# Disaster Avoidance, Disaster Relief, and Policy Coordination in a Federation

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**Abstract:** This paper presents a general equilibrium analysis of disaster policy in a federation. The national government is postulated to offer optimal disaster relief, a policy that creates moral hazards for subnational government and private sector decisionmakers. In equilibrium, subnational governments, which compete for mobile productive resources, choose inefficiently low amounts of costly disaster avoidance expenditures. This is true even when the national government subsidizes these expenditures through conditional matching grants, implying that national government mandates or direct control over local policy may be required to achieve efficient disaster avoidance.

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# 1 Introduction

The direct impacts of natural and man-made disasters are typically quite localized. Floods, hurricanes, earthquakes, tornadoes, ice storms, and terrorist attacks strike comparatively small geographic regions, such as portions of a coastline, a river valley, a particular city, or the areas near seismic fault lines. Although all regions are subject to some degree of disaster risk, the types and magnitudes of these risks differ widely in accordance with hydrological, climatic, topographical, geological, economic, and demographic circumstances.[1] By virtue of their continuous involvement in local economic development activities, land-use planning, local infrastructure investment, and numerous public safety (police, fire, rescue) services, state and local governments possess much of the detailed knowledge of local conditions necessary for efficient *ex ante* disaster avoidance and *ex post* disaster response and recovery. Local residents and property owners, who bear the principal direct costs of disasters, can monitor and reward the performance of subnational policymakers. Given the heterogeneity of risks among jurisdictions, the informational advantages of subnational governments, and the incentives facing local decisionmakers, it would appear, at first blush and in accordance with basic principles of fiscal federalism (Oates (1972), that much if not all of the responsibility for disaster policy would optimally be assigned to subnational governments such as states and localities. Indeed, subnational government policies do undoubtedly play major roles, directly and indirectly, in disaster avoidance, preparation, response, and recovery.

These considerations notwithstanding, however, the national government, at least in the US, has also been directly and indirectly involved in disaster policy, and to an increasing degree over time. For instance, the Federal government has been heavily engaged in flood-control projects, in the Mississippi River basin (including the ill-fated levee system around the city of New Orleans) and other regions, for many decades. The National Flood Insurance Program (NFIP) has offered flood insurance to property owners in flood-prone regions (at premiums lower than actuarially fair levels (see Congressional Budget Office (CBO) (2009)) and the Federal Emergency Management Agency (FEMA) is involved in many disaster mitigation, preparedness, and recovery activities. In 2003, the Department of Homeland Security was established as a Cabinet-level department, a direct consequence of a major man-made disaster (the 9/11 attacks).[2] The catastrophic flooding along the US Gulf Coast in 2005 has resulted in massive Federal disaster relief expenditures, approximately equal to the total value of all property losses caused

[1] Empirically, flooding – including hurricane-related flooding – accounts for the bulk of disaster losses in the US. During the period 1955-2003, annual flood losses, expressed as a proportion of state personal income, have ranged from less than 0.01% for some states (Delaware) to as high as 0.89% in others (North Dakota) (Wildasin (2007)). Total flood losses from 1929-2005 amounted to approximately $210 billion 2005 dollars (Pielke, et al. 2008), of which approximately half were attributable to flood losses from Katrina and other storms in 2005.

[2] Landmark Federal legislation pertaining to flood control includes the Flood Control Act of 1936 (see Arnold, 1988), the National Flood Insurance Act of 1968, the Disaster Relief Act of 1974 and the Robert T. Stafford Disaster Relief and Emergency Assistance Act of 1988.

by these floods.[3] In addition to policies that deal directly with disasters, many Federal government tax and expenditure policies (notably, transportation and other infrastructure projects that affect local and regional economic development) affect risk exposure and the *ex post* distribution of disaster costs. Of course, from a normative perspective, involvement by higher-level governments in various aspects of disaster policy may well be warranted. Disasters need not respect political boundaries, and large disasters frequently strike multiple subnational jurisdictions. It may be difficult for lower-level units of government to implement well-coordinated policies for *ex post* recovery from such disasters and to prepare for them *ex ante*.[4] Furthermore, disasters can disrupt important local and regional government functions, including their physical, human resource, and financial infrastructure and capacity, necessitating Federal government intervention in times of local crisis. Not least, *ex post* Federal government disaster relief may be viewed either as a form of redistribution toward disadvantaged households or as the execution of an implicit social insurance contract in which disaster-stricken households are indemnified by the rest of society (Varian 1980), both of which may have normative appeal.

Given the complex and contingent nature of the problems that disaster policies must address, both *ex ante* and *ex post*, it is perhaps not surprising that the responsibility for disaster policy is shared among multiple levels of government. But the ways in which these responsibilities are shared and the advantages and disadvantages of different assignments of responsibilities have not been the subject of extensive economic analysis.[5] The present paper investigates the interplay of national and subnational government policymaking and their economic implications, focusing especially on whether and how the *ex post* disaster relief and recovery policies of the national government affect *ex ante* disaster avoidance policies on the part of subnational governments in disaster-prone regions. It further examines whether and how the ensemble of national and subnational government policies affect the allocation of resources among regions that are more or less disaster prone. To carry out this analysis, it is necessary to model the policymaking behavior of both national and subnational governments. One key assumption, which may be justified on theoretical grounds in terms of time-consistency and lack of commitment mechanisms, and on empirical grounds by reference to the growing role of the Federal government in *ex post* disaster relief and recovery in recent decades, is that the national government can (and, in equilibrium, does) intervene after a disaster to assist those who have suf-

[3] A precise accounting of the magnitude of the losses and of Federal disaster relief expenditures is difficult, at best. Murray and Bea (2007) report Federal appropriations of approximately $80 billion for the 2005 hurricanes. To this should be added the indirect absorption of disaster losses by the Federal government through foregone tax revenues and through additional expenditures for unemployment insurance, Medicaid benefits, and the like. According to one government report (see GAO 2006), losses from Hurricane Katrina amounted to approximately $96 billion. Clearly, a very substantial portion of the costs of this disaster have been shifted to the national government and thus to the population residing outside of the disaster-stricken region.

