention behavior, hence an additional efficiency gain. However categorization may also entail adverse equity effects, particularly when some individuals are uninsurable or have to pay very high premiums—see Hoy (1989). The present article departs from this literature by focusing attention on the effect of risk classification on prevention incentives in a setting where insurers and applicants for insurance have symetric information on loss probabilities and prevention costs are private information to individuals. Using compensatory taxes and subsidies to restrict the effect of risk classification on insurance rating is at the origin of adverse effects on prevention both at the individual level and and at the community level. Our main purpose is to study how these incentive effects interact with the equity concern of the government.

The article is organized as follows. The section "Equity and Efficiency in Natural Disaster Insurance" focuses on individual prevention decision. It shows that there exists a trade-off between equity (or equality in the burden of natural disasters) and incentives (or efficiency in risk prevention): providing more incentives to prevention leads to less equality between individuals. However, this section also establishes a condition under which a competitive equilibrium with risk categorization and tax-subsidy transfers Pareto-dominates uniform pricing.[9] Under this condition, the gains from prevention associated with competitive insurance allows the government to compensate the individuals whose risk exposure remains high, so that nobody loses when we go from uniform pricing to competitive pricing. In other words, even if the government cannot use tailor-made compensatory mechanisms because of imperfect information on individual prevention costs, it is nevertheless a fact that risk categorization with a compensatory tax-subsidy schedule may be attractive for everybody. This will be the case if there is a substantial proportion of high-risk individuals with low prevention costs. We will provide some tentative estimates that suggest that the condition for a competitive equilibrium to be welfare enhancing is empirically plausible. The section "Prevention by Communities" focuses on the prevention by communities in the form of risk management plans. Local authorities decide on the implementation of such plans by balancing their costs and the aggregate private benefits of their citizens including the grants paid by the central government. Private benefits are distorted by compensatory tax and subsidies on insurance contracts. We will show that risk categorization and competitive insurance lead to more efficient decisions by local governments than in the case of uniform insurance pricing, which highlights the complementary roles of insurance markets and local risk management plans in the prevention and the mitigation of natural disasters. The final section concludes.

[9] In some European countries, natural disaster insurance is highly regulated and insurers are not allowed to charge risk-adjusted premiums. In particular, in France the coverage of natural catastrophes is statutorily included in property policies on payment of a percentage premium surcharge. Natural disaster insurance is provided in Spain by a state monopoly, the Consorcio de Compensacion de Seguros and in Switzerland through cantonal insurers. On the contrary, Germany, Italy, Poland, and the United Kingdom rely on private property insurance markets, but the penetration rates remain low in these countries.

EQUITY AND EFFICIENCY IN NATURAL DISASTER INSURANCE

The Model

Consider a risk of natural disaster in a country with two types of areas. Some inhabitants live in high-risk areas where the probability of a natural disaster is π_H and the other ones are in low-risk areas, with a disaster probability π_L, with $0 < \pi_L < \pi_H < 1$. The fraction of individuals initially located in a high-risk area is λ, with $0 < \lambda < 1$. For notational simplicity, we assume that all individuals suffer the same loss A in case of a natural disaster. W denotes their initial wealth, which is the same for everybody. The individuals who are living in high-risk areas may reduce their risk by moving to a low-risk area, which costs them c. The prevention cost c is differentiated among the inhabitants of the high-risk areas and it is private information to each individual: c is distributed over $[0, +\infty)$ according to the density $f(c)$ and cumulative distribution function $F(c)$. Inhabitants are expected utility maximizers and they display risk aversion with respect to their final wealth W_f. Their von Neumann–Morgenstern utility function is written as $u(W_f)$, with $u' > 0$ and $u'' < 0$.

Natural disaster insurance contracts specify the premium P and the indemnity I paid in case of a natural disaster. If no prevention cost has been incurred, we have $W_f = W - P$ if no disaster occurs and $W_f = W - A - P + I$ in case of a disaster. If the individual has gone from a high-risk area to a low-risk area to reduce the risk exposure, then $W_f = W - A - P + I - c$ or $W_f = W - P - c$ according to whether a disaster occurs or not.

In the main part of this article, we assume that the insurance market is competitive, with no transaction costs and risk neutral insurers. In practice, premium loadings play an important role in disaster insurance markets, including loadings related to insurers'cost of capital or to insurers'risk aversion. As shown in the Appendix, our main results remain valid in a more realistic framework with premiums loadings. More explicitly, loading would affect the insurance contracts offered in the market (they would not provide full coverage any more) but the same equity-efficiency trade-off would still exist and the links between incentives to individual prevention and community prevention would be unchanged.

The government may tax or subsidize insurance contracts differently according to the risk exposure. Let t_L be the lump sum *tax* in a low-risk area and let t_H be the lump sum *subsidy* in a high-risk area. Note that t_L and t_H are independent from the prevention cost c since it cannot be observed by the government. In words, case-by-case tailor-made transfers are not feasible. Given that individuals are risk averse and in the absence of transaction costs, competition leads insurers to offer contracts P_L, I_L in low-risk areas and P_H, I_H in high-risk areas, with actuarial premiums $P_L = \pi_L I_L + t_L$, $P_H = \pi_H I_H - t_H$ and full coverage $I_L = I_H = A$. We thus have

$$P_L = \pi_L A + t_L \tag{1}$$

$$P_H = \pi_H A - t_H \tag{2}$$

which means that the insurance premium is equal to the actuarial premium $\pi_L A$ or $\pi_H A$ increased by the tax t_L or reduced by the subsidy t_H.

