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ON THE OPTIMAL DESIGN OF DISASTER INSURANCE IN A FEDERATION*

Timothy J. Goodspeed, Andrew F. Haughwout

ABSTRACT: Recent experience with disasters and terrorist attacks in the US indicates that state and local governments rely on the federal sector for support after disasters occur. But these same governments are responsible for investing in infrastructure designed to reduce vulnerability to natural and man-made hazards. This division of responsibilities – regional governments providing protection from disasters and federal government providing insurance against their occurrence – leads to the tensions that are at the heart of our analysis. We show that when the federal government is committed to full insurance against disasters, regions will have incentives to under-invest in costly protective measures. We derive the structure of the optimal second-best insurance system when regional governments choose investment levels non-cooperatively and the central government cannot verify regional investment choices. Normally (though not always) this will result in lower intergovernmental transfers and greater investment. However, the second-best transfer scheme suffers from a time-inconsistency problem. Ex-post, the central government will be driven towards equalizing rather than the second-best grants, which results in a type of soft budget constraint problem. Sub-national governments will anticipate this and reduce their investment in protective infrastructure even further. We discuss these results in light of recent disaster policy outcomes in the US.

JEL Codes: H, H7, R5, Q5

Keywords: insurance, disasters, federalism, transfers, grants

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I. Introduction

Chaos in New Orleans in the wake of Hurricane Katrina and the controversy that continues to swirl around the public sector response have led to a broad discussion of the appropriate roles of various levels of government in disaster management and preparedness. A central theme in press and pundit accounts of what went wrong in New Orleans was conflict between those who argued that the disaster was attributable to local officials' failure to adequately prepare for an easily predictable set of events and those who blamed a slow and inadequate response by federal officials (Walter and Kettl 2006).

While recent events have brought these questions to the forefront of public debate, many of the same issues have arisen in previous disasters, including the earthquakes, hurricanes and floods that irregularly strike particular geographic areas of the US. Clearly, a combination of preparedness and effective response are crucial to minimizing the overall welfare losses from these region-specific shocks. Yet policy design must confront a tradeoff between efficiently allocating resources ex-ante to minimize potential losses, and dealing equitably with residents of regions that experience significant losses ex-post. This tradeoff and its implications for the design of public disaster insurance are the subject of the current study.

The problem of the public sector's role in preparing for and responding to disasters has been the subject of considerable recent scholarly interest. In part, this work has stemmed from a belief that natural hazards have increased in their frequency and intensity in recent years, a belief that appears to be largely consistent with at least a cursory review of the data on disaster declarations in the US.[1] In addition to their increased frequency, Richard Zeckhauser (2006) has argued that the distribution of disaster losses exhibits "fat tails" – losses experienced in the worst disasters are many times those experienced in the second worst – implying that the most serious events may be expected to be extraordinarily costly.[2]

Our paper is related to several strands of literature. The existence of natural hazards produces risks to income flows in particular places. One strand examines the role that federalist institutions can play in insuring residents of a federation against income loss (von Hagen 2007 provides a useful review). When shocks to regional incomes are imperfectly correlated, an insurance contract can be derived that transfers resources from regions that realize high income to those that sustain a negative shock. One example is when regional business cycles are not completely in phase. In such circumstances, a policy institution that provides a transfer to regions with strong growth fundamentals that are experiencing a downturn can enhance both aggregate stability and equity (see, for example, Bayoumi and Masson 1995). An empirical literature has sought to quantify the actual size of such transfers, an effort which is complicated by correlations in shocks across regions, by difficulty in distinguishing temporary from permanent shocks, and by the distinction between aggregate income and aggregate output. Melitz and Zumer (2002) summarize previous results and provide a well-founded

[1] See, for example, data on Presidentially declared disasters on the Federal Emergency Management Agency website http://www.fema.gov/news/disaster_totals_annual.fema; last accessed June 5, 2007. Note, however, that these declarations reflect losses, which are jointly determined by hazards and vulnerability.

[2] When the subject is broadened to include potential losses from terrorism - disasters planned and executed by intelligent opponents as compared to a relatively passive natural environment - the complexity and need for serious attention become even more pronounced.

estimate that central government redistribution offsets about 10 to 20 percent of shocks to personal income in four countries.[3] Within economically developed federations, central government insurance is thus an important resource for regions experiencing negative shocks.

A second strand emphasizes asymmetric information and the moral hazard aspects of intranational insurance as in Persson and Tabellini (1996).[4] We adapt many features of Persson and Tabellini's (1996) model to the study of natural disasters. Persson and Tabellini study the institutions of federalism in an economy characterized by uncertainty about future income in distinct regions of a federation, a situation that well describes the natural disaster setting. Like Persson and Tabellini, we abstract from household mobility and focus on sub-central governments. This focus does not imply that mobility is an unimportant feature of disasters. Indeed, location choice is a fundamental part of the process that determines vulnerability and is relevant to designing appropriate disaster response. Nonetheless, while residents may choose to relocate either before or after a disaster strikes, sub-central governments are usually defined by particular geographic areas and are thus fixed in place. We thus interpret our model as shedding light on the interplay between disaster risk and the institutions of federalism, not on the relationship between a central government and individuals. The latter interaction is considered by Kunreuther's (2006) work on public disaster insurance for individual households and firms and Wildasin's (2008b) work on federal disaster insurance with mobile households.

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[3] France, the UK, the US and Canada

[4] Other papers that study various aspects of asymmetric information and insurance in a federation include Bordignon, Manasse, and Tabellini (2001), Caplan, Cornes, and Silva (2000), Raff and Wilson (1997), and Lockwood (1999).

A third strand of literature relates to "second generation" models of federalism as reviewed by Oates (2005) for instance. This emerging literature is often characterized by models in which information, politics, and strategic decisions play important roles. Information problems, strategic interaction, and the objective of the central government are at the heart of our analysis, so our paper is also a contribution to this emerging body of literature.

Hazards policy in the United States is a complex interplay between the federal and state-local sectors. Broadly speaking, state and local officials bear primary responsibility for minimizing vulnerability to natural hazards through policies such as land use regulation, investment in protective infrastructure and providing resources designed to enhance emergency response.

While the federal government is involved in these activities to a limited extent (Corps of Engineers flood control grants are a prominent example), the bulk of federal resources are devoted to providing assistance to individuals and governments after disasters occur. Between fiscal years 1974 and 2005, Presidents declared over 1,200 disasters in the United States, and the federal government appropriated over 80 billion constant FY 2005 dollars for disaster relief. As indicated in Chart 1, as the annual number of declared disasters has risen, the average cost per year has risen above $3 billion.

While much of this relief was provided to individuals and businesses, a substantial portion takes the form of grants-in-aid to state and local governments.[5] Since 1998, the Federal Emergency Management Agency (FEMA) has obligated an average of over $2 billion per year to public sector disaster assistance. Roughly three quarters of

[5] The federal response to disasters may also include less obvious kinds of relief, like relaxation of standards for poverty relief. See (Chernick 2001).

these expenditures have been designated for ex post emergency response and repair of public facilities.[6] This division of responsibilities – sub-national (regional) governments providing protection from disasters and federal government providing insurance against their occurrence – leads to the tensions that are at the heart of our analysis.

First, when the federal government is committed to full insurance against disasters, regions will have incentives to under-invest in protective infrastructure in a Nash equilibrium. A second-best transfer scheme can be derived that reduces the under-investment problem, but the second-best transfer scheme suffers from a time-inconsistency problem. This highlights a second tension which is manifested in the timing of insurance commitments by the federal government. As indicated in Chart 1, more than half of the federal funds provided for disaster relief since 1990 have been the result of ex-post supplemental appropriations. That is, Congress has elected to appropriate large amounts of additional federal compensation to victims *after disasters occur*, raising questions the federal government's ability to commit to any second-best transfer scheme.[7]

The paper is organized as follows. Section II describes the economy we study, and lays out the basic model of federalism with uncertain incomes. In this section we also derive the optimal insurance scheme and level of investment in protective infrastructure for the federation. In section III, we derive non-cooperative regional investment levels for any transfer scheme and demonstrate that when individual regions act non-cooperatively, they will under-invest relative to the first-best optimum. In section IV, we

[6] These figures exclude the response to the September 11, 2001 terrorist attack. That event alone resulted in a $7 billion Congressional appropriation.
[7] Wildasin (2007, 2008a) suggests a mandatory disaster reserve fund as one possible solution to this problem.

derive the structure of the optimal second-best insurance system when regional governments choose investment levels non-cooperatively and the central government cannot verify regional investment choices. Second-best transfer levels will normally be less than the first-best for disasters (and the corresponding non-cooperative investment levels greater), but there is a surprising possibility that results in greater second-best transfers (and smaller investment levels) when the probability of a disaster is not too remote and the damage not too great. Section V shows that the central government will be unable to commit to the second-best transfer levels, and will instead opt for equalizing transfers ex-post; this leads to a type of soft budget constraint. Regions will anticipate the central government action, and their exploitation of this knowledge will result in even further under-investment in protective infrastructure in the Nash equilibrium. Section VI concludes with a discussion of what the model can teach us about the federal response to recent disasters and those yet to come.

