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Résumé: Cet article analyse le rôle de l'assurance privée dans la prévention et la réduction des dommages des catastrophes naturelles. Nous caractérisons le dilemme équité-efficacité auquel sont confrontés les décideurs politiques dans un contexte d'information imparfaite sur les coûts individuels de prévention. Il est montré qu'un marché concurrentiel d'assurance avec une tarification actuarielle, associé à des transferts sous forme de taxe ou de subvention, domine vraisemblablement les règles de tarification uniforme de l'assurance ou les schémas d'indemnisation financée par l'Etat. Le modèle montre comment des taxes différentiées sur les contrats d'assurance peuvent accroître les incitations à la prévention, tout en faisant bénéficier d'un transfert compensateur les individus dont les coûts de prévention sont élevés. L'article met aussi l'accent sur la complémentarité entre les incitations individuelles par la fiscalité et les incitations collectives par l'attribution de subventions aux collectivités locales qui mettent en place des politiques de prévention des risques de catastrophes naturelles.

Abstract: This paper 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 ratemaking 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 the individuales with high prevention costs. The paper also highlights the complementarity between individual incentives through tax cuts and collective incentives through grants to the local jurisdictions where risk management plans are enforced.

Mots clés : Catastrophes naturelles, Assurance, Prévention.

Key Words : Natural disasters, Insurance, Prevention, Mitigation.

Classification JEL: G22, H23, H77, Q54

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1 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. These events may be the prelude to a still more critical evolution in the future insofar as climate change seems to play a major role in this evolution[1]. Mitigating the consequences 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 attractive peril-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 post disaster assistance from governments or NGOs rather than paying an insurance premium to protect themselves against the consequences of natural hazards[2]. Secondly,

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[1] The Munich Re data base (Hoff et alii (2003); Munich Re (2005)) shows that the economic losses resulting from great weather disasters have increased by a factor of more than six when comparing the last ten years with the sixties, while the insured losses have been multiplied by ten. The number of reported small and mid-sized disasters reveals a similar trend.

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

property owners may not purchase disaster insurance because they under-estimate their true loss probability[3]. Thirdly, lower income consumers have difficulty affording insurance, and of course this obstacle is particularly important in developing countries. Fourthly, 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 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. 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 favour 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 analyse this dilemma in what follows. The starting point is a simple model of a regulated insurance market drawn from Latruffe and Picard (2004). In this model, prevention costs are supposed to be private information to the individuals[4]. The insurance market is competitive but the

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[3]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 US 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.

[4]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 in-

government may either levy taxes on insurance contracts or subsidize these contracts according to the risk exposure. Section 2 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[5]. 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. Section 2 provides some tentative estimates that suggest that the condition for a competitive equilibrium to be welfare enhancing is empirically plausible. Section 3 focuses on the preventive actions by local authorities in the form of risk management plans (e.g. floodplain 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 imperfect 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 and the outcome is only a second-best Pareto-optimum although it is improved by incentive contracts between local governments and the central government[6]. It is shown that risk categorization and competitive

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dividuals who have to pay large premiums because they cannot reduce their risk exposure.

[5]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 United Kingdom rely on private property insurance markets, but the penetration rates remain low in these countries.

[6]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 established by the US Congress in 1968 and

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. Section 4 concludes.

2 Equity and efficiency in natural disaster insurance

2.1 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 also 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.

We assume that the insurance market is competitive, with no transaction costs and risk neutral insurers. The government may tax or subsidize insurance contracts differently according to the risk exposure. Let t_L be the lump

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managed by the Federal Emergency Management Agency. See FEMA (2005). In a very abstract way, the model of Section 3 may be viewed as a theoretical schematisation of this system.

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 tailored-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.

2.2 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

$$t_H = (1 - \lambda)(\pi_H - \pi_L)A \equiv t_H^*$$
$$t_L = \lambda(\pi_H - \pi_L)A \equiv t_L^*$$

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

$$P^* = [\lambda \pi_H + (1 - \lambda)\pi_L] A \tag{3}$$

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 individual may prefer to opt out.