Uniform Insurance Pricing

We may first compute the tax and subsidy that would lead to complete equality between individuals: they would pay the same premium whatever their risk exposure, that is, $P_L = P_H$. In such a case, there is no incentive to prevention and the proportion of individuals who live in a high-risk area remains equal to λ. The government budget constraint requires that taxes paid in low-risk areas are equal to subsidies paid in high-risk areas, which gives $\lambda t_H = (1-\lambda)t_L$. Using $P_L = P_H$ then gives

$$t_H = (1-\lambda)(\pi_H - \pi_L)A \equiv t_H^* \tag{3}$$

$$t_L = \lambda(\pi_H - \pi_L)A \equiv t_L^* \tag{4}$$

while the insurance premium (the same in all areas whatever the risk exposure) is

$$P^* = [\lambda\pi_H + (1-\lambda)\pi_L]\,A. \tag{5}$$

Hence, the insurance premium is the actuarial premium computed with the average disaster probability $\lambda\pi_H + (1-\lambda)\pi_L$. Insureds are fully covered and their final wealth is $W_f = W - P^*$ and insurers charge P^* whatever the risk exposure. In fact, there is no need to levy taxes and to grant subsidies to reach this goal: all the government has to do is to prohibit categorical discrimination in insurance pricing. This is also equivalent to a state-funded assistance sheme in which the government would use its own resources to pay indemnities to the victims of natural disasters, without any role for the private insurance sector.

Let $P_{\max}$ be the maximum premium that low-risk individuals are ready to pay for full coverage. $P_{\max}$ is defined by

$$(1-\pi_L)u(W) + \pi_L u(W - A) = u(W - P_{\max}).$$

Obviously P^* may be larger than $P_{\max}$. In such a case, if low-risk individuals have the choice, they would prefer to stay uninsured rather than purchasing insurance at price P^*. In other words, the viability of the uniform pricing regime requires insurance to be compulsory, for otherwise low-risk individuals may prefer to opt out.

The Equity-Efficiency Trade-Off

From now on, we assume that natural disaster insurance is compulsory for all property owners, but some degree of categorical discrimination is enforced. Individuals living in a high-risk area would consider going to a low-risk area (or they may take any other prevention measure) if the decrease in the insurance premium is larger than the prevention cost, that is if

$$P_H - P_L > c$$

or equivalently, given (1) and (2), if $c < c^*$ where

$$c^* = (\pi_H - \pi_L)A - (t_L + t_H) \tag{6}$$

c^* is a threshold: the individuals with a prevention cost lower than c^* leave the high-risk area in which they were living to go to a low-risk area. Consequently, the proportion of individuals who are in low-risk areas comes up to $1 - \lambda + \lambda F(c^*)$. Note that the maximization of aggregate wealth would require migration from high-risk areas to low-risk areas when $c < c^{**}$ where $c^{**} = (\pi_H - \pi_L)A$. Equation (6) shows that $c^* < c^{**}$ when $t_L + t_H > 0$: the compensatory tax-subsidy shedule induces distortions in prevention by comparison with a nonregulated insurance market.

Let us start from the status quo situation where all individuals pay the same premium P^*. The tax subsidy mechanism will be Pareto-improving if three conditions are fulfilled.

1. We should have $P_H < P^*$, or equivalently $t_H \geq t_H^*$, so that individuals who continue living in a high-risk area are not penalized. Note that this condition implies that the individuals who leave the high-risk areas end up better off (they have the possibility to stay in the high-risk areas after all!).
2. We should have $P_L < P^*$, or equivalently $t_L \leq t_L^*$, so that individuals who were already living in a low-risk area are not penalized either.
3. Finally, the government budget constraint is written as

$$t_H[\lambda(1 - F(c^*)] = t_L[1 - \lambda + \lambda F(c^*)], \tag{7}$$

which means that the income from taxes is equal to subsidies.

Let us write $t_H = t_H^* + k$ where k denotes the increase in the subsidy to insurance contracts in high-risk areas, by comparison with the status quo situation with uniform insurance pricing. Equation (6) may then be rewritten as

$$c^* = (\pi_H - \pi_L)A - t_L - t_H^* - k.$$

Using (3) then gives

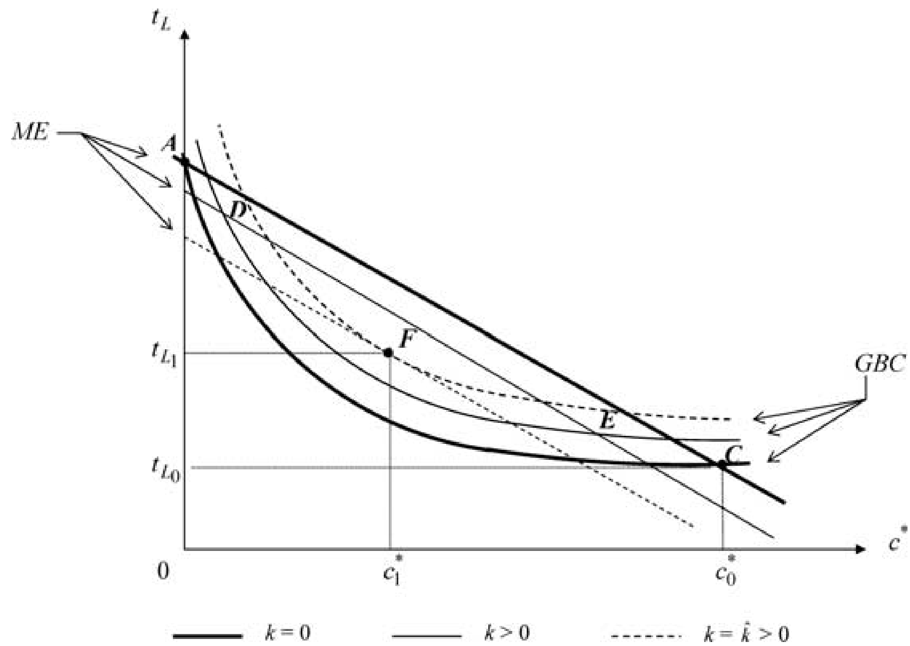
$$c^* = \lambda(\pi_H - \pi_L)A - t_L - k$$

and (4) yields

$$t_L = t_L^* - c^* - k. \tag{8}$$

Equation (8) yields a relationship between t_L and c^* for a given k. It corresponds to the *migration equilibrium* from high-risk areas to low-risk areas: more risk prevention (hence a larger threshold c^*) requires a lower tax rate on insurance contract in low-risk areas, for a given subsidization in high-risk areas (i.e., for a given k). In Figure 1, the migration equilibrium is represented by decreasing straight lines *ME* with slope equal to one in absolute value. There is one *ME* line for each value of k.