II. First-Best Transfers and Regional Investment

We begin with a simple model of a federation with two regional governments that are completely symmetric. To differentiate the two regions, variables for one of the regions are denoted with asterisks. Each region has certain income in period 1 and uncertain income in period 2. The uncertainty results from i.i.d. shocks. Uncertain income can be high with probability P or low with probability (1 – P). A region can use some of its period 1 certain income ($\bar{Y} = \bar{Y}^*$) to invest in protective infrastructure, I, (e.g. levies or first responder training), leaving it with Y = $\bar{Y}$ - I (or analogously Y* = $\bar{Y}^*$ - I) period 1 income. This investment increases the probability of ending up with high income, so P is a function of I. There are thus four joint possibilities for uncertain income:

i. (Y_H, Y^*_H) with probability P(I)P(I*)

ii. (Y_H, Y^*_L) with probability P(I)(1-P(I*))

iii. (Y_L, Y^*_H) with probability (1-P(I))P(I*)

iv. (Y_L, Y^*_L) with probability (1-P(I))(1-P(I*))

While we differentiate the regions by use of the asterisk, it should be clear that our assumption of symmetry implies that each variable has the same value for the starred and unstarred region (e.g. $Y_H = Y^*_H$; P(I) = P(I*); and so forth). As mentioned above, the first derivative of P(I) is positive, P'(I) > 0. We also assume the second derivative is negative, P''(I) < 0, i.e. we assume diminishing returns in production of protection. This seems an intuitively appealing assumption. For instance, making a levee wider always reduces the probability that it will fail, but adding a foot to a two-foot wide levee adds more protection from failure than adding the same amount to one that is ten feet wide.

For most of the paper, we model a three step decision process. In stage one, the central government commits to a transfer scheme. In the second stage, regional governments choose an investment level in light of the announced transfer scheme. Once investments are in place, the state of nature is revealed (disasters, if any, occur), incomes are realized and the transfers committed to in the first stage are made. In the final part of the paper we examine the dynamic consistency of the central government's first-stage transfer commitment by adding an additional stage where the central government may choose to revisit its transfer scheme ex-post.

First-best optimal transfers for given investment levels

Regions are assumed to be risk averse and risk sharing in the federation is accomplished through a set of self-funding transfers (i.e. the amount paid by one region is the amount received by the other). The central government wants to choose transfers for each (joint) state of nature $\{T_{HH}, T_{HL}, T_{LH}, T_{LL}\}$ where the first subscript refers to the state of nature of the unstarred region and the second subscript stands for the state of nature of the starred region. The central government's objective is to maximize the sum of expected utilities:

$$
\begin{aligned}
(1) \qquad & \underset{\{T_{HH}, T_{HL}, T_{LH}, T_{LL}\}}{\text{Max}} \; v(\bar{Y} - I) + v(\bar{Y}^* - I^*) \\
& + P(I)P(I^*)u(Y_H + T_{HH}) \\
& + P(I)(1 - P(I^*)u(Y_H - T_{HL}) \\
& + (1 - P(I))P(I^*)\, u(Y_L + T_{LH}) \\
& + (1 - P(I))(1 - P(I^*))\, u(Y_L + T_{LL}) \\
& + P(I)P(I^*)u(Y^*_H - T_{HH}) \\
& + P(I)(1 - P(I^*)u(Y^*_L + T_{HL}) \\
& + (1 - P(I))P(I^*)\, u(Y^*_H - T_{LH}) \\
& + (1 - P(I))(1 - P(I^*))\, u(Y^*_L - T_{LL})
\end{aligned}
$$

where we assume that period 1 and period 2 utility are additively separable. This yields the set of first-order conditions:

$$
(2) \qquad \frac{\partial u(Y_r + T_{rs})}{\partial T_{rs}} = \frac{\partial u^*(Y^*_s - T_{rs})}{\partial T_{rs}} \quad r, s \in (L, H)
$$

where u* henceforth denotes utility given the value of the starred region's arguments. This set of first order conditions say that transfers should be set to equalize the marginal utility of transfers, or equivalently the marginal utility of income, across the two regions. Given declining marginal utilities, this implies that after-transfer incomes should be equalized for all states of nature. Hence, optimal transfers for a given regional investment level in the first-best results in full risk-sharing. For cases (i) and (iv) above no transfers occur since incomes are already equal. For cases (ii) and (iii), income is transferred from the region that realizes high income to the one that realizes low income. Figure 1 illustrates the optimal first-best transfer for case (ii) above - (Y_H, Y^*_L).

First-best regional investment levels

Now consider the level of regional investment that maximizes the sum of expected utilities. Here there is no information problem since the central government is able to choose investment levels directly. In this case, the first-best optimal investment solves:

$$
\begin{aligned}
&\operatorname*{Max}_{I,I^*} v(\bar{Y}-I)+v(\bar{Y}^*-I^*)\\
&+P(I)P(I^*)u(Y_H+T_{HH})\\
&+P(I)(1-P(I^*)u(Y_H-T_{HL})\\
&+(1-P(I))P(I^*)\,u(Y_L+T_{LH})\\
(3)\qquad &+(1-P(I))(1-P(I^*))\,u(Y_L+T_{LL})\\
&+P(I)P(I^*)u(Y^*_H-T_{HH})\\
&+P(I)(1-P(I^*)u(Y^*_L+T_{HL})\\
&+(1-P(I))P(I^*)\,u(Y^*_H-T_{LH})\\
&+(1-P(I))(1-P(I^*))\,u(Y^*_L-T_{LL})
\end{aligned}
$$

The FOC with respect to I is:

$$
\begin{aligned}
&\frac{\partial P}{\partial I}\left[P^*\{u(Y_H)+u(Y_H^*)\}-(1-P^*)\{u(Y_L)+u(Y_L^*)\}\right]\\
(4)\qquad &+\frac{\partial P}{\partial I}(1-P^*)\left[\{u(Y_H-T_{HL})\}+\{u(Y^*_L+T_{HL})\}\right]\\
&-\frac{\partial P}{\partial I}P^*\left[\{u(Y_L+T_{LH})\}+\{u(Y^*_H-T_{LH})\}\right]=\frac{\partial v}{\partial Y}
\end{aligned}
$$

where we use the fact that $T_{HH} = T_{LL} = 0$. Analogously, the FOC with respect to I* is:

$$(4^*)\qquad \begin{aligned} &\frac{\partial P^*}{\partial I^*}\left[P\{u(Y_H)+u(Y_H{}^*)\}-(1-P)\{u(Y_L)+u(Y_L{}^*)\}\right] \\ &+\frac{\partial P^*}{\partial I^*}(1-P)\left[\{u(Y^*_H-T_{LH})\}+\{u(Y_L+T_{LH})\}\right] \\ &-\frac{\partial P^*}{\partial I^*}P\left[\{u(Y_L{}^*+T_{HL})\}+\{u(Y_H-T_{HL})\}\right]=\frac{\partial v^*}{\partial Y^*} \end{aligned}$$

With symmetric regions and transfers that exhibit full risk-sharing as derived above (4) reduces to:

$$(5)\qquad 2\frac{\partial P}{\partial I}P^*\left[u(Y_H)-u(Y_L+T_{LH})\right]-2\frac{\partial P}{\partial I}(1-P^*)\left[u(Y_L)-u(Y_H-T_{HL})\right]=\frac{\partial v}{\partial Y}$$

Analogously, (4*) reduces to:

$$(5^*)\quad 2\frac{\partial P^*}{\partial I^*}P\left[u(Y_H{}^*)-u(Y_L{}^*+T_{HL})\right]-2\frac{\partial P^*}{\partial I^*}(1-P)\left[u(Y_L{}^*)-u(Y_H{}^*-T_{LH})\right]=\frac{\partial v^*}{\partial Y^*}$$

Note that the implicit first-best optimal investment level for I depends on I* (through P*) and vice-versa; moreover, given the assumed symmetry, the first order conditions are identical so optimal first-best investment levels I and I* must be identical. Note also that if there were no transfers the first order condition (5) would not depend on I* and would reduce to:

$$(6)\qquad 2\frac{\partial P}{\partial I}\left[u(Y_H)-u(Y_L)\right]=\frac{\partial v}{\partial Y}$$

and analogously for (5*). The presence of the transfers has inserted an externality into the problem because they make it so that one region's investment affects the utility of the other region.