2.3 The equity-efficiency trade-off

From now on, we assume that natural disater 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

$$c^* = (\pi_H - \pi_L)A - (t_L + t_H). \tag{4}$$

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 $c^{**} = (\pi_H - \pi_L)A$. (4) shows that $c^* < c^{**}$ when $t_L + t_H > 0$: the compensatory tax-subsidy shedule induces distortions in prevention by comparison with a non-regulated 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.

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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

$$t_H \left[\lambda \left(1 - F(c^*) \right) \right] = t_L \left[1 - \lambda + \lambda F(c^*) \right]. \tag{5}$$

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 (4) may then be rewritten as

$$t_L = t_L^* - c^* - k \tag{6}$$

Equation (6) yields a relationship between t_L and c^* for a given k. It correspond 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. Using (5) allows us to rewrite the government budget constraint as

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

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 smaller the proportion of individuals in high 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 non-linear decreasing curves GBC in Figure 1[7]. In brief, a budget balanced tax-subsidy policy is characterized by t_L and c^* such that

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

equations (6) and (7) 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 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

$$\lambda > \frac{1}{1 + (\pi_H - \pi_L)Af(0)} \tag{8}$$

Condition (8) 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 beeing, assume that condition (8) hold and let's have a look at the consequences of an increase in k : how is the (Pareto-dominating) equilibrium 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 $\widehat{k}$) , 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 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 which is a decreasing function of k with $t_L(0) = t_{L_0}$ and $t_L(\widehat{k}) = t_{L_1}$.. For the individuals who stay in a high risk area, we have

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

with the prevention threshold $c^*(k) = t_L^* - t_L(k) - k$. 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 $k = \widehat{k}$. 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!

2.4   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[8]. 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

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[8]This is what is done in the National Flood Insurance Program in the US.

area far from a river may entail some costs to the newcomers (for example 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 paid in high risk areas, while the subsidy is paid in low risk areas. The prevention threshold in group i is thus

$$c^{i*} = (\pi_H - \pi_L)A - (t_L^i + t_H^i). \tag{9}$$

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

$$\sum_{i=1}^{n} \alpha^i \lambda^i [1 - F^i(c^{i*})] t_H^i = \sum_{i=1}^{n} \alpha^i \left[1 - \lambda^i + \lambda^i F^i(c^{i*}) \right] t_L^i. \tag{10}$$

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

$$\lambda^i > \frac{1}{1 + (\pi_H - \pi_L)A f^i(0)}. \tag{11}$$

(11) may hold for a subset of groups i in $\{1, ..., n\}$, even if (8) does not hold, which shows that categorization enhances efficiency[9].

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[9]For example, assume that groups are identically distributed among high risk 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 $\lambda^1 = \lambda^2 ... = \lambda^n$ and $F^1(c) > F^2(c)... > F^n(c)$. In such a case, we have $f^1(0) > f^2(0)... > f^n(0)$. Consequently, there exist a threshold group i^* such that (11) hold if and only if $i \leq i^*$.

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 nearby 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 low risk areas of groups 1 and 2. The government allocates the tax cuts to group 1. $f(c)$ 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 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[10]) cost is lower than c^* with

$$t_{L_1} = t_L^* - c^* \tag{12}$$

and

$$t_{L_1} = \frac{\lambda t_H^*[1 - F(c^*) - (1 - \mu)(1 - G(c^*))]}{(1 - \lambda)[\mu + (1 - \mu)G(c^*)] + \lambda F(c^*)} \tag{13}$$

(12) and (13) are analogous to (6) and (7), with $k = 0$. (12) 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. (13) is the government budget constraint and it correspond to the non linear locus GBC.