FIGURE 1
Migration Equilibrium and Government Budget Constraint



Using (7) allows us to rewrite the *government budget constraint* as

$$t_L = \frac{\lambda\left(t_H^* + k\right)[1 - F(c^*)]}{1 - \lambda + \lambda F(c^*)}. \tag{9}$$

This equation provides another relationship between the prevention threshold c^* and the tax rate rate in low-risk area t_L, for a given k. The more intense the prevention, the larger the proportion of individuals in low-risk areas and thus the smaller the tax that has to be levied in these areas to cover the subsidies paid in high-risk areas. The government budget constraint is represented by the nonlinear decreasing curves *GBC* in Figure 1.[10] There is one *GBC* curve for each value of k.

In brief, a budget balanced tax-subsidy policy is characterized by t_L and c^* such that Equations (8) and (9) are satisfied, for a given k. Such a policy Pareto-dominates the uniform insurance pricing policy without prevention if $k \geq 0$ (or equivalently $t_H \geq t_H^*$) and $t_L \leq t_L^*$, one (at least) of these inequalities being strictly satisfied.

In Figure 1, the lines in bold correspond to $k = 0$. Then the migration equilibrium and the government budget constraint are satisfied at a status quo state $t_L = t_L^*$, $c^* = 0$: this is point ***A*** in the figure. It corresponds to uniform insurance pricing: all individuals pay the same premium P^* whatever their risk exposure. However, Figure 1 shows that the two equilibrium conditions may also be satisfied at another

[10] A sufficient condition for the *GBC* curves to be convex is that $F(c)$ is (weakly) concave, i.e., $f(c)$ is nonincreasing. However, the results are independent from the convexity of these curves.

point (denoted by ***C***), with $c^* = c_0^* > 0$ and $t_L = t_{L_0} < t_L^*$: this new equilibrium is strictly preferred to the status quo equilibrium by the individuals who are in a low-risk area (possibly after migration) while the other ones are indifferent between the two equilibria. When we go from ***A*** to ***C***, the tax cut $t_L^* - t_{L_0}$ induces the relocation of a fraction $\lambda F(c_0^*)$ of the population from high-risk areas to low-risk areas and the corresponding surplus allows the government to keep its budget balanced, without any change in the subsidies granted to the insurance contracts in high-risk areas.

A sufficient condition for such a Pareto-dominating equilibrium to exist is that at point ***A*** the slope (in absolute value) of the *GBC* curve is larger than one. A simple computation shows that this will be the case when

$$\lambda > \frac{1}{1 + (\pi_H - \pi_L)Af(0)}. \tag{10}$$

Condition (10) is satisfied when the fraction of individuals living in risky areas is large enough and when a substantial number of these individuals have low prevention costs. Mathematically speaking, the larger $f(0)$ the lower the λ threshold for a Pareto improvement to be feasible.

The important question is whether this condition is likely to be satisfied in practice. We will come back to that in a moment. For the time being, assume that condition (10) holds and let us have a look at the consequences of an increase in k: how the (Pareto-dominating) equilibrium is changed when the insurance contracts in high-risk areas benefit from a larger subsidy rate. When k increases, *ME* shifts downward and *GBC* shifts upward. When k is positive but not too large (lower than an upper bound $\hat{k}$), *ME* and *GBC* cross twice, at points ***D*** and ***E***, but the Pareto-dominating equilibrium is at point ***E***. Comparing ***E*** and ***C*** shows that the increase in k has brought about a decrease in c^* and an increase in t_L: people in high-risk areas are better off and the ones in low-risk areas are worse off, but there is less risk prevention.

FIGURE 2
The Equity-Efficiency Trade-Off

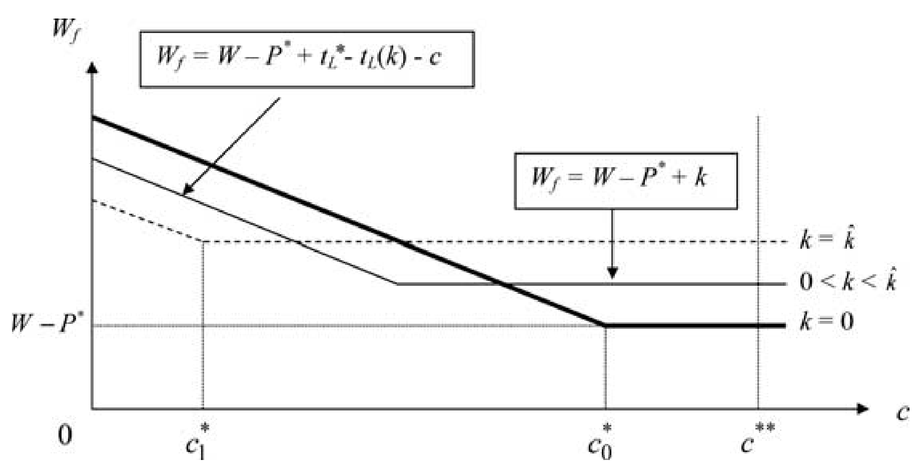


Figure 2 illustrates this trade-off between equity and efficiency. The horizontal axis measures prevention cost c, and the vertical axis measures the final wealth W_f. For the people who are located in a low-risk area (possibly after migration), we have

$$W_f = W - P_L - c = W - P^* + t_L^* - t_L(k) - c$$

with $c = 0$ if the individual was initially in a low-risk area, and $t_L(k)$ is the tax rate at the Pareto-dominating equilibrium which is an increasing function of k with $t_L(0) = t_{L_0}$ and $t_L(\hat{k}) = t_{L_1}$. For the individuals who stay in a high-risk area, we have

$$W_f = W - P_H = W - P^* + k.$$

The prevention threshold is $c^*(k) = t_L^* - t_L(k) - k$ with $c^*(0) = c_0^*$ and $c^*(\hat{k}) = c_1^*$. Maximizing aggregate social welfare would lead to choose $k = 0$, so that prevention is as large as possible, while a Rawlsian approach to utilitarianism (make the poorest as well off as possible) would recommend to choose $k = \hat{k}$. The trade-off between equity and efficiency is pervasive in economics and the problem of regulating a market for natural disaster insurance is not an exception to the rule!