III. Non-cooperative Regional Investment

We now want to explore the Nash equilibrium investment levels of the two regions as they act non-cooperatively. From here on we will use the symmetry of regions to economize on notation. Symmetry implies that transfers paid by each region when it has high income and the other region has low income are the same ($T_{HL} = T_{LH}$) so we henceforth simplify by letting $T = T_{HL} = T_{LH.}$ The unstarred region's optimal choice of protective investment will solve the following problem:

$$
\begin{aligned}
&\underset{I}{\text{Max}}\ v(\overline{Y} - I) \\
&+ P(I)P(I^*)u(Y_H) \\
(7)\qquad &+ P(I)(1 - P(I^*)u(Y_H - T) \\
&+ (1 - P(I))P(I^*)\, u(Y_L + T) \\
&+ (1 - P(I))(1 - P(I^*))\, u(Y_L)
\end{aligned}
$$

The first order condition, which defines the reaction function for the unstarred region, is:

$$(8)\quad P'(I)P(I^*)\left[u(Y_H) - u(Y_L + T)\right] - P'(I)(1 - P(I^*))\left[u(Y_L) - u(Y_H - T)\right] = v_Y$$

The level of investment of the unstarred region depends on the level of investment of the starred region because of P(I*). To derive the slope of the reaction function, write the reaction function defined by (8) in implicit form, $\phi(I, I^*, T) = 0$. Using the implicit function theorem, the slope of the reaction function for the unstarred region is:

$$(9)\quad \frac{dI}{dI^*} = -\frac{\phi_{I^*}}{\phi_I}$$

Assuming that $Y_H > Y_L + T$, i.e. that the transfer cannot make the region hit by a negative shock have more income than it would have received had it gotten a positive shock, the sign of ϕ_I is negative:

$$(10)\ \phi_I = P''(I)P(I^*)\left[u(Y_H) - u(Y_L + T)\right] - P''(I)(1 - P(I^*))\left[u(Y_L) - u(Y_H - T)\right] < 0$$

Given that $Y_H > Y_L + T$, the first term in brackets is positive and since P''(I) is negative the entire first term must be negative. The second term in brackets must be negative given that $Y_H – T > Y_L$ and since P''(I) is negative (and is multiplied by -1), the entire second term must also be negative. Hence, $\phi_I < 0$. Concavity of the utility function (i.e. risk aversion) implies that ϕ_{I^*} is negative. To see this, note that ϕ_{I^*} is:

$$(11) \quad \phi_{I^*} = P'(I)P'(I^*)\left[u(Y_H) - u(Y_L + T)\right] - P'(I)(-P'(I^*))\left[u(Y_L) - u(Y_H - T)\right]$$
$$= P'(I)P'(I^*)[u(Y_H) + u(Y_L) - u(Y_L + T) - u(Y_H - T)]$$

Since $T < Y_H - Y_L$,we can write T as $\alpha(Y_H - Y_L)$ where $0<\alpha<1$. Hence,

$$(11') \quad \phi_{I^*} = P'(I)P'(I^*)[u(Y_H) + u(Y_L) - u(Y_L + \alpha(Y_H - Y_L)) - u(Y_H - \alpha(Y_H - Y_L))]$$
$$= P'(I)P'(I^*)[u(Y_H) + u(Y_L) - u(Y_L(1-\alpha) + \alpha Y_H) - u(Y_H(1-\alpha) + \alpha Y_L)]$$

Adding and subtracting $\alpha u(Y_H)$ and $\alpha u(Y_L)$ yields:

$$(11'') \quad \phi_{I^*} = P'(I)P'(I^*)[\alpha u(Y_H) + (1-\alpha)u(Y_H) + \alpha u(Y_L) + (1-\alpha)u(Y_L)$$
$$-u(Y_L(1-\alpha) + \alpha Y_H) - u(Y_H(1-\alpha) + \alpha Y_L)]$$

The definition of concavity states $\alpha u(Y_H)+ (1-\alpha)u(Y_L)< u(\alpha Y_H+ (1-\alpha)Y_L)$ and $\alpha u(Y_L)+ (1-\alpha)u(Y_H)< u(\alpha Y_L+ (1-\alpha)Y_H)$. Hence, $\phi_{I^*} < 0$ and the slope of the reaction function is therefore negative.

An intuitive description of (8) is as follows. The right hand side of (8) represents the direct marginal cost of greater investment which results in lower period 1 certain income and consumption. The left hand side represents the marginal expected increase in period 2 utility resulting from the fact that an increase in investment increases the probability of ending up with Y_H and decreases the probability of ending up with Y_L. Comparing to the first order conditions from the first-best problem, these are the same except that the two left hand side terms are multiplied by two in (5). This is because one region's investment decision affects the probability of ending up in each of the four joint income possibilities. The region takes into account the effect of its investment on its own utility, but does not take into account the effect on the utility of the other region. In other words, region 2 benefits from an increase in region 1's probability of ending up with Y_H (holding region 2's probabilities constant). Region 1 ignores this benefit in its investment decision and invests too little in protective infrastructure from a social point of view.

Given the smooth concavity of the objective function, the reaction functions are continuous. To make sure that the reaction functions intersect, we impose the condition that when a region's investment is zero, the marginal benefit of investment for that region is greater than the marginal cost. As is well know, a sufficient condition for the resulting Nash equilibrium to be asymptotically stable relates to the slopes of the reaction functions, and in particular that the absolute value of the slope is less than 1. This requires $\phi_{I*} < \phi_I$ which, using the above derivatives, requires

$$(12) \quad P'(I)P'(I^*)[u(Y_H)+u(Y_L)-u(Y_L+T)-u(Y_H-T)]$$
$$< P''(I)P(I^*)\left[u(Y_H)-u(Y_L+T)\right]-P''(I)(1-P(I^*))\left[u(Y_L)-u(Y_H-T)\right]$$
$$= P''(I)P(I^*)[u(Y_H)+u(Y_L)(1-\frac{1}{P(I^*)})-u(Y_L+T)-u(Y_H-T)(1-\frac{1}{P(I^*)})]$$

Since $Y_H - T > Y_L$ and $P(I^*)<1$, the bracketed term in the third line associated with ϕ_I is greater than the bracketed term in the first line associated with ϕ_{I*}. Hence, what is needed to ensure asymptotic stability is that the absolute value of P''(I)P(I*) is not too small relative to P'(I)P'(I*). There are various ways of interpreting this, but the essential requirement is that the reaction function I(T, I*) plotted in Figure 2 needs to intersect the reaction function I*(T, I) from below. That is, the derivative of P(I) cannot diminish too rapidly.   An alternative way to express this is that disaster is a low frequency, high cost event with investment having a relatively small expected payoff so that P(I*) is large, P'(I) and P'(I*) are smallish, and P''(I) is small but greater in absolute value than P'(I)P'(I*)/P(I*).

Analogously to (8) above, the first order condition for the starred region is:

$$(8^*)\ \frac{\partial P^*}{\partial I^*}P(I)\left[u(Y^*_H\ )-u(Y^*_L\ +T\ \ )\right]-\frac{\partial P^*}{\partial I^*}(1-P(I))\left[u(Y^*_L\ )-u(Y^*_H\ -T\ \ )\right]=\frac{\partial v^*}{\partial Y^*}$$

Solving (8*) for I* would yield the reaction function of the starred region, I*(T,I). The symmetry of the problem implies that the two reaction functions are also symmetric. Hence, the reaction function for the starred region is also a downward sloping function of I and the Nash equilibrium levels of investment (I(T), I*(T)) that simultaneously solve these two first order conditions would be identical for each region; we denote this Nash equilibrium investment level as I(T)=I*(T). Figure 2 shows the Nash equilibrium graphically.

To summarize, the central government can offer full risk-sharing, which would be first-best optimal if the central government could also choose regional investment levels. However, if regions choose their own investment levels while the central government offers full risk-sharing transfers, regions acting non-cooperatively will underinvest in protective infrastructure.

IV. Second-Best Transfers

We have thus far shown that if the central government commits and offers first-best optimal transfers with full risk-sharing while regions choose their investment levels and act non-cooperatively, regions will tend to underinvest in protective infrastructure from a national perspective. Thus, first-best investment and first-best risk-sharing transfers cannot both be achieved under these circumstances. We next consider whether the central government can design a second-best transfer system that would achieve higher overall welfare.