[4] Needless to say, even if a benevolent and well-informed higher level government could improve the efficiency of disaster policy, a less benevolent or less well-informed higher level government may make matters worse. See Kousky *et al.* (2006) for a critical perspective on Federal government policy regarding the Mississippi River Basin.

[5] For recent studies, see Chernick (2001), Goodspeed and Haughwout (2006), and Wildasin (2007, 2008) and references therein.

fered losses. This fundamental assumption gives rise to a moral hazard problem with far-reaching implications. In particular, when combined with the hypothesis that subnational governments pursue policies that reflect the interests of local stakeholders, national government *ex post* disaster policies imply that subnational governments undertake inefficiently low levels of *ex ante* disaster avoidance. The question then arises as to what further policies might remedy this inefficiency. Plausibly, intergovernmental transfers, such as matching grants that are conditioned on local precautionary effort, could help to coordinate policies among levels of government. Surprisingly, however, such instruments fail completely to induce efficient disaster-avoidance policies on the part of subnational governments. Within the simplified setting of the model, this suggests that direct central government regulation and control of disaster avoidance policy is the only feasible means through which efficient *ex ante* policies can be achieved. In practice, informational, constitutional, and other constraints would present insuperable barriers to such a completely centralized approach to disaster avoidance.[6] The potential policy implications of this problem are discussed further in the conclusion. For the moment, let us simply note that the analysis is related to the problem of "soft budget constraints", "bailouts", and associated discussions of institutional structure in federations that have been the subject of recent attention in the literature of fiscal federalism (see, e.g., Besfamille and Lockwood (2008), Inman (2003), Oates (2005), Wildasin (1997)).

## 2 A Model of Region-Specific Risk, Insurance, and Preparedness

Before spelling out the formal analysis, a concise outline of the essential features of the model may be helpful. There is a region – henceforth called the "Coast" and represented by the subscript $C$ – that is at risk of some important adverse event, whether natural (hurricanes, earthquakes) or man-made (terrorist attacks). Private insurance against this risk is unavailable.[7] This adverse event, which occurs with probability $\pi$, causes losses to

[6] To illustrate the practical limitations of Federal government control over local flood control and avoidance policy, note, as just one example, that the Federal flood control project around New Orleans was long plagued by technical, financial, and environmental problems, as discussed in GAO reports from 1976 and 1982. Furthermore, it is well recognized that the local flood plain maps prepared for the NFIP may fail to take into account the multitude of important local developments: as NFIP actuaries have expressed it (Hayes and Jacobson (2001, p. A-3), "Some of the factors that increase flood hazard (e.g., local urban drainage problems and urbanization of other parts of the watershed) are virtually impossible to quantify if the Flood Insurance Study process is to remain cost effective." In the US, there are approximately 3,000 counties, 20,000 municipalities, and tens of thousand of other local governments, – a grand total of about 90,000, as of the 2007 Census of Governments. Notably, this total includes about 37,000 "special districts", many of which are involved in water, sewage, transportation, and other infrastructure projects. Detailed national-level control of the policies of such a numerous and diverse set of localities would present substantial management challenges, even for the most well-organized national bureaucracy.

[7] Focusing only on residential flood loss risks, the National Flood Insurance Program (NFIP) insures some 5 million properties, compared to the estimated 0.25 million covered by private insurance. See CBO (2009, p. 9) and Dixon *et al.* (2007, p. 19). The absence of private insurance emerges endogenously from the model presented below.

residents of the region. In reality, these losses take many forms: (i) loss of life, physical injury, loss of personal property, (ii) losses from economic disruption such as lost earnings, high prices for consumption goods, destruction of private wealth, and other market impacts; and (iii) losses of services provided by regional governments due to loss of or harm to physical and institutional infrastructure and government personnel, as well as additional taxes and charges that are paid by residents in order to compensate for these losses, to replace infrastructure, and to restore services. To reduce the problem to its essentials, assume that all worker/households in the region are identical, and that the total of all of these different types of losses have a monetized value, net of any private insurance, of $L$ per household. Once these losses occur, an optimizing higher-level government – the national government, say – provides disaster relief to "the" regional government, which should be interpreted as the aggregate or representative of many atomistic local governments serving the Coastal region) or, perhaps, directly to the region's residents. These transfers, which offset the losses experienced by Coastal residents and are socially optimal in the sense that they maximize *ex post* social welfare, are financed through general levies imposed by the national government on agents throughout the entire economy, including, in particular, residents not living on the Coast. All other regions, called "Inland", are treated as an aggregate and are assumed to face no disaster risk.

All agents – households, firms, governments at all levels – recognize the possibility of an adverse event and are assumed to know its true probability and magnitude. At first, this probability $\pi$ and the magnitude of the loss $L$ are treated as exogenously given. Subsequently, however, these are assumed to depend (negatively) on preventive expenditures, observable to all, undertaken by the Coastal government, and denoted by $z$ ("height and strength of levees" is one possible interpretation). The national government may assist the regional government in financing these expenditures. An important question is whether the regional government undertakes an efficient amount of expenditures on "levees." Evidently, addressing this question requires a model of Coastal government decisionmaking so that its response to incentives, including the incentives that emerge from national government policies, can be analyzed. The model assumes that the Coastal government chooses policies that are optimal from the perspective of affected local interests.

Finally, to capture the effects of government policies on interregional resource allocation, households are assumed to be interregionally mobile and to choose their region of residence and employment so as to maximize *ex ante* expected utility. In particular, the "disaster relief policy" of the national government – that is, the *ex post* transfers that it makes to the Coastal government or residents – affects decisionmaking at all prior stages, including the equilibrium allocation of population among regions.

Although this model is very stylized, it can be used to analyze several different margins of public and private decisionmaking. Among the questions to study are these: does

the prospect of *ex post* transfers lead to excessive concentration of population in the Coastal region, and thus to excessive (expected) losses from the adverse event? If the Coastal government can expend resources to reduce the likelihood of the adverse event, does spend the efficient amount, or possibly too little or too much? Are there national government policies that can lead the Coastal government to choose more efficient levels of preventive expenditures?