Improving the Trade-Off

Until now we have assumed that all the individuals were indistinguishable apart from their risk exposure. Suppose on the contrary that individuals can be categorized in n groups: there is a fraction α^i of "type i individuals," and among them a proportion λ^i is initially localized in a high-risk area, with $\sum_{i=1}^n \alpha^i = 1$ and $\sum_{i=1}^n \alpha^i \lambda^i = \lambda$.

For example, in the case of flood insurance, we may distinguish new buildings from old ones and we may also separate regions according to the frequency of floods.[11] In crop insurance, we may categorize farms according to the type of plants they grow and to their location. The fraction of high-risk individuals and the probability distribution of prevention costs are likely to differ from one category to the next. In particular, categorization may be correlated with prevention cost. For example, setting up a new building in an area far from a river may entail some costs to the newcomers (e.g., if a railway line runs alongside the river and makes transportation easier for the residents or if the river lanscape is particularly pleasant), but these costs are likely to be lower than for the move of inhabitants who would have to leave the place in which they settled a long time ago. Likewise, in some geological environments and for some plants, growing draught-resistant species may not entail a strong decrease in yield, while the loss is probably substantial under other conditions. In such cases, the categories are signals on prevention cost and categorizing the tax-subsidy schedule enhances efficiency.

Let t_H^i and t_L^i be, respectively, the subsidy and the tax for the insurance contract in group i. As before, the tax is levied in high-risk areas, while the subsidy is granted in low-risk areas. The prevention threshold in group i is thus

$$c^{i*} = (\pi_H - \pi_L)A - \left(t_L^i + t_H^i\right). \tag{11}$$

[11] This is what is done in the NFIP in the United States.

Let $f^i(c)$ and $F^i(c)$ be, respectively, the density and the cumulative distribution of prevention costs in group i, with $\lambda F(c) = \sum_{i=1}^{n} \alpha^i \lambda^i F^i(c)$. The government budget constraint is now written as

$$\sum_{i=1}^{n} \alpha^i \lambda^i [1 - F^i(c^{i*})] t_H^i = \sum_{i=1}^{n} \alpha^i [1 - \lambda^i + \lambda^i F^i(c^{i*})] t_L^i. \qquad (12)$$

Let us consider a status quo situation with uniform pricing, no categorization, and no prevention: $t_H^i = t_H^*$, $t_L^i = t_L^*$ and $c^{i*} = 0$ for all i. Consider a certain group i and suppose that t_H^i is kept equal to t_H^*, which means that type i individuals in high-risk areas are not put at a disadvantage by comparison with the status quo. We may induce prevention by some of these individuals (the ones with small prevention costs) by lowering t_L^i under t_L^*. One can easily check that this is compatible with the equilibrium of the government budget if

$$\lambda^i > \frac{1}{1 + (\pi_H - \pi_L) A f^i(0)}. \qquad (13)$$

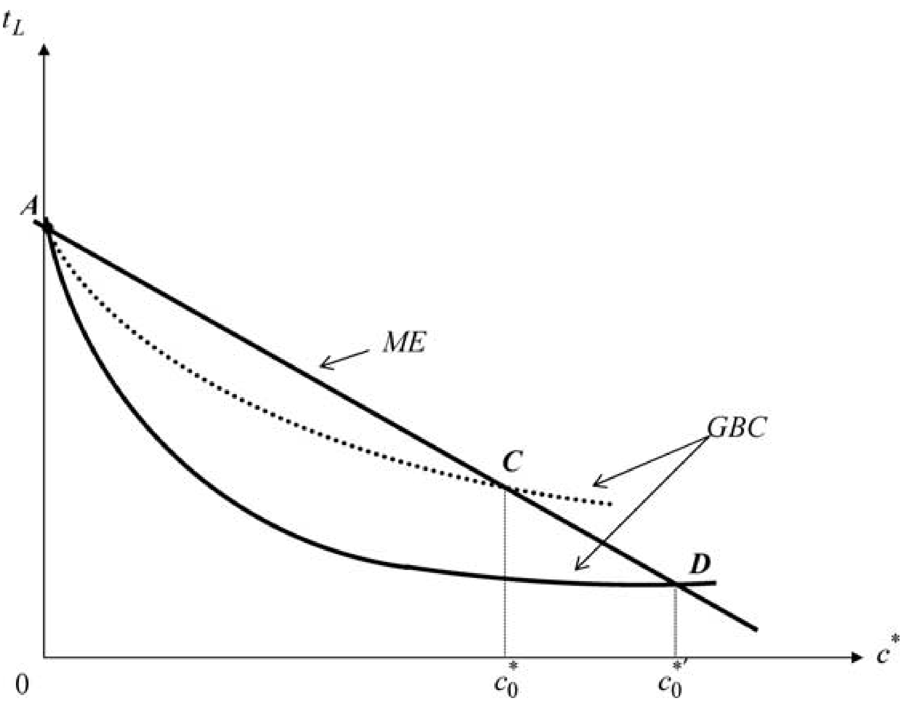
Equation (13) may hold for a subset of groups i in $\{1, \ldots, n\}$, even if (10) does not hold, which shows that categorization enhances efficiency.[12]

Another way to improve the trade-off between equity and efficiency is to categorize the low-risk areas. Indeed the incentive power of tax cuts is larger in the low-risk areas that are close to high-risk zones than in remote low-risk zones, because it is cheaper to move to the nearby low-risk zones. Categorizing low-risk areas may thus improve our trade-off by targeting tax cuts.