As before we assume that the central government's problem is to choose T to maximize the sum of expected utilities. However, now the central government is assumed to know the reaction functions and Nash equilibrium investment choices I(T) = I*(T) so it recognizes that regions' investment choices will depend on the transfer they receive. In this case, the second-best transfers solve:

$$
\begin{aligned}
&\operatorname*{Max}_T \; v(\bar{Y} - I(T)) + v(\bar{Y}^* - I^*(T)) \\
&+ P(I(T))P(I^*(T))u(Y_H) \\
&+ P(I(T))(1 - P(I^*(T))u(Y_H - T) \\
&+ (1 - P(I(T)))P(I^*(T))\, u(Y_L + T) \\
(13) \qquad &+ (1 - P(I(T)))(1 - P(I^*(T)))\, u(Y_L) \\
&+ P(I(T))P(I^*(T))u(Y^*_H) \\
&+ P(I(T))(1 - P(I^*(T))u(Y^*_L + T) \\
&+ (1 - P(I(T)))P(I^*(T))\, u(Y^*_H - T) \\
&+ (1 - P(I(T)))(1 - P(I^*(T)))\, u(Y^*_L)
\end{aligned}
$$

where I(T) = I*(T) are the Nash equilibrium investment levels and the FOC for T is:

$$
\begin{aligned}
&(14.0) && P(1-P^*)\frac{\partial u(Y_H - T)}{\partial T} = (1-P^*)P\frac{\partial u(Y^*_L + T)}{\partial T} \\
&(14.1) && -\left[u(Y_H - T) + u(Y^*_L + T)\right]\left[\frac{\partial P}{\partial I}\frac{\partial I}{\partial T}(1-P^*) - \frac{\partial P^*}{\partial I^*}\frac{\partial I^*}{\partial T}P\right] \\
&(14.2) && -\left[u(Y^*_H - T) + u(Y_L + T)\right]\left[\frac{\partial P^*}{\partial I^*}\frac{\partial I^*}{\partial T^*}(1-P) - \frac{\partial P}{\partial I}\frac{\partial I}{\partial T}P^*\right] \\
(14) \quad &(14.3) && +\left[u(Y_H) + u(Y^*_H)\right]\left[\frac{\partial P}{\partial I}\frac{\partial I}{\partial T}P^* + \frac{\partial P^*}{\partial I^*}\frac{\partial I^*}{\partial T}P\right] \\
&(14.4) && -\left[u(Y_L) + u(Y^*_L)\right]\left[\frac{\partial P}{\partial I}\frac{\partial I}{\partial T}(1-P^*) + \frac{\partial P^*}{\partial I^*}\frac{\partial I^*}{\partial T}(1-P)\right] \\
&(14.5) && +\left[\frac{\partial v}{\partial I}\frac{\partial I}{\partial T} + \frac{\partial v}{\partial I^*}\frac{\partial I^*}{\partial T}\right]
\end{aligned}
$$

We can simplify by using the envelope theorem, which in our context states that regions will always pick an investment level along their respective reaction functions so (8) and (8*) will be satisfied. Using in addition the symmetry properties, the first order condition for T simplifies to:

(15)
$$\frac{\partial u(Y_H - T)}{\partial T} = \frac{\partial u(Y_L + T)}{\partial T} + \left[\frac{\partial P}{\partial I}\frac{\partial I}{\partial T}\right]\left[\left(\frac{1}{1-P}\right)2u(Y_H) - \left(\frac{1}{P}\right)2u(Y_L)\right]$$
$$= \frac{\partial u(Y_L + T)}{\partial T} + \left[\frac{\partial P}{\partial I}\frac{\partial I}{\partial T}\frac{2u(Y_L)}{P}\right]\left[\left(\frac{P}{1-P}\right)\left(\frac{u(Y_H)}{u(Y_L)}\right) - 1\right]$$

Notice that this equation is identical to the first-best first order condition for transfers except for the additional term on the right hand side, which we will denote A.

To sign the additional term A, we will sign each of the two bracketed terms that comprise A. Since $\partial P/\partial I>0$, the sign of the first bracketed term depends on the sign of $\partial I/\partial T$, the change in the Nash equilibrium investment level given a change in transfers. We can state the following proposition:

Proposition 1*: Higher transfers decrease each region's Nash Equilibrium level of investment, that is $\partial I/\partial T<0$.*

Proof: The proof proceeds by first deriving the direction of the shift in the reaction function when T changes. We show the reaction function shifts down when T increases. Given symmetry, both reaction functions shift by the same amount in the same direction, and since the reaction functions are downward sloping, such a shift results in lower investment by both regions in the new Nash Equilibrium. To derive the sign of the shift in the reaction function, we can again use the implicit function theorem as above. The change in the reaction function when T changes is:

$$(16) \quad \frac{dI}{dT} = -\frac{\phi_T}{\phi_I}$$

We have already shown that ϕ_I is negative (see above). Hence, the sign of the shift of the reaction function is the same as the sign of ϕ_T. To derive ϕ_T, differentiate (8) with respect to T:

$$(8') \qquad \phi_T = -\frac{\partial P}{\partial I} P(I^*) \frac{\partial u(Y_L + T)}{\partial T} + \frac{\partial P}{\partial I}(1 - P^*(I^*)) \frac{\partial u(Y_H - T)}{\partial T}$$

To sign this derivative note first that

$$\frac{\partial u(Y_L + T)}{\partial T} > 0 \text{ and } \frac{\partial u(Y_H - T)}{\partial T} < 0$$

Since $\partial P/\partial I > 0$, both terms of (8') are negative. Hence ϕ_T is negative and the reaction function shifts down; symmetry implies the same is true of the reaction function (8*). Since both reaction functions are downward sloping and shift down, the Nash Equilibrium level of investment of each region decreases with increases of T. QED.

Given proposition 1, the first bracketed term of A is negative. The sign of the second bracketed term of A depends on the relationship between P/(1-P) and $u(Y_H)/u(Y_L)$. The second bracketed term of A will be positive iff $\frac{u(Y_H)}{u(Y_L)} > \frac{1-P}{P}$ and negative iff $\frac{u(Y_H)}{u(Y_L)} < \frac{1-P}{P}$. For interpretation it is useful to note that the second bracketed term is negative if expected utility in the low-income state is greater than expected utility in the high-income state.

We are now in a position to evaluate the sign of A.

Proposition 2*: The sign of the term A is negative iff* $\frac{u(Y_H)}{u(Y_L)} > \frac{1-P}{P}$ *and positive iff*

$$\frac{u(Y_H)}{u(Y_L)} < \frac{1-P}{P} \quad .$$

Proof: Since the first term of A is negative, A will be negative iff the second bracketed term is positive and A will be positive iff the second bracketed term is negative. The proposition follows immediately since the second bracketed term is positive iff $\frac{u(Y_H)}{u(Y_L)} > \frac{1-P}{P}$, and the second bracketed term is negative iff $\frac{u(Y_H)}{u(Y_L)} < \frac{1-P}{P}$. QED.

As we have evaluated the sign of A, we are in a position to compare first and second-best transfers. We can state the following proposition:

Proposition 3*: Optimal second-best transfers will be less than optimal first-best transfers iff* $\frac{u(Y_H)}{u(Y_L)} > \frac{1-P}{P}$ *(that is, expected utility in the high-income state is greater than expected utility in the low-income state). Optimal second-best transfers will be greater than first-best transfers iff* $\frac{u(Y_H)}{u(Y_L)} < \frac{1-P}{P}$ *(that is, expected utility in the low-income state is greater than expected utility in the high-income state).*

Proof:

Given Proposition 2, Proposition 3 follows from examination of the first-order conditions for second-best transfers (15) and the first-order conditions for first-best transfers (2). QED.

A graphical depiction can be provided by reference to Figure 1. We have noted that (15) is identical to (2) except for the additional term on the right hand side denoted A. This additional term is added to the marginal utility of income for the region that suffers a low income shock. If A is positive, more weight is given to the marginal utility of the region suffering from the low-income shock than under the first-best so the marginal utility line of the starred region in figure 1 is shifted up and transfers are higher. If A is negative, less weight is given to the marginal utility of the region suffering the low-income shock than under the first-best, the marginal utility of the starred region shifts down, and transfers are lower. These possibilities are illustrated in Figure 3.