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

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. Categorization 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 categorization of low risk areas enhances the equity-efficiency trade-off. There is actually risk prevention at equilibrium if the slope of the GBC curve in absolute value is larger than one. A simple calculation shows that this is the case if

$$\lambda > \frac{1}{1 + \frac{(\pi_H - \pi_L)Af(0)}{\mu}} \tag{14}$$

Condition (14) is an extension of condition (8) to the case where low risk areas are categorized. When the size of the group 1 areas decreases, μ decreases and condition (14) is more easily satisfied[11].

Is condition (14) 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 one year. Assume that $\lambda = 0.05, \mu = 0.10, \pi_H = 0.10, \pi_L = 0.02$. In words, 5% of the population is supposed to be subject to a severe risk of flood (10% chance per year of beeing the victim of a flood) while the risk is much lower for 95% of the population (only 2% chance). Furthermore, $0.95 \times 10\% = 9.5\%$ 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 $[0, 2\overline{c}]$, with $\overline{c}$ the average prevention cost for new buildings. $\overline{c}$ is the average additional expenditure per year to escape from the high flood risk. We then have $f(0) = 1/2\overline{c}$. 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 $\overline{c} = rI$, where r is the discount rate. Condition (14) may be rewritten as

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

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[11]It is particularly interesting to observe that condition (14) 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.

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 $I/A < 70\%$ 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%! If we take a 5% interest rate, the upper bound on I/A falls to 42% 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.

3   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 foodplain 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.

Consider a local authority which may suppress the high risk areas within its jurisdiction through a risk management plan at cost θ. 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 $F(c)$. If location decisions were efficient within the jurisdiction, then all individuals with a prevention cost less than c^{**} should move to a low risk area. Then the aggregate expected wealth per inhabitant would be equal to

$$W - [1 - \lambda + \lambda F(c^{**})]\pi_L A - \lambda[1 - F(c^{**})]\pi_H A - \lambda \int_0^{c^{**}} cf(c)dc \quad (15)$$

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

$$W - \pi_L A - \theta \quad (16)$$

if the risk management plan is adopted. Comparing (15) and (16) shows that the socially efficient decision rule requires the local authority to adopt the

risk management plan if $\theta \leq \Phi(c^{**})$, where

$$\Phi(c^{**}) \equiv \lambda\{[1 - F(c^{**})]c^{**} + \int_0^{c^{**}} cf(c)dc\}$$

Now assume that the local authority adopts the risk management plan only if it increases the expected wealth of the inhabitants within the jurisdiction, given the insurance premiums that have to be paid in high risk and low risk areas[12]. If the risk management plan is not adopted, then the expected wealth of the inhabitants is

$$W - [1 - \lambda + \lambda F(c^*)]P_L - \lambda[1 - F(c^*)]P_H - \lambda \int_0^{c^*} cf(c)dc \qquad (17)$$

while it becomes

$$W - P_L - \theta \qquad (18)$$

if the plan is adopted. Comparing (17) and (18) shows that the plan is actually adopted if $\theta \leq \Phi(c^*)$. Since function Φ 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 $\Phi(c^*) < \theta \leq \Phi(c^{**})$, 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 $\Phi(0) = 0$, 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, then it can induce the local authorities to adopt the plan when it is optimal to do so. It just needs to pay a subsidy $s(\theta) = \theta - \Phi(c^*)$ when $\Phi(c^*) < \theta \leq \Phi(c^{**})$ conditionally on the plan beeing adopted, and no subsidy otherwise. Under such a scheme, the plan will be adopted if and only if $\theta \leq \Phi(c^{**})$.