Let us turn now to a more detailed description of the model. Most of the interesting incentive questions arise from an *ex ante* perspective, when economic decisions are made in anticipation of future policies. For this reason, the model has a sequential structure. From the viewpoint of regional economic development incentives, households and firms should be viewed as making decisions with fairly long time horizons, one or more decade into the future, and, for this reason, the model does not attempt to incorporate the fine structure of fiscal and regulatory policies, focusing instead on a more aggregative treatment of taxes and expenditures that represent the anticipated fiscal burdens and benefits faced by different agents over long periods of time.

The sequence of events and basic structure of the model are as follows. First, there is a fixed total population $\bar{n}$ of *ex ante* identical working households in the economy. In the first stage of the model, these households determine where to reside, choosing where they will live and work so as to maximize expected utility. Next, production takes place in each region, using the labor of households located there and immobile resources called "land". These factors of production are employed by competitive firms and each is paid its competitive equilibrium return; $w_i$ denotes the wage per worker in region $i$, and $R_i$ is the rent accruing to "landowners", i.e., the owners of immobile resources. Landowners, who are assumed to be risk neutral, are a distinct group, separate from worker-households, and are the sole recipients of rents to fixed factors.[8] At this stage, all non-state contingent national and subnational tax and expenditure policies are executed. Uncertainty about the state of nature is resolved in the third stage, that is, after production has taken place. With probability $\pi$, known to all, a disaster occurs in the Coastal region. If disaster strikes, each Coastal resident suffers a loss with a monetized value of $L$ per household. In this event, national state-contingent fiscal policies (disaster relief and its financing) are executed. At no stage do any agents make incorrect forecasts of equilibrium market conditions or policies.

A fundamental hypothesis, maintained throughout, is that the national government cannot prevent itself from "benign" *ex post* fiscal intervention, in the form of compensatory transfers, if the Coast is struck by a disaster. In this event, the national government is assumed to impose some combination of lump-sum taxes on all households and landown-

[8]Other interregionally-mobile resources, such as capital or different types of labor, could be incorporated in the analysis without changing the results, but these are suppressed for ease of exposition. The implications of including such resources are discussed again, informally, at the end of Section 4.

ers in the economy, the proceeds of which are used to indemnify Coastal residents for any losses not covered by private insurance, so as to maximize a utilitarian social welfare function. (The details of the financing of these transfers is discussed further below.) To justify this crucial hypothesis, note that it is exactly the policy that a benevolent central government would pursue if it seeks, in a time-consistent fashion, to maximize the sum of utilities for all households in the economy, given the fiscal instruments postulated to be at its disposal. (See Caplan et al. (2000) for use of this type of model and references to related literature.) Equivalently, this is the policy that maximizes the *ex ante* expected utility of all households in the economy, again given the postulated fiscal instruments and assuming that policies must be time-consistent.

It is easy to see that this hypothesized behavior of the central government creates moral hazard. First, note that no Coastal resident would purchase private insurance, relying instead on the national government to cover the entire loss $L$ from any disaster.[9] Second, the knowledge that these losses will be covered creates incentives for inefficient locational choices by households in the first stage, as will be discussed in more detail.

Some remarks on interpretation may help to justify the strong simplifying assumptions on which the model rests. The loss $L$ suffered by each coastal resident should be interpreted broadly to include not only "private" damage such as destruction of housing, but also the value of disruptions to public services (schools, public safety, water, electricity, transportation, etc.) and even lost "future" income (beyond the explicit horizon of the model) due to disruption of local production. In the formal setup of the model, the central government transfers an amount $L$ to each resident, but this transfer should likewise be interpreted broadly to include (i) direct cash and in-kind transfers to residents, (ii) transfers to the regional government that are then passed through to local residents (e.g., community-provided food and shelter), and (iii) transfers to the regional government that allow it to maintain the provision of public services (water, health, electricity, etc.) to local residents. For the purposes of this analysis, it is the anticipation of central government assistance to the "region" in the event of disaster, not the precise breakdown of this assistance into "private" and "public" components, that is crucial. Hence, the underlying losses $L$ as well as the compensatory central government transfers should be viewed as broad aggregates. Clearly, these stark simplifying assumptions sweep aside many important policy questions, certainly worthy of attention and further analysis, about disaster assistance and its distribution. As always, the rationale for such simplification is to isolate certain important considerations in a transparent fashion.

*Regional Government Policy Instruments*

The regional government in the Inland region performs no function in the model. The

[9]This important fact is actually implied by Proposition 2 below, which shows that the benevolent national government provides full compensation to Coastal residents in the event of a disaster.

Coastal regional government may undertake *ex ante* public expenditures, denoted by $z$, which negatively affect (a) the probability of disaster – i.e., $\pi = \pi(z)$ with $\pi' < 0$; (b) the magnitude of any disaster losses – i.e., $L = L(z)$ with $L' < 0$; or both of these. These outlays should be thought of as precautionary expenditures for disaster avoidance or relief.

Regional government expenditures must be financed *ex ante* from some combination of own-source taxes imposed on local residents in the amount $\tau_n$ or on local landowners in the amount $\tau_R$, plus fiscal assistance from the central government in the form of lump-sum grants $\lambda$ or matching grants in support of disaster-avoidance expenditures. Let $\mu$ represent the fraction of such expenditures paid for by grants, so that the total amount of matching grants is $\mu z$. The budget constraint for the Coastal regional government is thus

$$(1-\mu)z = n_C\tau_n + \tau_R + \lambda. \tag{1}$$

Other types of pure or impure regional public goods (for example, congestable public goods like education) could easily be added to the model with no important effect on the key results below, but these are suppressed for notational convenience.