The surprising result that second-best transfers can be greater than first-best transfers starts from the fact that the central government has two somewhat conflicting goals that it is trying to balance. One is to redistribute income to equalize marginal utilities. The other is to correct for under-investment. However, from the ex-ante perspective changing transfers that impact investment also impact the probability of the (Y_L, Y^*_L) and (Y_H, Y^*_H) outcomes, even though no transfers are made in these situations ex-post. When the expected utility of both regions ending up with high income is greater than the expected utility of both regions ending up with low income, we get the intuitive result that the central government decreases its redistributive grants in order to increase investment. Lower transfers increase the probability of (Y_H, Y^*_H) which has a greater expected utility in this case. However, if expected utility is higher for the (Y_L, Y^*_L) outcome than for the (Y_H, Y^*_H) outcome, the central government can induce the higher expected utility (Y_L, Y^*_L) outcome by giving more transfers because this lowers investment and hence makes the (Y_L, Y^*_L) possibility more likely.

It is perhaps this contrast between second- and first-best transfers that distinguishes the disaster case from other shocks to regional incomes. Disasters are by definition low probability, high-cost events that would typically result in very large shocks to regional income and utility. More common, lower cost shocks – perhaps like those associated with regional business cycles – are those in which second-best transfers may exceed first-best.

V. Commitment and Ex-post Central Government Grants

Up to this point, we have assumed that the central government commits to the second-best ex-ante optimal transfers derived in the previous section. However, second-best transfers that are smaller than first-best transfers require the central government to effectively ex-ante commit to punish regions that end up with a disaster in order to increase the incentive of regions to invest in protective infrastructure and thereby lessen the costs of the disaster. But there is a real question concerning the credibility of the central government commitment. If the central government cannot credibly commit, a different and distinct reason for underinvestment in protective infrastructure will arise: the anticipation by a region that ex-post transfers from the central government can be influenced by its investment choices. Given this, the region can exploit the anticipated reaction of the central government (effectively exploiting a soft budget constraint) and further under-invest in protective infrastructure.

To model this, we consider the central government's choice of transfers from an ex-post perspective. We maintain our normative framework and assume that the central government's objective function is the sum of regions' utilities. Ex-post, the central government chooses transfers to maximize

$$\text{(17)} \qquad \underset{\{T_{rs},r,s\in(L,H),r\neq s\}}{\text{Max}} u(Y_r + T_{rs}) + u(Y^*_s - T_{rs})$$

The first order conditions are:

(18) $$\frac{\partial u(Y_r + T_{rs})}{\partial T_{rs}} = \frac{\partial u^*(Y^*_s - T_{rs})}{\partial T_{rs}} \quad r, s \in (L, H), r \neq s$$

Ex-post, the central government will not implement second-best transfers; rather, it will want to equate the marginal utility across regions, which implies that it wants to equalize incomes ex-post. Ex-post optimal transfers are thus

(19) $$T_{LH} = \frac{Y^*_H - Y_L}{2}, T_{HL} = \frac{Y_H - Y^*_L}{2}$$

Before we consider a region's ex-ante investment decision, we note that ex-ante a region predicts these ex-post transfers to be

(20) $$\tau_{LH} = \frac{P(I^*)Y^*_H - (1 - P(I))Y_L}{2}, \tau_{HL} = \frac{P(I)Y_H - (1 - P(I^*))Y^*_L}{2}$$

The regions realize that their ex-ante behavior will change the predicted ex-post transfer since greater investment is going to increase the probability of a high income outcome and decrease the probability of a low income outcome, and each region would want to take this into account in its ex-ante investment decision. Differentiating the predicted ex-post transfers yields:

(21) $$\frac{\partial \tau_{HL}}{\partial I} = \frac{1}{2}\frac{\partial P}{\partial I} Y_H > \frac{\partial \tau_{LH}}{\partial I} = \frac{1}{2}\frac{\partial P}{\partial I} Y_L > 0; and$$

(21*) $$\frac{\partial \tau_{LH}}{\partial I^*} = \frac{1}{2}\frac{\partial P}{\partial I^*} Y^*_H > \frac{\partial \tau_{HL}}{\partial I^*} = \frac{1}{2}\frac{\partial P}{\partial I^*} Y^*_L > 0$$

Hence, higher investment increases the predicted transfer paid in the event of a high income outcome by more than it increases the predicted transfer received in the event of a low income outcome. This is a type of soft budget constraint.

Now consider the ex-ante investment decision of the unstarred region when it realizes that the central government will implement the optimal ex-post transfers. The region's investment decision will solve:

$$
\begin{aligned}
(22) \qquad & \underset{I}{\text{Max}}\, v(\bar{Y} - I) \\
& + P(I)P(I^*)u(Y_H) \\
& + P(I)(1 - P(I^*)u(Y_H - \tau_{HL}) \\
& + (1 - P(I))P(I^*)\, u(Y_L + \tau_{LH}) \\
& + (1 - P(I))(1 - P(I^*))\, u(Y_L)
\end{aligned}
$$

The first order condition is:

$$
\begin{aligned}
(23) \qquad & \frac{\partial P}{\partial I} P^*\left[u(Y_H) - u(Y_L + \tau_{LH})\right] - \frac{\partial P}{\partial I}(1 - P^*)\left[u(Y_L) - u(Y_H - \tau_{HL})\right] \\
& + \frac{\partial u(Y_H - \tau_{HL})}{\partial \tau_{HL}} \frac{\partial \tau_{HL}}{\partial I} P(1 - P^*) + \frac{\partial u(Y_L + \tau_{LH})}{\partial \tau_{LH}} \frac{\partial \tau_{LH}}{\partial I}(1 - P)P^* = \frac{\partial v}{\partial I}
\end{aligned}
$$

To derive the slope of the reaction function, write the reaction function defined by (23) in implicit form, $\varphi(I, I^*, \tau) = 0$. Using the implicit function theorem, the slope of the reaction function for the unstarred region is:

$$
(24) \qquad \frac{dI}{dI^*} = -\frac{\varphi_{I^*}}{\varphi_I}
$$

We can show that φ_I is negative. To see this note that φ_I is:

$$(25)\ \varphi_I = P''(I)P(I^*)\left[u(Y_H)-u(Y_L+\tau)\right] - P''(I)(1-P(I^*))\left[u(Y_L)-u(Y_H-\tau)\right]$$
$$-P'(I)P(I^*)\frac{\partial u(Y_L+\tau)}{\partial\tau}\frac{\partial\tau}{\partial I} + P'(I)(1-P(I^*))\frac{\partial u(Y_H-\tau)}{\partial\tau}\frac{\partial\tau}{\partial I}$$
$$+P'(I)(1-P(I^*))\frac{\partial u(Y_H-\tau)}{\partial\tau}\frac{\partial\tau}{\partial I} + P(I)(1-P(I^*))\frac{\partial^2 u(Y_H-\tau)}{\partial\tau\partial I}\frac{\partial\tau}{\partial I} + P(I)(1-P(I^*))\frac{\partial u(Y_H-\tau)}{\partial\tau}\frac{\partial^2\tau}{\partial I^2}$$
$$-P'(I)P(I^*)\frac{\partial u(Y_L+\tau)}{\partial\tau}\frac{\partial\tau}{\partial I} + P(I^*)(1-P(I))\frac{\partial^2 u(Y_L+\tau)}{\partial\tau\partial I}\frac{\partial\tau}{\partial I} + P(I^*)(1-P(I))\frac{\partial u(Y_L+\tau)}{\partial\tau}\frac{\partial^2\tau}{\partial I^2}$$
$$= P''(I)P(I^*)\left[u(Y_H)-u(Y_L+\tau)\right] - P''(I)(1-P(I^*))\left[u(Y_L)-u(Y_H-\tau)\right]$$
$$-2P'(I)P(I^*)\frac{\partial u(Y_L+\tau)}{\partial\tau}\frac{\partial\tau}{\partial I} + 2P'(I)(1-P(I^*))\frac{\partial u(Y_H-\tau)}{\partial\tau}\frac{\partial\tau}{\partial I}$$
$$+P(I)(1-P(I^*))\frac{\partial^2 u(Y_H-\tau)}{\partial\tau\partial I}\frac{\partial\tau}{\partial I} + P(I)(1-P(I^*))\frac{\partial u(Y_H-\tau)}{\partial\tau}\frac{\partial^2\tau}{\partial I^2}$$
$$+P(I^*)(1-P(I))\frac{\partial^2 u(Y_L+\tau)}{\partial\tau\partial I}\frac{\partial\tau}{\partial I} + P(I^*)(1-P(I))\frac{\partial u(Y_L+\tau)}{\partial\tau}\frac{\partial^2\tau}{\partial I^2}$$