However, it is very unlikely that the central government knows θ 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)

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

are available. Suppose that the only difference between the local jurisdictions is about the cost of their risk management plan and let $H(\theta)$ be the cumulative distribution function of θ among jurisdictions. 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 where $\theta - s \leq \Phi(c^*)$ which corresponds to a fraction $H(\Phi(c^*) + s)$ of the jurisdictions. Some simple calculations then lead to write the government budget constraint as

$$t_L = \frac{\lambda(t_H^* + k)[1 - H(\Phi(c^*) + s)][1 - F(c^*)] + H(\Phi(c^*) + s)s}{[1 - H(\Phi(c^*) + s)][1 - \lambda + \lambda F(c^*)] + H(\Phi(c^*) + s)} \qquad (19)$$

which is an extension of (7) to the case where the central governement affects grants to local authorities. Consider the case where $k = 0$. Assume first that $s = 0$. Equation (19) simplifies to

$$t_L = \frac{\lambda t_H^*[1 - F(c^*)]}{1 - \lambda + \lambda F(c^*) + \frac{H(\Phi(c^*))}{1 - H(\Phi(c^*))}} \qquad (20)$$

Equations (7) and (20) are respectively represented by the GBC and GBC' curves in Figure 4. Comparing (20) with (7) shows that GBC' is under GBC. 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 is lighter 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 differenciated insurance pricing incites local authorities to adopt risk management plans. Inversely, these plans reduce the tax burden in high risk areas which stimulates individuals prevention decisions.

The GBC'' curve represents equation (19) when s is positive. When s is not too large, then GBC'' is under GBC' and it leads to an even larger prevention threshold $c_0^{*\prime\prime}$. In words, if the central government aims at maximizing prevention without putting the individuals with high prevention costs at a disadvantage (that is by choosing $k = 0$), then it should provide incentives to individual prevention through tax cuts on insurance contract 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.

4   Conclusion

This paper 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 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. Firstly, uniform insurance pricing is likely to be Pareto-dominated by risk-based pricing with an adequate transfer schedule. Secondly, the government can improve the trade-off by categorizing individuals or areas. Thirdly, 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.