*Central Government Policy Instruments*

In the event of a disaster, the central government imposes lump-sum taxes on all households in the economy and on landowners in order to compensate Coastal residents, partially, fully, or not at all, for their losses. As a matter of notational convention, assume that the losses are initially absorbed by the central government, and let $T_{iw}$ be the per-household taxes on residents and $T_{iR}$ the taxes on landowners in each region, $i = C, I$. The central government must finance its disaster relief, i.e.,

$$n_C L = \sum_{i=I,C} \left(n_i T_{iw} + T_{iR}\right). \tag{2}$$

Note that these taxes are collected only in the event of a disaster and are thus stochastic, i.e., $T_{iw} = T_{iR} = 0$ with probability $1 - \pi$. Allowing these state-contingent central government taxes to take on different values allows for any possible degree of net central government disaster relief. For example, setting $T_{Cw} = L$ and $T_{IR} = T_{Iw} = T_{CR} = 0$ would correspond to the case where all disaster losses are absorbed by Coastal residents. In that case, although the losses fall on the central government (appearing on the left-hand side of (2)), these losses are "clawed back" through taxes on Coastal residents, meaning, in effect, that there is no central government disaster relief. On the other hand, setting $T_{Cw} = 0$ would imply that Coastal residents are not harmed at all in the event of a disaster, with other taxpayers – landowners or Inland workers – paying the necessary taxes to finance this relief from the central government. Since these tax variables are to be selected by the central government, the level of central government disaster relief is endogenous to the model.

The central government must also impose taxes *ex ante* to finance any fiscal transfers to the Coastal regional government. Furthermore, to allow for the possibility that the central government may choose policies *ex ante* that affect regional development, let $t_{iw}$ and $t_{iR}$ denote region-specific taxes imposed on households and landowners, respectively, in region $i$.[10] The *ex ante* central government balanced-budget constraint is

$$\sum_{i=I,C} (n_i t_{iw} + t_{iR}) = \lambda + \mu z. \tag{3}$$

*Production.* Assume that output in each region is a strictly increasing and concave function $f_i(n_i)$, $f_i' > 0 > f_i''$, of the number of resident worker-households. Given that factor prices are determined *ex ante* in competitive factor markets,

$$w_i = f_i'(n_i), \qquad R_i = f_i(n_i) - n_i f_i'(n_i). \tag{4}$$

These factor prices are determined prior to the realization of the state of nature and are thus not random.

*Households.*

Let $u(y_i)$ be the common strictly increasing and concave utility function for all worker-residents in region $i$, $i = C, I$, where $y_i$ is state-contingent net income (or consumption). A household's net income may differ from its wages because of taxes $\tau_n$ paid to the Coastal regional government, if it resides there, and because of taxes paid *ex ante* ($t_{iw}$) or *ex post* ($T_n$) to the central government. The net incomes of residents in each region are thus

$$y_I = w_I - t_{Iw} - T_{Iw} = f_I'(\bar{n} - n_C) - \tau_n - t_{Iw} - T_{Iw} \tag{5}$$

$$y_C = w_C - \tau_n - t_{Cw} - T_{Cw} = f_I'(n_I) - \tau_n - t_{Cw} - T_{Cw} \tag{6}$$

where the condition $n_C + n_I = \bar{n}$ is used to eliminate $n_I$. Since the $T_{iw}$'s may be nonzero if a disaster occurs, but are zero otherwise, these net incomes are stochastic. Note that the expression for $y_C$ incorporates the fact that the central government fully compensates Coastal residents for any losses, as already explained.

The expected utility of Inland residents can now be expressed as

$$\begin{aligned} EU_I \equiv \pi(z) u\left(f_I'[\bar{n} - n_C] - \tau_n - t_{Iw} - T_{Iw}\right) \\ + (1 - \pi(z))\, u\left(f_I'[\bar{n} - n_C] - \tau_n - t_{Iw}\right) \end{aligned} \tag{7}$$

[10] These fiscal instruments should be interpreted as the *net* fiscal burdens imposed on each group, taking *all* central government tax and expenditure policies together. The case where the *ex ante* fiscal treatment of households in each region must be uniform can be represented by imposing the constraint that $t_{Iw} = t_{Cw}$, as discussed at the end of Section 3. Such an "equal treatment" condition certainly seems natural for some aspects of tax and expenditures policies. In practice, however, different types of taxes differentially affect different regions that have different incomes, education levels, age structures, and industrial compositions. Furthermore, on the expenditure side, national transportation, agricultural, housing, health, cash transfers, and many other policies also influence the interregional allocation of population and investment. Thus, it seems appropriate, as a central case, to suppose that the national government has a sufficiently rich set of policy instruments to differentiate the fiscal treatment of households in different regions.

while that of Coastal residents is

$$\begin{aligned} EU_C \equiv \pi(z) u\left(f_C'(n_C) - \tau_n - t_{Cw} - T_{Cw}\right) \\ + \left(1 - \pi(z)\right) u\left(f_C'(n_C) - \tau_n - t_{Cw}\right) \end{aligned} \tag{8}$$

using (5), (6), and the fact that $T_{iw} = 0$ when there is no disaster. The expected utility of residents in each region thus depends on the policies of both levels of government and on the number of residents in each region.

*Landowners.*

The net rents accruing to landowners in each region are given by

$$R_I^n \equiv R_I - T_{IR} - t_{IR} = f_I(\bar{n} - n_C) - (\bar{n} - n_C) f_I'(\bar{n} - n_C) - T_{IR} - t_{IR} \tag{9}$$

$$R_C^n \equiv R_C - T_{CR} - t_{CR} - \tau_R = f_C(n_C) - n_C f_C'(n_C) - T_{CR} - t_{CR} - \tau_R. \tag{10}$$

Because the taxes $T_{iR}$ are collected *ex post* only if a disaster occurs, net rents are random variables. As mentioned, landowners are assumed to be risk-neutral.