Given the assumed symmetry of the regions, we can show that the sum of the sixth and eighth terms is zero. To see this, note that adding terms six and eight yields

$$(26)\quad P(1-P)\frac{\partial^2\tau}{\partial I^2}\left[\frac{\partial u(Y_H-\tau)}{\partial\tau} + \frac{\partial u(Y_L+\tau)}{\partial\tau}\right]$$

But from the central government's first order conditions, the region knows that the central government will equate marginal utilities ex-post, so (26) is zero. Hence, (25) reduces to

$$(25')\ \varphi_I = P''(I)P(I^*)\left[u(Y_H)-u(Y_L+\tau)\right] - P''(I)(1-P(I^*))\left[u(Y_L)-u(Y_H-\tau)\right]$$
$$-2P'(I)P(I^*)\frac{\partial u(Y_L+\tau)}{\partial\tau}\frac{\partial\tau}{\partial I} + 2P'(I)(1-P(I^*))\frac{\partial u(Y_H-\tau)}{\partial\tau}\frac{\partial\tau}{\partial I}$$
$$+P(I)(1-P(I^*))\frac{\partial^2 u(Y_H-\tau)}{\partial\tau\partial I}\frac{\partial\tau}{\partial I} + P(I^*)(1-P(I))\frac{\partial^2 u(Y_L+\tau)}{\partial\tau\partial I}\frac{\partial\tau}{\partial I}$$

The first two terms are identical to the corresponding derivative associated with the reaction function defined by equation (8). As with that derivative, given that $Y_H > Y_L + T$ and $P''(I)<0$, the first two terms are negative. The second two terms are also negative since $P'(I)>0$, $\partial u(Y_H - \tau)/\partial\tau < 0$, $\partial u(Y_L + \tau)/\partial\tau > 0$, and $\partial\tau/\partial I>0$. The sign of the fifth and sixth terms depend on the sign of the cross partials $\partial u^2(Y_L + \tau)/\partial\tau\partial I$ and $\partial u^2(Y_H - \tau)/\partial\tau\partial I$. These are negative since $\partial u^2(Y_L + \tau)/\partial\tau\partial I = (\partial u^2(Y_L + \tau)/\partial\tau^2)*(\partial\tau/\partial I) < 0$ and $\partial u^2(Y_H - \tau)/\partial\tau\partial I = -(\partial u^2(Y_H - \tau)/\partial\tau^2)*(\partial\tau/\partial I) < 0$. Intuitively a higher investment level increases the expected transfer which increases utility at a decreasing rate. As the other parts of the fifth and seventh terms are positive, these two terms must be negative. As all the terms are negative, $\varphi_I < 0$.

The derivative φ_{I*} is

$$
\begin{aligned}
(27) \quad \varphi_{I*} &= P'(I)P'(I^*)\left[u(Y_H\ )-u(Y_L\ +T\ \ )\right]+P'(I)P'(I^*)\left[u(Y_L\ )-u(Y_H\ -T\ \ )\right] \\
&-P'(I)P(I^*)\frac{\partial u(Y_L+\tau)}{\partial\tau}\frac{\partial\tau}{\partial I^*}+P'(I)(1-P(I^*))\frac{\partial u(Y_H-\tau)}{\partial\tau}\frac{\partial\tau}{\partial I^*} \\
&+P(I)(-P'(I^*))\frac{\partial u(Y_H-\tau)}{\partial\tau}\frac{\partial\tau}{\partial I}+P(I)(1-P(I^*))\frac{\partial^2u(Y_H-\tau)}{\partial\tau\partial I^*}\frac{\partial\tau}{\partial I} \\
&+(1-P(I))P'(I^*)\frac{\partial u(Y_L+\tau)}{\partial\tau}\frac{\partial\tau}{\partial I}+P(I^*)(1-P(I))\frac{\partial^2u(Y_L+\tau)}{\partial\tau\partial I^*}\frac{\partial\tau}{\partial I}
\end{aligned}
$$

The first two terms are identical to the corresponding derivative associated with the reaction function defined by equation (8). We have already shown that concavity of the utility function implies that the sum of these two terms is negative. Given the assumed symmetry of the regions, we can show that the sum of terms three and five is zero and the same for the sum of terms four and seven. To see this, note that adding terms three and five yields

$$(28) \quad -P'P\frac{\partial\tau}{\partial I}\left[\frac{\partial u(Y_L+\tau)}{\partial\tau}+\frac{\partial u(Y_H-\tau)}{\partial\tau}\right]$$

But from the central government's first order conditions, the region knows that the central government will equate marginal utilities ex-post, so (28) is zero. The same is true when we sum terms four and seven. Hence, (27) reduces to

(27') $$\varphi_{I^*} = P'(I)P'(I^*)\big[u(Y_H) - u(Y_L + T)\big] + P'(I)P'(I^*)\big[u(Y_L) - u(Y_H - T)\big]$$
$$+P(I)(1-P(I^*))\frac{\partial^2 u(Y_H - \tau)}{\partial\tau\partial I^*}\frac{\partial \tau}{\partial I} + P(I^*)(1-P(I))\frac{\partial^2 u(Y_L + \tau)}{\partial\tau\partial I^*}\frac{\partial \tau}{\partial I}$$

The third and fourth terms are negative since $\partial u(Y_H - \tau)/\partial\tau < 0$, $\partial u(Y_L + \tau)/\partial\tau > 0$, and $\partial\tau/\partial I^* > 0$. Hence, $\varphi_{I^*} < 0$. As both φ_{I^*} and φ_I are negative, the slope is negative.

To make sure that the reaction functions intersect, we impose the condition that when a region's investment is zero, the marginal benefit of investment for that region is greater than the marginal cost. A sufficient condition for the resulting Nash Equilibrium to be asymptotically stable is that the absolute value of the slope is less than 1. This requires $\varphi_{I^*} < \varphi_I$ which, using the above derivatives, requires

(29) $$P'(I)P'(I^*)[u(Y_H) + u(Y_L) - u(Y_L + T) - u(Y_H - T)]$$
$$+P(I)(1-P(I^*))\frac{\partial^2 u(Y_H - \tau)}{\partial\tau\partial I^*}\frac{\partial \tau}{\partial I} + P(I^*)(1-P(I))\frac{\partial^2 u(Y_L + \tau)}{\partial\tau\partial I^*}\frac{\partial \tau}{\partial I}$$
$$< P''(I)P(I^*)\big[u(Y_H) - u(Y_L + T)\big] - P''(I)(1-P(I^*))\big[u(Y_L) - u(Y_H - T)\big]$$
$$-2P'(I)P(I^*)\frac{\partial u(Y_L + \tau)}{\partial\tau}\frac{\partial \tau}{\partial I} + 2P'(I)(1-P(I^*))\frac{\partial u(Y_H - \tau)}{\partial\tau}\frac{\partial \tau}{\partial I}$$
$$+P(I)(1-P(I^*))\frac{\partial^2 u(Y_H - \tau)}{\partial\tau\partial I}\frac{\partial \tau}{\partial I} + P(I^*)(1-P(I))\frac{\partial^2 u(Y_L + \tau)}{\partial\tau\partial I}\frac{\partial \tau}{\partial I}$$
$$= P''(I)P(I^*)[u(Y_H) + u(Y_L)(1 - \frac{1}{P(I^*)}) - u(Y_L + T) - u(Y_H - T)(1 - \frac{1}{P(I^*)})]$$
$$-2P'(I)P(I^*)\frac{\partial u(Y_L + \tau)}{\partial\tau}\frac{\partial \tau}{\partial I} + 2P'(I)(1-P(I^*))\frac{\partial u(Y_H - \tau)}{\partial\tau}\frac{\partial \tau}{\partial I}$$
$$+P(I)(1-P(I^*))\frac{\partial^2 u(Y_H - \tau)}{\partial\tau\partial I}\frac{\partial \tau}{\partial I} + P(I^*)(1-P(I))\frac{\partial^2 u(Y_L + \tau)}{\partial\tau\partial I}\frac{\partial \tau}{\partial I}$$

Given symmetry, the last two terms on the left hand side of the inequality are equal to the last two terms on the right hand side of the inequality. Hence (29) simplifies to

$$(29') \quad P'(I)P'(I^*)[u(Y_H)+u(Y_L)-u(Y_L+T)-u(Y_H-T)]$$
$$< P''(I)P(I^*)[u(Y_H)+u(Y_L)(1-\frac{1}{P(I^*)})-u(Y_L+T)-u(Y_H-T)(1-\frac{1}{P(I^*)})]$$
$$-2P'(I)P(I^*)\frac{\partial u(Y_L+\tau)}{\partial \tau}\frac{\partial \tau}{\partial I}+2P'(I)(1-P(I^*))\frac{\partial u(Y_H-\tau)}{\partial \tau}\frac{\partial \tau}{\partial I}$$