That may be illustrated as follows. Assume that low-risk areas are categorized in two groups: the low-risk areas located near high-risk areas are in group 1 and the other ones are in group 2. Hence, we now consider three types of areas: high-risk areas and groups 1 and 2 low-risk areas. The government allocates the tax cuts to group 1. The variables $f(c)$ and $F(c)$ still denote the density and cumulative distribution functions of the prevention cost (the cost induced by a movement from a high-risk area to a group 1 area). Possible moves from group 2 to group 1 should also be taken into account because some individuals initially located in group 2 may choose to move to group 1 in order to benefit from the tax cut. Assume that a fraction μ of the individuals initially located in a low-risk area are in a group 1 area and a fraction $1 - \mu$ is in a group 2 area and we denote by $g(c)$ and $G(c)$ the density and cumulative distribution function of the cost incurred by the individuals who may move from group 2 to group 1. Let t_{L_1} and t_{L_2} be, respectively, the tax rate on insurance contracts in the group 1 and group 2 areas. The subsidy rate in the high-risk area is still denoted by t_H and we assume $t_H = t_H^*$. The government chooses $t_{L_2} = t_L^*$ since no incentive effect could be expected

[12] For example, assume that groups are identically distributed among high- and low-risk areas and that they are ranked according to increasing prevention costs. Ranking is in the first order stochastic dominance sense. We thus have $\lambda^1 = \lambda^2 \cdots = \lambda^n$ and $F^1(c) > F^2(c) \cdots > F^n(c)$ for all c. In such a case, we have $f^1(0) > f^2(0) \cdots > f^n(0)$. Consequently, there exists a threshold group i^* such that (13) holds if and only if $i \leq i^*$.

FIGURE 3
Equilibrium With Categorization of Low-Risk Areas



from a tax cut in the group 2 area. Individuals in a high-risk area or in group 2 move to group 1 if their prevention (or transfer[13]) cost is lower than c^* with

$$t_{L_1} = t_L^* - c^* \tag{14}$$

and

$$t_{L_1} = \frac{\lambda t_H^*[1 - F(c^*) - (1-\mu)(1 - G(c^*)]}{(1-\lambda)[\mu + (1-\mu)G(c^*)] + \lambda F(c^*)} \equiv \Psi(c^*, \mu). \tag{15}$$

Equations (14) and (15) are analogous to (8) and (9), with $k = 0$. Equation (14) is the migration equilibrium condition and it is represented in Figure 3 by a decreasing straight line *ME* with slope equal to one in absolute value. Equation (15) is the governement budget constraint: for μ given, it corresponds to the nonlinear locus *GBC*. The locus in italics is the *GBC* curve when there is no categorization of low-risk areas, which corresponds to $\mu = 1$: all individuals in the low-risk areas benefits from the tax cut. We have

$$\frac{\partial \Psi}{\partial \mu} = \frac{\lambda t_H^* F(c^*)[1 - G(c^*)]}{[(1-\lambda)(\mu + (1-\mu)G(c^*)) + \lambda F(c^*)]^2} > 0.$$

[13] This is pure opportunism (not risk prevention) for the individuals coming from group 2 areas.

Categorizing low-risk areas (i.e., choosing μ lower than one) thus lowers the *GBC* curve and leads to more prevention: at the crossing between *ME* and *GBC*, c^* is larger under categorization (at point ***D***) than when there is no categorization (at point ***C***). Hence the categorization of low-risk areas enhances the equity-efficiency trade-off. There is actually risk prevention at equilibrium if at point ***A*** the slope of the *GBC* curve in absolute value is larger than one. A simple calculation shows that this is the case if

$$\lambda > \frac{1}{1 + \frac{(\pi_H - \pi_L)Af(0)}{\mu}}. \tag{16}$$

Condition (16) is an extension of condition (10) to the case where low-risk areas are categorized. When the size of the group 1 areas decreases, μ decreases and condition (16) is more easily satisfied.[14]

Is condition (16) likely to be satisfied in practice? We may calibrate the parameters of the model to answer this question roughly. Consider the case of flood insurance, and suppose we target the insurance for new buildings. The time period is 1 year. Assume that $\lambda = 0.05$, $\mu = 0.10$, $\pi_H = 0.10$, $\pi_L = 0.02$. In words, 5 percent of the population is supposed to be subject to a severe risk of flood (10 percent chance per year of being the victim of a flood) while the risk is much lower for 95 percent of the population (only 2 percent chance). Furthermore, 0.95×10 percent $= 9.5$ percent of the population is initially living in the low-risk areas chosen for tax cuts. A is the value of damaged property in case of flood. Suppose that the prevention cost is uniformly distributed over an interval $[0, 2\bar{c}]$, with $\bar{c}$ the average prevention cost for new buildings. The variable $\bar{c}$ is the average additional expenditure per year to escape from the high flood risk. We then have $f(0) = 1/2\bar{c}$. Suppose that on average moving the new building to a low-risk group 1 area entails an additional investment cost I if the prefered location is in a high-risk area. Then we may write $\bar{c} = rI$, where r is the discount rate. Condition (16) may be rewritten as

$$\frac{I}{A} < \frac{\lambda(\pi_H - \pi_L)}{2\mu r(1 - \lambda)}$$

which gives an upper bound for the ratio of the average additional investment cost over the value of damaged property in case of flood. When $r = 0.03$, the condition is $I/A < 70$ percent, which seems to be highly likely. It would be hard to believe that flood prevention increases the cost of a new building by more than 70 percent! If we take a 5 percent interest rate, the upper bound on I/A falls to 42 percent and it is still likely to be satisfied. If the group 1 zone shrinks (μ is smaller) then the upper bound on I/A is larger.

[14] It is particularly interesting to observe that condition (16) is independent from functions G and g. In other words, the condition for categorization to be welfare improving does not depend on the distribution of the cost incurred by opportunistic individuals who may move from a group 2 area to a group 1 area in order to benefit from the tax cut.