*Equilibrium.*

Conditional on national and regional government policies, it is apparent from (5) and (6) that utility in each state of nature can be determined once the value of $n_C$ is known. The probability of disaster and thus the expected utility of a resident in region $i$ also depends on $z$. The equilibrium value of $n_C$ equalizes the expected utility of residents in each region, conditional on government fiscal policies, i.e., it satisfies

$$EU_I(n_I, \alpha, \beta) = EU_C(n_C, \alpha, \beta) \tag{11}$$

where $\alpha \equiv (z, \tau_n, \tau_R)$ is the vector of Coastal regional government policies and where $\beta \equiv (t_{Iw}, t_{Cw}, t_{CR}, t_{IR}, \lambda, \mu, T_{Iw}, T_{Cw}, T_{IR}, T_{CR})$ is the vector of central government fiscal policies. Monotonicity of the utility function and concavity of the production function implies that $\partial EU_I/\partial n_C - \partial EU_C/\partial n_C > 0$; in words, the Inland region becomes increasingly attractive relative to the Coastal region, the more households reside in the latter. Hence, (11) can be used to determine the (unique) equilibrium value of $n_C$ as a function $\Phi(\alpha, \beta)$ of the policies chosen at each level of government. Substituting into (10) then determines the equilibrium net rents accruing to landowners in each region for any set of policies chosen by the regional and central governments.

The policies of each level of government must be feasible, i.e., must satisfy their balanced-budget constraints. The Coastal regional government treats the policies of the central government as parameters and is assumed to choose its policies in order to maximize expected net land rents, taking as given the expected utility that local residents must obtain. These assumptions are justified because the Coastal "government" is actually the aggregate of many independent and atomistic governments, each "small" and "open."

This implies, first, that each small local government's individual policies have only a negligible influence on the behavior of the central government, and, secondly, that these policies have only a negligible influence on the utility of any mobile resources – in this case, the expected utilities of mobile households.[11]

## 3 Regional and Central Government Tax Policies

It is convenient to start the analysis by examining the special case where the level of public good provision $z$ and central government grant policies ($\lambda$ and $\mu$) are exogenously fixed at some arbitrary levels. Because $z$ is fixed, so is the probability of disaster, $\pi$, as is the amount of intergovernmental transfers $\lambda + \mu z$. With these parameters fixed, we may focus on the determination of regional and central government tax (and transfer) policies.

*Equilibrium Regional Government Tax Policies.*

Given a fixed level of public expenditures, the regional government has only to choose its tax instruments to finance these outlays so as to maximize net land rents, taking as given the policies of the central government and also treating the expected utility of resident households as parametrically given at some level $\overline{EU}$. The condition that

$$EU_C(n_C, \alpha, \beta) = \overline{EU} \tag{12}$$

similarly to (11), can be used to solve for $n_C$ implicitly as a function $\phi(\alpha, \beta)$. In particular,

$$\frac{\partial \phi}{\partial \tau_n} = \frac{1}{f''_C} < 0. \tag{13}$$

Substituting from the regional government budget constraint (1) into (10) to eliminate $\tau_R$, the regional government's problem is to

$$\textbf{(P.1)} \quad max_{<\tau_n>} f_C(\phi[\cdot]) - \phi(\cdot) f'_C(\phi[\cdot]) + \tau_n \phi(\alpha, \beta) - (1 - \mu)z + \lambda$$

for which the first-order condition is

$$(-n_C f''_C + \tau_n) \frac{\partial \phi}{\partial \tau_n} + n_C = 0. \tag{14}$$

Hence:

[11] See Sonstelie and Portney (1978) for an early analysis along these lines, Fischel (2001) for extensive motivation, illustrations, applications, and references to related literature, and Wildasin (2006) for further exposition of this standard approach. It goes without saying that other models of regional government decisionmaking could be used and that the following results depend on the specification used here, including the assumption of costless mobility.

**Proposition 1:** The optimal tax policy for the Coastal government is to impose no (net) taxes at all on resident households and to finance all expenditures from taxes on immobile resources.

This result, which is standard for models of small, open jurisdictions, means that the tax instrument $\tau_n$ can be ignored in the remaining analysis. As a corollary, note that the regional government, through its choice of $\tau_n$, could achieve any desired level of population. The regional government therefore has no incentive to utilize any regulatory policies that directly control population, such as zoning constraints, and such policies can therefore be ignored in this model without loss of generality.[12]

*Central Government Tax Policies.*

The central government is assumed to pursue policies that maximize the *ex ante* sum of expected utilities of households plus net land rents. It solves two problems: the *ex post* problem of financing disaster relief, in which it treats the allocation of households among regions as fixed, and the *ex ante* problem of financing any grants and of making any redistributive transfers among households and landowners.

The "disaster relief financing problem" requires the central government to choose $T_{Iw}, T_{Cw}$, $T_{IR}, T_{CR}$ to maximize

$$n_C u(f'_C - t_{Cw} - T_{Cw}) + n_I u(f'_I - t_{Iw} - T_{Iw}) + R^n_C + R^n_I \tag{15}$$

subject to (2). Substituting from the latter into (15) to eliminate the taxes on land rents, the central government's *ex post* financing problem reduces to

$$\textbf{(P.2)} \quad max_{<T_{Cw},T_{Iw}>} \quad n_C u(f'_C - t_{Cw} - T_{Cw}) + n_I u(f'_I - t_{Iw} - T_{Iw}) + R_C + R_I - n_C L + \sum_{i=I,C} (n_i T_{iw} - t_{iR}) - \tau_R \tag{16}$$

for which the first-order conditions imply

$$u'_i(f'_i - t_{iw} - T_{iw}) = 1, \quad i = 1, 2 \tag{17}$$

which means that there is some common level of *ex post* net income or consumption $K$ received households in both regions, i.e.,

$$f'_i(n_i) - t_{iw} - T_{iw} = K, \quad i = C, I. \tag{18}$$

[12] As a matter of interpretation, it might be more accurate to say that zoning and other regulatory constraints are subsumed by the assumption that local lump-sum taxes can be used in the first place, à la Hamilton (1975). But, within this model, such taxes appear as superfluous instruments. It is important to remember, however, that the local head taxes $\tau_n$, like their national-level counterparts, are to be interpreted as *net* fiscal burdens. If local governments provide congestible local public goods, as is true in practice, then the optimal local policy is to set taxes in a lump-sum fashion equal to marginal congestion cost, relying on land taxes for any additional needed revenues (or to distribute any net surplus). The $\tau_n$ variables should be understood to represent local head taxes net of marginal congestion costs, and these are set equal to zero, as Proposition 1 indicates. See Wildasin (1986) for explicit treatment of these matters and for references to related literature.