The right hand side of the inequality can be further simplified because the last two terms can be written as:

$$-2P'(I)P(I^*)\frac{\partial \tau}{\partial I}\left[\frac{\partial u(Y_L+\tau)}{\partial \tau}+\frac{\partial u(Y_H-\tau)}{\partial \tau}\right]+2P'(I)\frac{\partial u(Y_H-\tau)}{\partial \tau}\frac{\partial \tau}{\partial I}$$

As above, from the central government's first order conditions the region knows that the central government will equate marginal utilities ex-post, so the bracketed term is zero and (29') reduces to

$$(29'') \quad P'(I)P'(I^*)[u(Y_H)+u(Y_L)-u(Y_L+T)-u(Y_H-T)]$$
$$< P''(I)P(I^*)[u(Y_H)+u(Y_L)(1-\frac{1}{P(I^*)})-u(Y_L+T)-u(Y_H-T)(1-\frac{1}{P(I^*)})]+2P'(I)\frac{\partial u(Y_H-\tau)}{\partial \tau}\frac{\partial \tau}{\partial I}$$

This is identical to the condition for asymptotic stability with respect to the reaction function defined by (8) except for the addition of the last term (which is negative). As we are concerned with the absolute value, the addition of this term increases the absolute value of the right hand side of the inequality. Hence the sufficient condition for asymptotic stability is somewhat eased relative to the reaction function defined by (8).

The analogous first-order condition for the starred region is:

$$(23^*) \quad \begin{aligned} &\frac{\partial P^*}{\partial I^*}P\left[u(Y^*_H)-u(Y^*_L+\tau_{HL})\right]-\frac{\partial P^*}{\partial I^*}(1-P)\left[u(Y^*_L)-u(Y^*_H-\tau_{LH})\right] \\ &+\frac{\partial u(Y^*_H-\tau_{LH})}{\partial \tau_{LH}}\frac{\partial \tau_{LH}}{\partial I^*}P^*(1-P)+\frac{\partial u(Y^*_L+\tau_{HL})}{\partial \tau_{HL}}\frac{\partial \tau_{HL}}{\partial I^*}(1-P^*)P=\frac{\partial v^*}{\partial I^*}\end{aligned}$$

Solving (23*) for I* yields the reaction function of the starred region, and the symmetry of the problem implies that the two reaction functions are also symmetric. Hence, the above discussion of the unstarred region's reaction function applies equally to the starred region's reaction function, which is downward sloping. The Nash Equilibrium levels of investment that simultaneously solve these two first order conditions would be identical for each region.

We can compare investment levels to the earlier case by reference to Figure 2. We show that the reaction functions pictured in Figure 2 are both lower. The first two terms of (23) and (23*) are the same as equations (8) and (8*) from before, so from our previous analysis we know that there will be an incentive to under-invest because of the externality. We now have two additional terms to analyze, however. The second two terms on the left-hand side of (23) and (23*) arise from the fact that the regions know that ex-post transfers will be affected by its' investment decision. We can sign these terms because we know that $\partial u/\partial \tau_{HL} < 0$ and $\partial u/\partial \tau_{LH} > 0$ in (23) and $\partial u^*/\partial \tau_{HL} > 0$ and $\partial u^*/\partial \tau_{LH} < 0$ in (23*). The remaining parts of the two additional terms in (23) and (23*) are positive, so the third term is negative and the fourth is positive. Furthermore, we know from (21) and (21*) that the negative term is larger than the positive term so the sum of the two additional terms of (23) and (23*) is negative, and the marginal benefit of investment is lower than in (8) and (8*). The reaction functions pictured in Figure 2 are therefore both lower and thus the Nash equilibrium investment levels are also lower. This is the effect of each region's exploitation of the anticipated central government transfers (the anticipation of a type of soft budget constraint). As it undertakes its ex-ante investment decision, the region realizes that the central government will have an incentive to equalize incomes ex-post and each region consequently has less incentive to invest. In the Nash Equilibrium, as both regions anticipate the central government response, both will further under-invest in protective infrastructure relative to the initial non-cooperative Nash Equilibrium.

VI. Conclusion

This paper has studied a model of federalism which highlights the tradeoff between providing appropriate incentives for protection at the local level and insuring actual losses after a disaster occurs. Our results indicate that when regional governments undertake disaster prevention measures and act non-cooperatively, federal disaster insurance will result in underinvestment in pre-disaster protective investment. As in Persson and Tabellini (1996), centralization of the provision of protective infrastructure would eliminate inefficiency by eliminating the moral hazard. Unobservable or unverifiable local efforts to prevent disasters makes typical externality prescriptions (such as matching grants) difficult to implement.

When the relative probability of a disaster is low, second-best federal transfers involve rewarding the successful avoidance of disasters. But the effectiveness of such a regime requires credible ex-ante commitment by the federal government. This commitment may be difficult to sustain. Again, the evidence provides some support to this result. In recent years, initial Congressional appropriations to the Disaster Relief Fund have been heavily supplemented after disasters have occurred (see Chart 1). When the central government cannot commit to the second-best transfers and regions anticipate ex-post equalizing transfers, they will further under-invest to influence anticipated future transfers, taking advantage of a type of soft budget constraint.

Unfortunately, we believe that current US disaster policies may be susceptible to the dual problems of unverifiable local investment and a federal inability to commit to solutions that would lower the moral hazard problem. In particular, since information about local vulnerability – and which protective investments actually reduce this vulnerability - is likely to be most easily available to regional officials, the principal responsibility for protective investment falls on state and local governments. Meanwhile, a large share of post-disaster relief funds comes from the federal fisc. Our model suggests that in this institutional environment states have significant incentives to underinvest in protective infrastructure.

Steinberg's (2000, pp 103-111) account of the National Flood Insurance Program (NFIP) is an example of the incentives of unverifiable local investment at work. The NFIP, adopted in 1968, offers insurance to residents of 100-year floodplains at heavily subsidized rates. In exchange, local officials were to increase protection by requiring that new structures be built above the 100-year flood level. Yet in the interest of economic development, officials in some locations granted numerous variances to these regulations, leading to ever-expanding claims on the flood insurance program.

While the model presented here provides preliminary insights into the nature of the problems raised by natural disasters, we see several directions in which this work could be extended. Here we describe two of these. Both of these extensions may add some richness to the findings reported here, but we believe that neither is likely to reverse our main conclusions.

We model regional government investment in protective infrastructure, but another major source of risk mitigation by state and local government consists of regulations: building codes, land use restrictions and the like. Such regulations are often seen from the state perspective as diminishing local economic growth, implying that our modeling assumption captures the basic issue. Nonetheless, explicit treatment of the choice between structural and regulatory mitigation techniques might yield more nuanced insights.

A second possible extension concerns the potential for spillovers from protective investments. In the case of flood control, for example, structures built to prevent flooding in one location can increase their probability in others. A well-known example is levees on the Mississippi River, which force flood waters to other, unprotected, locations. Generalizing the model to account for such externalities in the effects of protective investments will allow a more complete examination of the issues.

The problems raised by geographically-concentrated shocks to income, regardless of their probability and magnitude, are difficult to solve. We study a simple model that we believe captures features of US disaster policy. In our model, sub-national under-provision of disaster protection will result first from full federal ex-ante insurance. Second-best transfers can be devise to reduce the problem of sub-optimal investment, but these suffer from a time-consistency problem. If regions anticipate the time-consistent policy of equalizing transfers, their exploitation of this type of soft budget constraint will result in a further reduction in sub-national protective infrastructure investment. The challenge is to provide appropriate incentives for local protective actions, whether regulatory or structural, while maintaining the benefits of insurance against large shocks.

This is a difficulty that has bedeviled disaster policy makers for generations. Rewarding successful *avoidance* of disasters is one path to the constrained optimum. Achieving these benefits, however, requires more post-disaster discipline on the part of Congress than it has historically demonstrated.

REFERENCES

Bayoumi, Tamim, and Paul Masson, 1995. "Fiscal Flows in the United States and Canada: Lessons for Monetary Union in Europe," *European Economic Review* 39, pp. 253-74.

Bea, Keith, 2005. "Federal Stafford Act Disaster Assistance: Presidential Declarations, Eligible Activities, and Funding," CRS Report to Congress.

Bordignon, Massimo, Paolo Manasse and Guido Tabellini, 2001, "Optimal regional redistribution under asymmetric information," *American Economic Review*, 91 , 709-723.