PREVENTION BY COMMUNITIES

Let us now examine the relationship between natural disaster insurance and prevention by the communities which have authority to adopt and enforce risk prevention regulations within their jurisdiction. These regulations are costly to the inhabitants: for example, in the case of a flood plain management program, being tough on building standards or development permits entails additional investment costs to the families, property developers and businesses and ultimately it may bring about a decrease in the price of buildings plots.

Assume there are m communities indexed by $j = 1, \ldots, m$. The variable λ still denotes the fraction of the population located in a high-risk area if there is no prevention (neither individually by moving to a low-risk area, nor collectively through a risk management plan). The distribution of individual prevention costs is still described by the density $f(c)$ and the cumulative distribution $F(c)$. The population of community j amounts to the fraction β_j of the whole population of the country, with a proportion λ_j of individuals initially living in a high-risk area, with $\sum_{j=1}^{m} \beta_j = 1$ and $\sum_{j=1}^{m} \beta_j \lambda_j = \lambda$. Let $f_j(c)$ and $F_j(c)$ be respectively, the density and the cumulative distribution function of prevention costs in community j, with $\lambda F(c) = \sum_{j=1}^{m} \beta_j \lambda_j F_j(c)$.

Assume that community j can suppress the high-risk areas within its jurisdiction through a risk management plan at cost θ_j. If location decisions were efficient within jurisdiction j, then all individuals with a prevention cost less than c^{**} should move to a low-risk area. Then the aggregate expected wealth per inhabitant in jurisdiction j would be equal to

$$W - \left[1 - \lambda_j + \lambda_j F_j(c^{**})\right]\pi_L A - \lambda_j \left[1 - F_j(c^{**})\right]\pi_H A - \lambda_j \int_0^{c^{**}} c f_j(c)\, dc \qquad (17)$$

in the absence of a risk management plan, while it becomes

$$W - \pi_L A - \theta_j \qquad (18)$$

if the risk management plan is adopted. Comparing (17) and (18) shows that the socially efficient decision rule requires the local authority to adopt the risk management plan if $\theta_j \leq \Phi_j(c^{**})$, where

$$\Phi_j(c^{**}) \equiv \lambda_j \left\{ \left[1 - F_j(c^{**})\right] c^{**} + \int_0^{c^{**}} c f_j(c)\, dc \right\}.$$

Now assume that the local authority adopts the risk management plan only if it increases the expected wealth of the inhabitants within jurisdiction j, given the insurance premiums that have to be paid in high-and low-risk areas.[15] If the risk management

[15] We could contemplate other decision criterions, such as majority voting among inhabitants, without affecting the results qualitatively.

plan is not adopted, then the expected wealth of the inhabitants is

$$W - \left[1 - \lambda_j + \lambda_j F_j(c^*)\right] P_L - \lambda_j \left[1 - F_j(c^*)\right] P_H - \lambda_j \int_0^{c^*} c f_j(c)\, dc \tag{19}$$

while it becomes

$$W - P_L - \theta_j \tag{20}$$

if the plan is adopted. Comparing (19) and (20) shows that the plan is actually adopted if $\theta_j \leq \Phi_j(c^*)$. Since function Φ_j is increasing and $c^* < c^{**}$ when $t_H + t_L > 0$, we deduce that the decisions of the local authority may not maximize aggregate social welfare. More explicitly, when $\Phi_j(c^*) < \theta_j \leq \Phi_j(c^{**})$, the risk management plan is not adopted though it should be. In the extreme case of uniform insurance pricing (i.e., when $P_L = P_H = P^*$), we have $c^* = 0$ and since $\Phi_j(0) = 0$, it turns out that the plan is never adopted. In words, when the government enforces compensatory transfers between insurance contracts, it reduces the incentives of local authorities to adopt costly prevention measures, and these incentives may even fully vanish when inhabitants pay the same premium whatever their risk exposure.

If the central government knows θ_j, then it can induce community j to adopt the plan when it is optimal to do so. It just needs to pay a subsidy $s_j(\theta_j) = \theta_j - \Phi_j(c^*)$ when $\Phi_j(c^*) < \theta_j \leq \Phi_j(c^{**})$ conditionally on the plan beeing adopted, and no subsidy otherwise.[16] Under such a scheme, the plan will be adopted if and only if $\theta_j \leq \Phi_j(c^{**})$.

However, it is very unlikely that the central government knows θ_j for all j precisely enough to be able to implement such a scheme. It is much more realistic to assume that only uniform subsidies (conditional on the plan beeing adopted) are available. If there is a government grant s to any local jurisdiction where a risk management plan is adopted, then such plans will be adopted in any jurisdiction j where $\theta_j - s \leq \Phi_j(c^*)$ Let $J(c^*, s) = \{j \text{ such that } \theta_j - s \leq \Phi_j(c^*)\}$ be the set of communities where a risk management plan is adopted. Keeping in mind that c^* is given by (6), we see that more risk management plans are adopted when t_L or t_H decrease and when s increases. In other words, the collective risk prevention by communities can be stimulated in two ways: either directly by increasing the governmental grant to communities with risk management plans or indirectly by decreasing the taxes and subsidies on insurance contracts. Let $|J(c^*, s)|$ be the cardinal number of $J(c^*, s)$, i.e., the number of communities with a risk management plan. $|J(c^*, s)|$ is increasing in c^* and s, with $|J(0, 0)| = 0$. Some simple calculations then lead to write the government budget constraint as

$$t_L = \frac{\left(t_H^* + k\right) \sum_{j \notin J(c^*,s)} \beta_j \lambda_j \left[1 - F_j(c^*)\right] + s|J(c^*, s)|}{\sum_{j \notin J(c^*,s)} \beta_j \left[1 - \lambda_j + \lambda_j F_j(c^*)\right] + \sum_{j \in J(c^*,s)} \beta_j} \tag{21}$$

[16] The risk type of individuals is supposed to be public information: function Φ_j is thus known to the central government.

which is an extension of (9) to the case where the population is splitted between communities and where the central governement affects grants to local authorities.