In effect, the central government uses its policy instruments to insure risk-averse households against the costs of disaster. (This is the full-insurance result mentioned in Section 2.) Note further that because central government policies equalize the *ex post* utilities of residents of both regions in the event of disaster, the *ex ante* equilibrium (11) can only be satisfied if utilities in both regions are also equalized *ex post* if no disaster occurs.

It is convenient to analyze *ex ante* central government policy by assuming first that its grant policies (the parameters $\lambda$ and $\mu$) are arbitrarily fixed, in order to focus on the choice of *ex ante* revenue policies. The central government is assumed to maximize the sum of expected utilities for all households plus expected rents for landowners, taking into account the fact that its policies may effect the allocation of households among regions, i.e., it chooses $t_{Cw}, t_{Iw}, t_{CR}, t_{IR}$ to maximize

$$\bar{n}EU_C + \sum_{i=C,I} ER_i^n \tag{19}$$

subject to (3), taking into account the fact that expected utilities are equalized between regions by (11) and where $ER_i^n$ denotes expected net rents in region $i$.

Note that the *ex ante* allocation of labor, and thus gross land rents, are non-stochastic. Substituting from (3) and (1) into the expressions for expected net rents, one can eliminate the variables $t_{CR}, t_{IR}$, and $\tau_R$; netting out intergovernmental transfers, and using (18) to eliminate the variables $T_{iw}$,

$$\begin{aligned}\sum_{i=C,I} ER_i^n &= \sum_{i=C,I} R_i + \pi\left(\sum_{i=C,I} n_i T_{iw} - n_C L\right) + \sum_{i=C,I} n_i t_{iw} - z \\ &= \sum_{i=C,I} R_i + \pi\left(\sum_{i=C,I} n_i \left[f_i' - t_{iw} - K\right] - n_C L\right) + \sum_{i=C,I} n_i t_{iw} - z. \end{aligned} \tag{20}$$

The central government's *ex ante* problem can thus be written as

$$\textbf{(P.3)} \quad max_{<t_{Cw}, t_{Iw}>} W \equiv \bar{n}\left(\pi u(K) + (1-\pi)u(f_C'(n_C) - t_{Cw})\right) + \sum_{i=C,I} ER_i^n. \tag{21}$$

where $n_C = \Phi$ and $n_I = \bar{n} - \Phi$ everywhere in this expression because the *ex ante* equilibrium condition (11) must hold. Note finally from (11) that[13]

$$\frac{\partial \Phi}{\partial t_{Cw}} = \frac{1}{f_C'' + f_I''} = -\frac{\partial \Phi}{\partial t_{Iw}}. \tag{22}$$

It is now possible to characterize the optimal central government tax policies from the first-order conditions for $t_{Cw}$ and $t_{Iw}$. The objective function $W$ depends on these policies

[13]This follows because utilities, and therefore marginal utilities, are equalized across regions in both states of the world.

directly and also through their impact on the interregional allocation of workers, given by $\Phi$. In condensed form, the first-order conditions are

$$\frac{dW}{dt_{Cw}} = -\bar{n}(1-\pi)u'_C(f' - t_{Cw}) - \pi n_C + n_C + \frac{\partial W}{\partial \Phi}\frac{\partial \Phi}{\partial t_{Cw}} = 0$$
$$\frac{dW}{dt_{Iw}} = -\pi n_I + n_I + \frac{\partial W}{\partial \Phi}\frac{\partial \Phi}{\partial t_{Iw}} = 0, \tag{23}$$

where $u'_C$ denotes the expected marginal utility of income or consumption in the Coastal region. Using (22) and summing,

$$u'_C(f'_C - t_{Cw}) = 1 \iff f'_C - t_{Cw} = K \iff f'_I - t_{Iw} = K \tag{24}$$

where the first equivalence follows from (18) and the second follows from (11).

**Proposition 2:** The central government finances disaster relief in such a way that none of the costs of a disaster are borne by risk-averse households in either region, i.e., the entire cost of a disaster is financed by risk-neutral owners of immobile resources. The central government's *ex ante* tax/transfer policies insure that the net incomes of households in both regions are equal and independent of the state of nature.

Finally, how do central government policies affect the allocation of households among regions? Using (24) in either of the first-order conditions (23) and calculating explicitly the derivatives of $W$ and $\Phi$, one can show that

$$t_{Cw} - t_{Iw} = \pi L, \tag{25}$$

and hence

**Proposition 3:** The central government's optimal *ex ante* tax policy imposes a differentially heavier burden on Coastal residents, equal to their expected losses from a disaster.

Whereas Proposition 2 may be viewed as a "redistribution" result, Proposition 3 – which is another facet of the same analysis – may be viewed as an "efficiency" result. While optimal central government policies relieve risk-averse households from the variability of income associated with disaster, this insurance relief can also distort locational incentives, drawing too many residents to the Coastal region (and of course thereby raising the expected social losses from disasters). Proposition 3 states that the central government, while insuring households from disaster-related losses, also creates fiscal incentives to limit the amount of settlement in the Coastal region to an efficient amount. To do this, it applies differential fiscal policies to residents of each region, either by subsidizing Inland residents relative to those in the Coastal region, or by taxing the latter more heavily relative to the former.

If one imposes the constraint that the central government must apply equal fiscal treatment to the residents of both regions, i.e., that $t_{Cw} = t_{Iw}$, then full insurance of disaster risk in the Coastal region is no longer optimal, unless some other policy instruments, such as regulatory controls, can be used to limit the size of the population in the Coastal region. As already noted above (see Prop. 1), the regional government has no incentive to impose such controls. The potential use of such controls by the central government, which raises questions about "mandates" and subnational government autonomy, is discussed further below.[14]

# 4 Intergovernmental Fiscal and Regulatory Relations

The preceding results have all been derived taking as given the expenditure policies – specifically, the amount of disaster avoidance expenditures $z$ – of the regional government, as well as the intergovernmental transfers of the central government. These results therefore provide valid characterizations of the tax policies of each level of government whether or not Coastal disaster avoidance expenditures have been optimized. Let us now turn to the choice of $z$.