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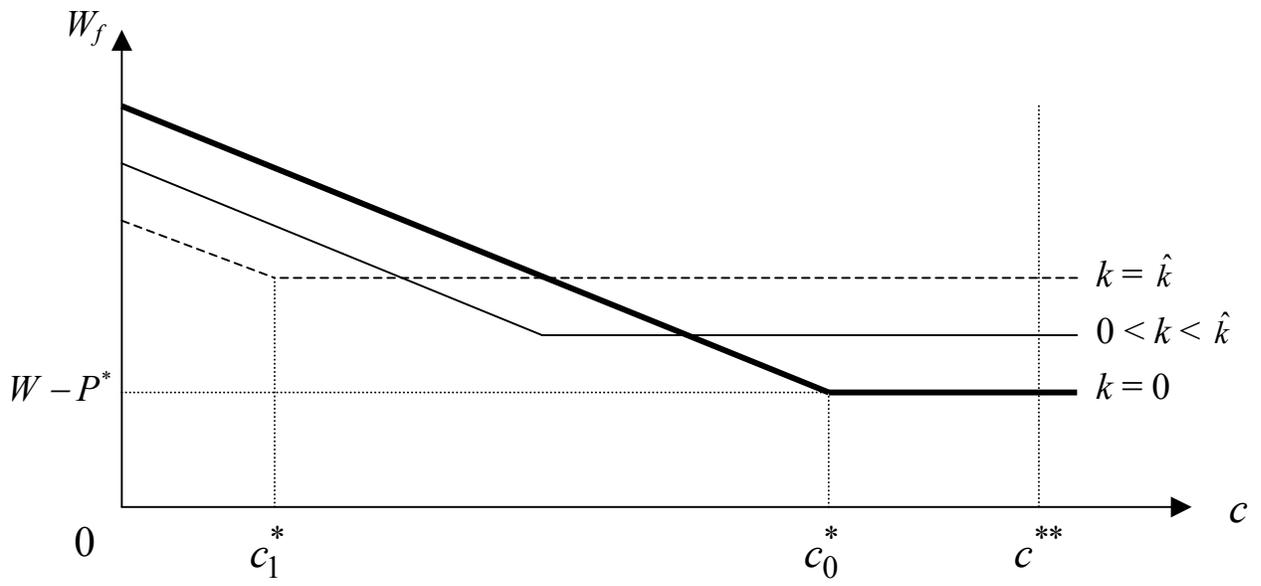