Consider the case where $k = 0$ and assume first that $s = 0$. Equation (21) simplifies to

$$t_L = \frac{t_H^* \sum_{j \notin J(c^*,0)} \beta_j \lambda_j \left[1 - F_j(c^*)\right]}{\sum_{j \notin J(c^*,0)} \beta_j \left[1 - \lambda_j + \lambda_j F_j(c^*)\right] + \sum_{j \in J(c^*,0)} \beta_j}. \tag{22}$$

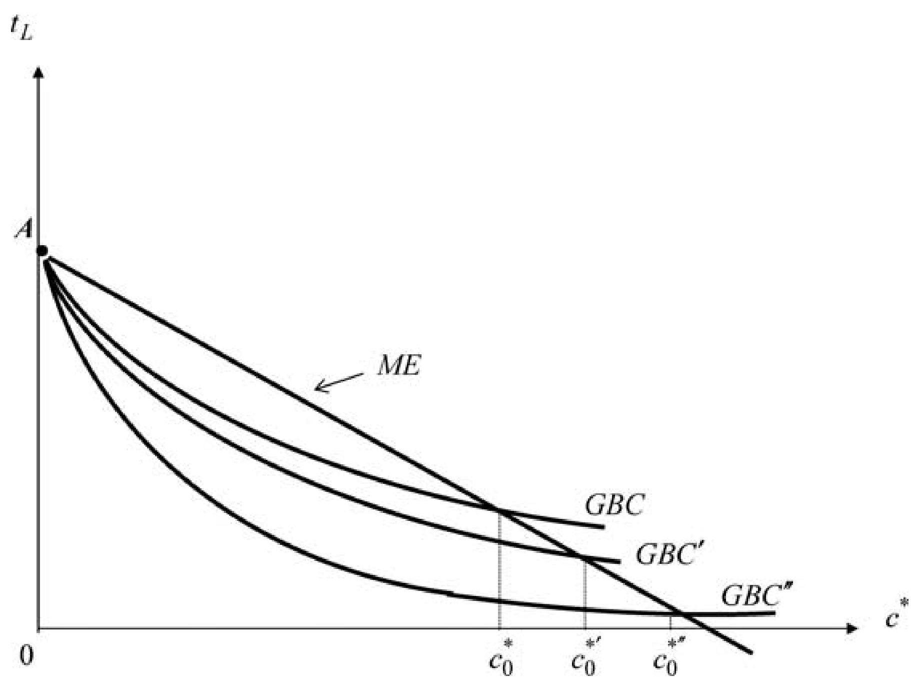
We have

$$\sum_{j \notin J(c^*,0)} \beta_j \lambda_j \left[1 - F_j(c^*)\right] < \sum_{j=1}^{m} \beta_j \lambda_j \left[1 - F_j(c^*)\right] = \lambda \left[1 - F(c^*)\right] \tag{23}$$

and

$$\sum_{j \notin J(c^*,0)} \beta_j \left[1 - \lambda_j + \lambda_j F_j(c^*)\right] + \sum_{j \in J(c^*,0)} \beta_j > \sum_{j=1}^{m} \beta_j \left[1 - \lambda_j + \lambda_j F_j(c^*)\right] = 1 - \lambda + \lambda F(c^*). \tag{24}$$

FIGURE 4
Equilibrium With Subsidies to Local Jurisdictions



Equations (23) and (24) give

$$t_L < \frac{\lambda t_H^*[1 - F(c^*)]}{1 - \lambda + \lambda F(c^*)} \tag{25}$$

when (22) holds.

Equations (9)—with $k = 0$—and (22) are, respectively, represented by the *GBC* and *GBC′* curves in Figure 4. Equation (25) shows that *GBC′* is under *GBC* and both curves concur at $c^* = 0$ because $|J(0, 0)| = 0$. Consequently, under $k = s = 0$, the second-best Pareto-efficient prevention cost threshold increases from c_0^* to $c_0^{*\prime}$. If local authorities adopt risk management plans, then the overall proportion of high-risk areas decreases and, for unchanged subsidies t_H^* paid in high-risk areas, the tax burden per insured can be decreased in low-risk areas, which reinforces the incentive to move to these areas. In other words, individual prevention and collective prevention by local authorities strengthen together. Providing individual incentives through risk-based insurance pricing incites local authorities to adopt risk management plans. Inversely, these plans allow the central government to reduce the tax burden per inhabitant in low-risk areas, which stimulates individuals prevention decisions.

The *GBC″* curve represents Equation (21) when $k = 0$ and s is positive. If there are communities with sufficiently low prevention costs, then there exists $s > 0$ such that *GBC″* is under *GBC′* at least for c^* not too large.[17] Figure 4 corresponds to the case where *GBC″* is under *GBC′* for all c^*. This is the case when increasing the grant s leads to a strong increase in the number of risk management plans: in such a case the additional cost of grants paid by the central government to local jurisdictions is more than compensated by the induced decrease in the subsidies paid in high-risk areas and increase in the taxes levied in low-risk areas. Then paying grants to local jurisdictions leads to an even larger prevention threshold $c_0^{*\prime\prime}$. In words, when local jurisdictions are sufficiently responsive to monetary incentives, the central government should provide incentives to individual prevention through tax cuts on insurance contracts in targeted low-risk areas and simultaneously it should grant subsidies to local jurisdictions where risk management plans are enforced. Both mechanisms are not substitutable: they are complementary and their incentive power intensify one another.