Assume that the Coastal government chooses its expenditure policy $z$ so as to maximize net land rents, subject to its budget constraint (1), taking as given the expected utility of mobile households, (12) and the vector $\beta$ of central government policies. Because central government policies equalize utilities across states of nature, the choice of $z$, which affects the probability of disaster, has no effect on the equilibrium allocation of residents among regions because utilities are equalized across states of nature.[15] An increase in $z$ therefore does not affect local gross land rents $f_C - \phi(\cdot) f'_C$ and thus only affects local net land rents through its impact on the local tax on landowners which, by (1), is given by $(1-\mu)z - \lambda$. This means that a one-unit increase in $z$ always depresses net land rents by the amount $1 - \mu$. Hence,

**Proposition 4:** The regional government has no incentive to incur any costs for the provision of public goods and services that reduce the probability of disaster, i.e., the level of $z$ chosen by the regional government is 0, even if the central government subsidizes

[14]The possibility that central government disaster relief may result in excessive development of the Coast has been widely recognized. As discussed, e.g., by Pielke et al. (2008), it seems clear that economic development of US coastal regions during the past century has played a major role in increased disaster losses. As Albouy (2009) notes, Federal tax policies may also contribute to such development trends, which may be either augmented or diminished by other central government policies, including agricultural, transportation, and trade policies. Whether increased twentieth-century US coastal development has been economically inefficient, even taking possibly excessive disaster losses and tax distortions into account, is not easily gauged, given the high productivity and amenity attractions (see, e.g., Albouy (2010)) of coastal regions.

[15]Differentiating (12) with respect to $z$ yields $\pi' \left[u(f'_C[\cdot] - \tau_n - t_{Cw} - T_{Cw}) - u(f'_C[\cdot] - \tau_n - t_{Cw})\right]$ which, by (24), is equal to 0. Hence $\partial\phi/\partial z = 0$.

local expenditures at any rate up to 100%.

This stark result highlights the interplay of incentives between central and regional government policies. Given that the central government follows policies that redistribute incomes among mobile households and that achieve an efficient allocation of households among regions, there is no "local" benefit from incurring costs in order to reduce the probability of disaster. In the absence of central government policies, of course, the local incentives could be very different, but given the (assumedly) unavoidably "benevolent" actions of the central government, there is no local payoff from disaster avoidance, i.e., there is moral hazard. Note that this is true even if the central government finances some or even very much of the cost of disaster avoidance.

Obviously, the regional government policy of setting $z = 0$ is not generally efficient. Given that the central government pursues optimal tax-transfer policies as described in the preceding section, is it easy to see that the socially-efficient choice of $z$ is to set $z$ at a level $z^*$ such that the marginal expected reduction in disaster losses is equal to one, i.e.

$$-n_C \left(\pi'[z^*]L[z^*] + \pi[z^*]L'[z^*]\right) = 1 \tag{26}$$

where $n_C$ is evaluated at its equilibrium level. Provided that $-n_C \left(\pi'[0]L[0] - \pi[0]L'[0]\right) > 1$, that is, provided that the first units of effort in disaster avoidance produce positive net expected benefits, efficiency requires a positive level of disaster avoidance and preparedness expenditures.

With the policy instruments postulated so far, there is no means by which the central government can induce the desired level of *ex ante* expenditures by the regional government. In particular, neither lump-sum nor matching grants affect regional government spending on $z$. This does not mean that these policies have no effect on regional welfare, of course. In particular, as noted in the proof of Prop. 4, Coastal net land rents are strictly increasing in the level of transfers received from the central government. Lump-sum grants are thus desirable from the local perspective and, if $z$ were somehow exogenously fixed at a positive value, an increase in matching grants would also benefit Coastal landowners by shifting some of the burden of local expenditures to the central government. From the perspective of central government policymaking, however, it is clear that simple lump-sum or matching grants alone are of distinctly limited usefulness in eliciting subnational government avoidance efforts.

If the central government is permitted to regulate the level of regional government preparedness, it could in principle simply require the regional government to set the efficient of *ex ante* disaster expenditures $z^*$. If initially $\lambda = \mu = 0$, the cost of this "unfunded mandate" falls entirely on local landowners in the Coastal region, while producing no benefit for them. If $\mu > 0$, then the burden on local landowners resulting from mandated regional government spending is the unmatched or "local effort" portion of that spending, $(1-\mu)z^*$. In terms of the political economy of intergovernmental fiscal relations, the

regional government authorities should be expected to oppose any mandated expenditures that are not fully funded with transfers from the central government. Alternatively, one could imagine a "package" or contract in which the regional government provides a mandated level of disaster expenditures, say $z^*$, and in which the central government offers a package of compensation, in the form of some combination of lump-sum and matching grants, such that $\lambda + \mu z^* \geq z^*$. In this case, the regional government has no incentive to oppose the mandated expenditures, which are then fully financed by the central government. Note that matching grants would play no special role in such a "policy package": what matters is that local rent recipients are compensated for the provision of a specified level of services required by the national government. The "relative price" effect of matching grants are irrelevant, and a lump-sum grant $\lambda = z^*$ provides a sufficient instrument for the national government to "purchase" the acquiescence of local interests to the national mandate.

Of course, to the extent that the regional government can lobby for more intergovernmental transfers, it has an incentive to do so, irrespective of any use of funds for disaster preparedness. Furthermore, upon receiving grant funds "for the purpose" of financing disaster preparedness, the regional government has no incentive to use the funds for that purpose; indeed, the payoff to local interests from these funds is enhanced, to the extent that they can be transferred directly or indirectly to those interests rather than being used to finance disaster avoidance and preparedness, since, as noted, local disaster avoidance efforts do not enhance the welfare of local owners of immobile resources. Note that these incentives all arise from the underlying structure of central government disaster relief and from the *ex ante* and *ex post* revenue structures chosen by both the regional and central governments.