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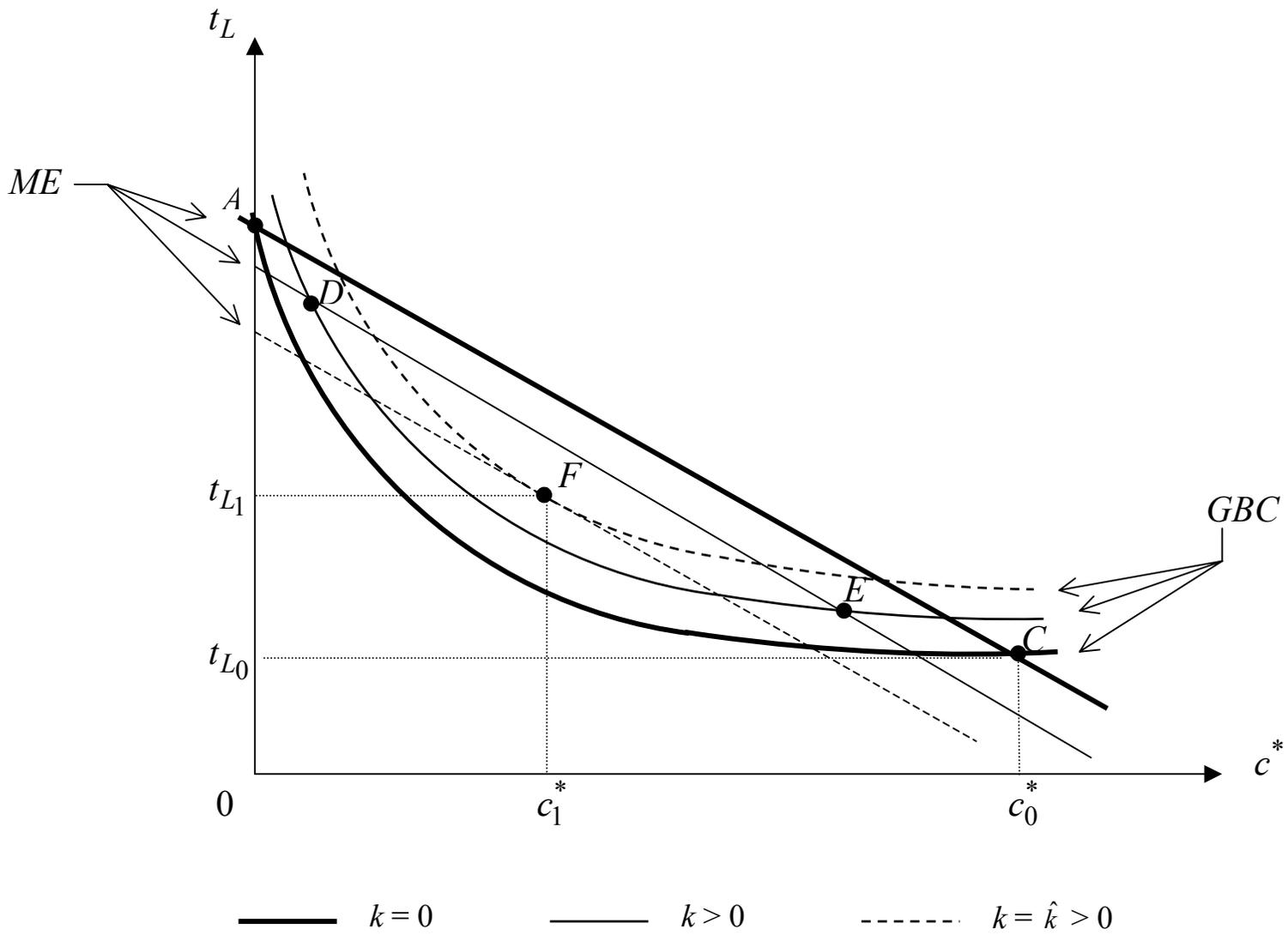