CONCLUSION

This article has investigated the equity-efficiency trade-off in the regulation of natural disaster insurance. This trade-off follows from the imperfect observability of prevention cost. The regulator is then unable to implement tailor-made compensatory transfers between high cost and low cost individuals. For the sake of simplicity, we

[17] To appraise the net effect of a grant s on the government budget, observe first that the government's net resources increase by $\beta_j\lambda_j(t_H + t_L) - s$ when community j enforces a risk management plan. Note also that c^* is close to 0 when (t_H, t_L) is close to (t_H^*, t_L^*). Hence if there exists at least one community—say community k—such that $\theta_k < \beta_j\lambda_j(t_H^* + t_L^*)$ for all $j = 1, \ldots, m$, then choosing s such that $\theta_k < s < \beta_j\lambda_j(t_H^* + t_L^*)$ for all j leads community k (and possibly other communities) to adopt a risk management plan and it yields an increase in the government's net resources at the same time when c^* is close to 0.

have focused on the prevention of natural disaster, but the same logic is at work in the case of mitigation. It can be summarized in a few words. Inducing more prevention or more mitigation through insurance requires that risk-based premiums are charged by insurers. This inevitably penalizes the individuals who cannot escape risk at reasonable cost. The regulator is thus confronted with a dilemma between sharing the burden of natural disaster risks in a more egalitarian way in a Rawlsian perspective and improving the efficiency of risk reduction incentives.

Several results emerge from our analysis of this equity-efficiency trade-off. First, uniform insurance pricing is likely to be Pareto-dominated by risk-based pricing with an adequate transfer schedule. Second, the government can improve the trade-off by categorizing individuals or areas. Third, actuarial insurance pricing urges local communities to implement costly risk management programs, but compensatory taxes and subsidies chosen by the central government induce distortions in local decision-making. Therefore, it is socially useful to pay conditional grants to the local communities that get involved in such programs.

APPENDIX

This Appendix shows how our main results can be extended to the case where premiums include some loading at rate $\sigma > 0$. In such a case we have

$$P_L = (1+\sigma)\pi_L I_L + t_L$$
$$P_H = (1+\sigma)\pi_H I_H - t_H.$$

Under premiums loading insurers offer partial coverage contracts (P_L, I_L) and (P_H, I_H) that maximize policyholders' expected utility.[18] Let U_L be the expected utility of an individual who is located in a low-risk area. We have

$$U_L = \max_{I \geq 0}\{(1-\pi_L)u(W-(1+\sigma)\pi_L I - t_L - c) + \pi_L u(W - A - (1+\sigma)\pi_L I + I - t_L - c)\}$$

with $c = 0$ if the individual is initially located in a low-risk area and $c > 0$ if he (she) has moved from a high-risk area to a low-risk area by incurring the prevention cost c. The variable U_L depends on $t_L + c$ and we may write $U_L = U_L(t_L + c)$ with $U'_L < 0$. Likewise, U_H denotes the expected utility of the inhabitants of high-risk areas, with

$$U_H = \max_{I \geq 0}\{(1-\pi_H)u(W-(1+\sigma)\pi_H I + t_H) + \pi_L u(W - A - (1+\sigma)\pi_H I + I + t_H)\}$$

and we may write $U_H = U_H(t_H)$ with $U'_H > 0$.

[18] Equilibrium contracts depend on the loss probability. They also depend on lump sum taxes and subsidies and on incurred prevention expenditures because of a wealth effect. This wealth effect vanishes when $u(.)$ is CARA.

The egalitarian allocation is reached when individuals get the same expected utility level in high- and low-risk areas and the government budget constraint is balanced. It corresponds to taxes t_L^* and subsidies t_H^* such that

$$U_H\left(t_H^*\right) = U_L\left(t_L^*\right) \tag{A1}$$

and

$$\lambda t_H^* = (1-\lambda)t_L^*. \tag{A2}$$

In such a case, moving from a high-risk area to a low-risk area provides expected utility $U_L(t_L^* + c)$, which is lower than $U_H(t_H^*)$ for all $c > 0$. Hence, there is no incentive to prevention under the egalitarian tax-subsidy scheme t_H^*, t_L^*. On the contrary, when t_H and t_L are such that

$$U_H(t_H) < U_L(t_L)$$

then there is a prevention cost threshold $c^* > 0$ such that

$$U_H(t_H) = U_L\left(t_L + c^*\right),$$

i.e.,

$$c^* = U_L^{-1}(U_H(t_H)) - t_L \tag{A3}$$

and all individuals with prevention costs lower than c^* move from high-risk areas to low-risk areas.

We may still write $t_H = t_H^* + k$. Equation (A3) then gives

$$t_L = U_L^{-1}\left(U_H\left(t_H^* + k\right)\right) - c^*. \tag{A4}$$

Equations (A3) and (A4) are extensions of (6) and (8) to the case where insurance premiums include a loading σ. In particular, Equation (A4) corresponds to the migration equilibrium and it can be represented by decreasing lines *ME* with slope equal to one in absolute value in the same way as in Figure 1. When $k = 0$, the *ME* line crosses the vertical line at $t_L = U_L^{-1}\ (U_H(t_H^*)) = t_L^*$ as in Figure 1. The government budget constraint may still be written as (9) and it is represented by the *GBC* curve as in Figure 1. The qualitative conclusions of the sections "Equity and Efficiency in Natural Disaster Insurance" and "Prevention by Communities" are thus unchanged. In particular, a sufficient condition for a market equilibrium to Pareto-dominate the egalitarian allocation is that the slope (in absolute value) of the *GBC* is larger than one when $c^* = 0$. This is the case when

$$(1-\lambda)^2 - \lambda t_H^* f(0) < 0. \tag{A5}$$

Using (A2) allows us to rewrite (A5) as

$$1 - \lambda - t_L^*(\lambda) f(0) < 0 \tag{A6}$$

where $t_L^*(\lambda)$ is given by (A1) and (A2). One easily check that there exists $\bar{\lambda} \in (0, 1)$ such that

$$1 - \bar{\lambda} - t_L^*(\bar{\lambda}) f(0) = 0 \tag{A7}$$

and (A6) holds when $\lambda > \bar{\lambda}$.

When $\sigma = 0$, insurers offer full insurance contracts at fair premium. In that case $t_L^*(\lambda) = \lambda\,(\pi_H - \pi_L)A$ and (A7) gives

$$\bar{\lambda} = \frac{1}{1 + (\pi_H - \pi_L)Af(0)},$$

which corresponds to condition (10).

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