Finally, a brief comment is in order regarding the role of "land" in the preceding analysis. Land, as an immobile resource, plays a crucial role in equilibrating the spatial equilibrium of the economy; it is what prevents corner solutions in which either Inland or Coast is uninhabited. Similarly, landowners play a crucial role as claimants of the rents that accrue to their immobile resource, to whose interests local policymakers respond in choosing local fiscal and disaster avoidance policies. Other fixed resources and their owners, including labor, could also play these roles in the model, merely by relabeling, although significant labor and capital mobility must be assumed in any analysis that seeks to focus attention on the issue of regional development in an economy with unevenly distributed disaster risks.

# 5 Conclusion

The problem of disaster response and preparedness presents challenging problems for the public sector in a federal system like that of the US. The natural and perhaps irresistible imperative to provide *ex post* relief to disaster victims, a fundamental building block of the model developed above, creates potential incentive problems from an *ex ante* perspective. These incentives can affect the behavior of both private economic agents and of the subnational governments which are traditionally called upon to play important roles in disaster avoidance, preparedness, relief, and recovery. The recent hurricane disasters along the US Gulf Coast have brought renewed attention to these issues, which of course arise not only in the context of weather-related disasters but also in connection with geological catastrophes (earthquakes, volcanic eruptions, tsunamis) and man-made disasters such as terrorism.

The preceding analysis has examined the incentives that arise from decentralized locational choices made by individual households and decentralized disaster avoidance policies chosen by subnational governments, in an economy where these decisions are made in advance of the realization of a potential region-specific disaster. The interplay of policymaking between the central and the subnational governments creates potential adverse incentives for inefficient behavior. The central government may be able to obviate inefficient locational choices by households through the use of regionally-differentiated fiscal policies that, in effect, shift the burden of *ex post* disaster relief to mobile households who decide to locate in a disaster-prone region in the form of *ex ante* fiscal burdens that can be interpreted as a form of insurance premium. However, the problem of efficient subnational government decisionmaking remains – and arises, in a stark form, in this stylized model, in which regional governments elect not to devote their fiscal resources to the *ex ante* financing of disaster avoidance and preparedness. They fail to do so, even if their expenditures are supported by fiscal transfers from the central government. Faced with inefficient decisionmaking by subnational authorities, the central government may attempt to "mandate" more efficient disaster preparedness at the regional government level. If less than fully funded, the regional government has incentives to oppose such mandates. Even if fully funded, the regional government has incentives to use fiscal transfers for other purposes, giving rise to monitoring and enforcement issues in the implementation of the intergovernmental "contract" that go beyond the scope of the present analysis.

In conclusion, it is worth highlighting the practical importance of finding suitable incentives for efficient disaster avoidance policies. Aside from dealing with such disasters as have customarily occurred in the past, the prospect of rising sea levels associated with global warming brings with it an increased risk of coastal flooding throughout the world. As discussed in Stern (2007, 76), for instance, approximately 200 million people around

the world live in coastal floodplains and about $1 trillion in assets are at less than 1 m elevation above sea level and (p. 81) approximately 270 million people and $2 trillion worth of GDP would be threatened by a 5 m rise in sea level. Nordhaus (2006, 19) notes, however, that "[e]stimating the cost of climate change requires considering adaptations to changing conditions" such as "greater setbacks from shoreline, retreat from vulnerable areas, abandonment of damaged areas after damaging storms, and higher or improved coastal protection." The risk from rising sea levels "depends primarily on capital mobility, which in turn depends upon the type of capital (compare airplanes with ports), the depreciation rate (compare houses with computers), as well as coordination factors and political boundaries (such as the location of cities, building codes, and national boundaries)." (p. 18) Note that subnational governments, including particularly local governments, have traditionally played decisive roles in determining the location and density of residential property (housing), transportation infrastructure (including ports), setbacks from shoreline and other floodplain development controls, building codes, and so forth. (See Fischel (2001) for extensive discussion of local land use controls and planning.) Should rising sea levels threaten the world's coastal floodplains, will local governments, perhaps aided by higher level governments, facilitate or impede efficient adaptations to increased flood risks? What institutional arrangements could improve the efficiency of these adaptations? Taking the experience of the Gulf Coast flooding as an illustration, do existing institutions seem to produce efficient or inefficient outcomes?[16]

In the search for institutional structures that provide not only *ex post* relief for disasters, when they occur, but *ex ante* incentives for efficient decisionmaking that can limit the extent and probability of disasters, the incentives of private and public agents cannot be wished away. The preceding analysis has highlighted some of the ways in which these incentives can interact in the necessarily complex structure of a federal system of government that sets policies affecting private-sector decisionmakers. No doubt not every feature of the results of this analysis would be robust to changes in the specification of the underlying model, but the analysis demonstrates how perverse incentives can arise in a multi-level, multi-stage decisionmaking context such as that is observed in practice in the US and in other countries with federal governance structures. There is obviously extensive scope for further systematic investigation of these issues which, it is to be hoped, may contribute to a more complete understanding of institutional structures and perhaps even to better institutional and policy outcomes. One possibility that may be worth further study is a requirement that state governments establish *ex ante* disaster reserves, a credible device that establishes rewards for costly precautionary efforts by subnational authorities. The comparative costs for different states under such a program

[16]Of course, it may be a mistake to attempt to draw far-reaching conclusions from the experience of the single event of Hurricane Katrina. On the other hand, this one disaster empirically dominates all other floods, taken together, during the past half century for which disaster loss data are available. As discussed in actuarial and other literature, the distributions of storm loss damages are heavy tailed, and, from an empirical viewpoint, disaster policy must mainly be assessed with reference to very rare but extremely large disasters. See, e.g., Rootzen and Tajvidi (1997), Schirmacher *et al.* (2005), and Wildasin (2008) for further analysis and discussion of the importance of extreme events in disaster losses.

are discussed further in Wildasin (2007).

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