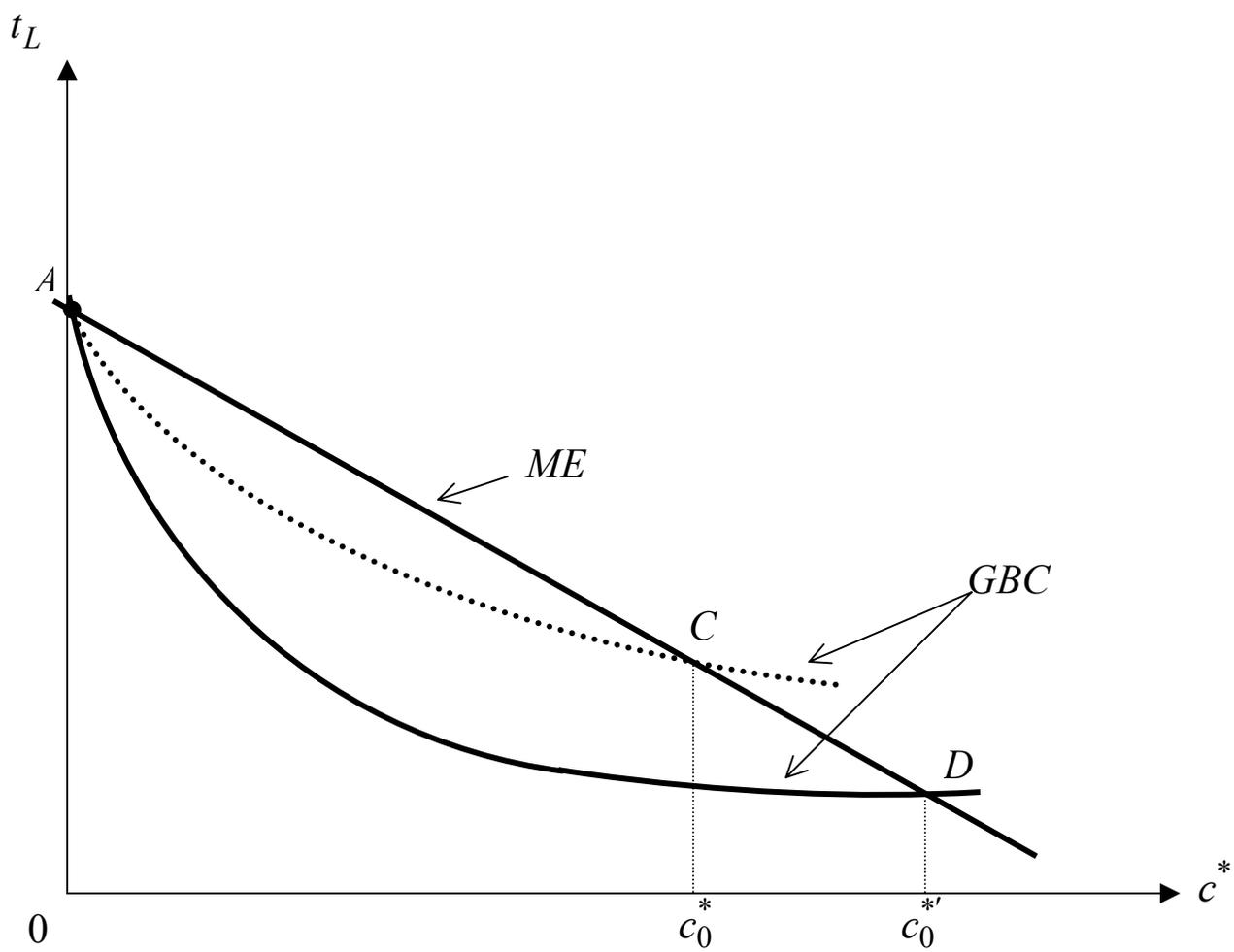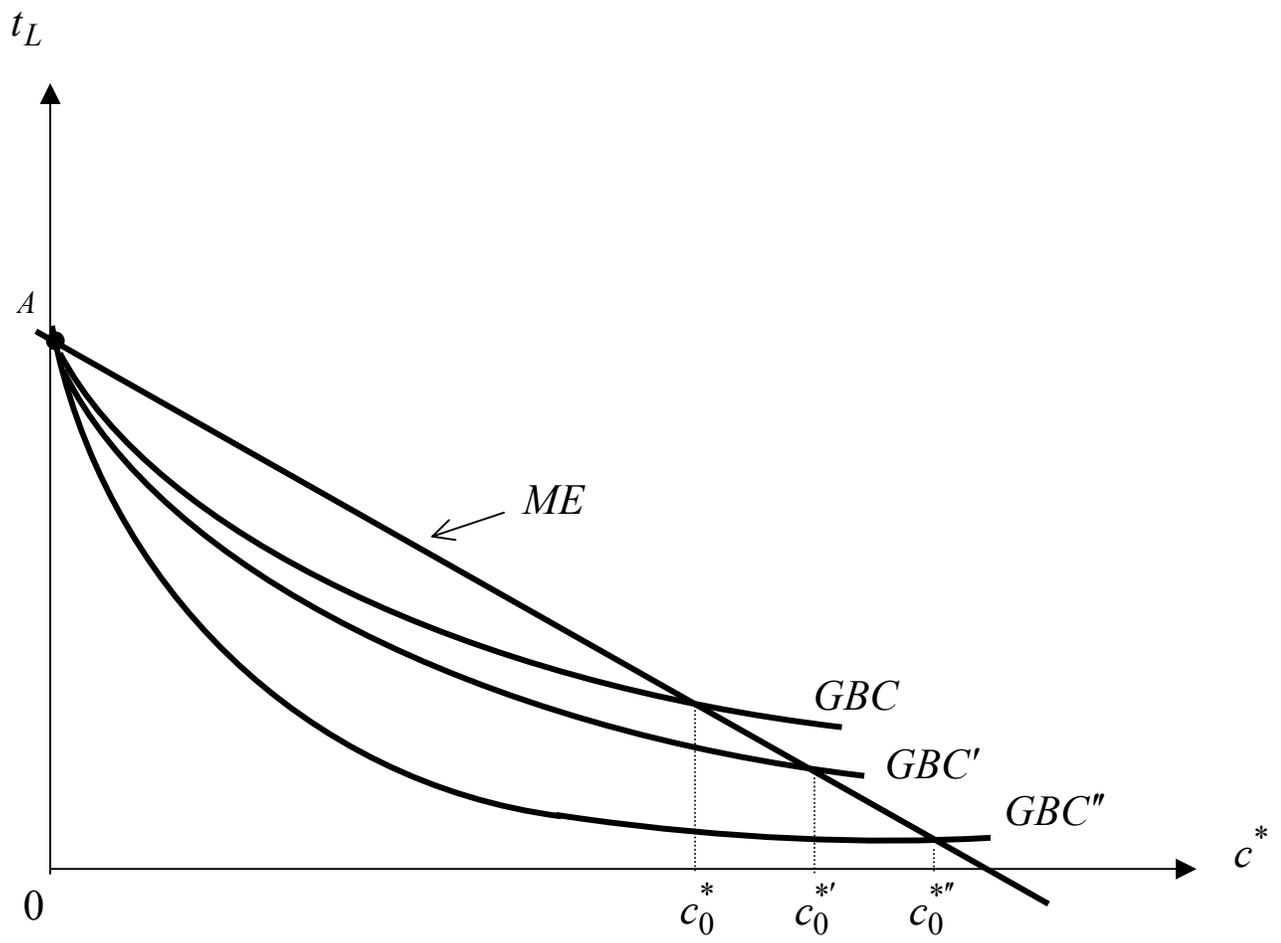
Figure 1

Figure 2

Figure 3

Figure 4