Caplan, Arthur J., Richard C. Cornes and Emilson C. D. Silva 2000. "Pure public goods and income redistribution in a federation with decentralized leadership and imperfect labor mobility" *Journal of Public Economics*, Volume 77, Issue 2, pp. 265-284.

Chernick, H. 2001. "The Fiscal Impact of 9/11 on New York City" in *Resilient City: The Economic Impact of 9/11*, H. Chernick ed., 295-320. New York, NY: Russell Sage.

Goodspeed, Timothy, 2002. "Bailouts in a Federation," *International Tax and Public Finance* 9, pp.409-421, August.

von Hagen, Jurgen, 2007. "Achieving Economic Stabilization by Sharing Risk within Countries." in Robin Boadway and Anwar Shah, eds. *Intergovernmental Fiscal Transfers: Principles and Practice*. Washington, DC: World Bank.

Kunreuther, Howard, 2006. "Has the Time Come for Comprehensive Natural Disaster Insurance?" in *On Risk and Disaster: Lessons from Hurricane Katrina,* Ronald Daniels, Donald Kettl and Howard Kunreuther, eds. Philadelphia: University of Pennsylvania Press.

Lockwood, Ben. 1999. "Inter-regional insurance," *Journal of Public Economics*,72(1),1 -37.

Melitz, Jacques and Frederic Zumer, 2002. "Regional redistribution and stabilization by the center in Canada, France, the UK and the US: A reassessment and new tests," *Journal of Public Economics* 86, pp. 263-286.

Oates, Wallace. 2005. "Toward A Second-Generation Theory of Fiscal Federalism" *International Tax and Public Finance*, 12, 349–373.

Persson, Torsten and Guido Tabellini, 1996. "Federal Fiscal Constitutions: Risk Sharing and Moral Hazard," *Econometrica* 64, pp. 623-646.

Raff, Horst and J.D. Wilson. 1997. "Income redistribution with well-informed local governments." *International Tax and Public Finance* 4, 407-427.

Steinberg, Ted, 2000. *Acts of God: The Unnatural History of Natural Disaster in America,* New York: Oxford University Press.

Walters, Jonathan and Donald Kettl, 2006. "The Katrina Breakdown," in *On Risk and Disaster: Lessons from Hurricane Katrina,* Ronald Daniels, Donald Kettl and Howard Kunreuther, eds. Philadelphia: University of Pennsylvania Press.

Wildasin, D.E. 2007. "Disaster Policy in the US Federation: Intergovernmental Incentives and Institutional Reform," *National Tax Association, Proceedings of the 99th Annual Conference*, 171–178.

Wildasin, D.E. 2008a. "Disaster Policies: Some Implications for Public Finance in the U.S. Federation," *Public Finance Review* 36 (4), 497-518.

Wildasin, David, 2008b. "Disaster Avoidance, Disaster Relief, and Policy Coordination in a Federation," Working Paper, University of Kentucky.

Zeckhauser, Richard, 2006. "Floods, Fires, Earthquakes and Pine Beetles: JARring Actions and Fat Tails," presentation at Berkeley Symposium on Real Estate, Catastrophic Risk and Public Policy, available at http://urbanpolicy.berkeley.edu/Presentations/zeckhauser.ppt, last accessed September 1, 2006.

Figure 1
Optimal First-Best Transfer for (Y_H, Y^*_L) case

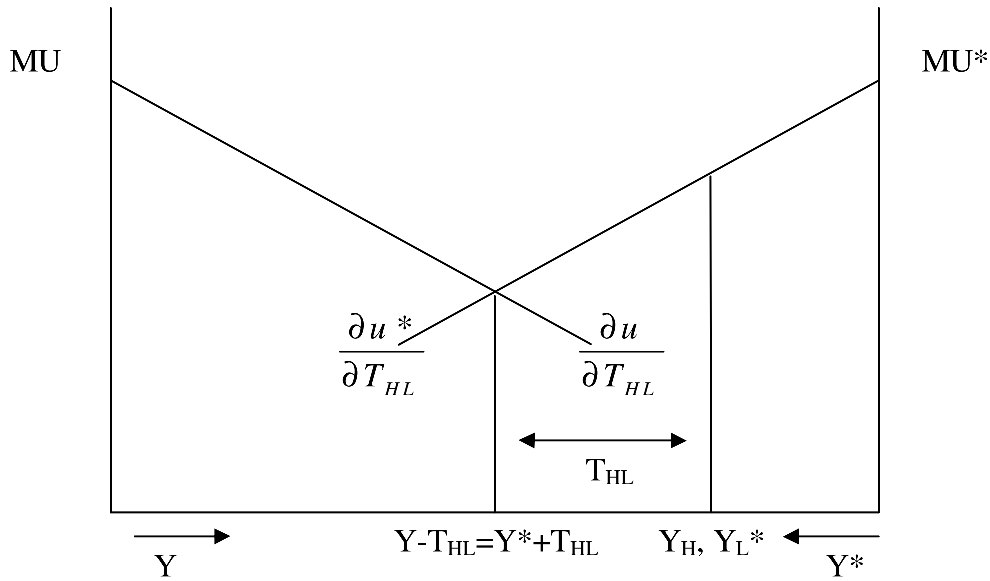


Figure 2
Nash Equilibrium Regional Investment

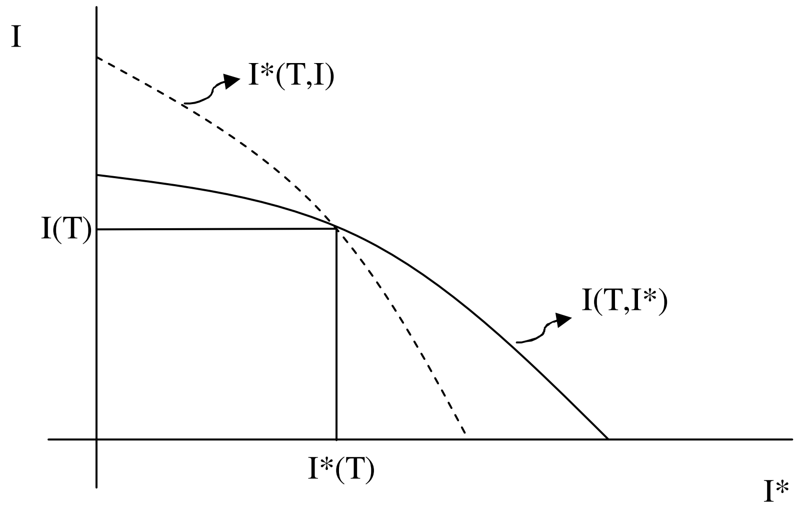


Figure 3
Second-Best Transfers can be Greater or Less than First-Best Transfers

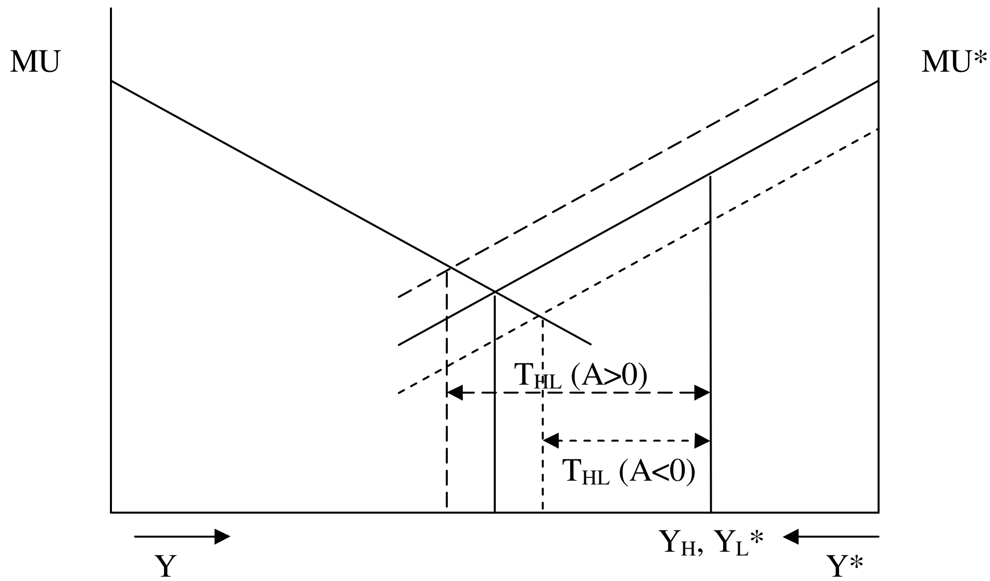
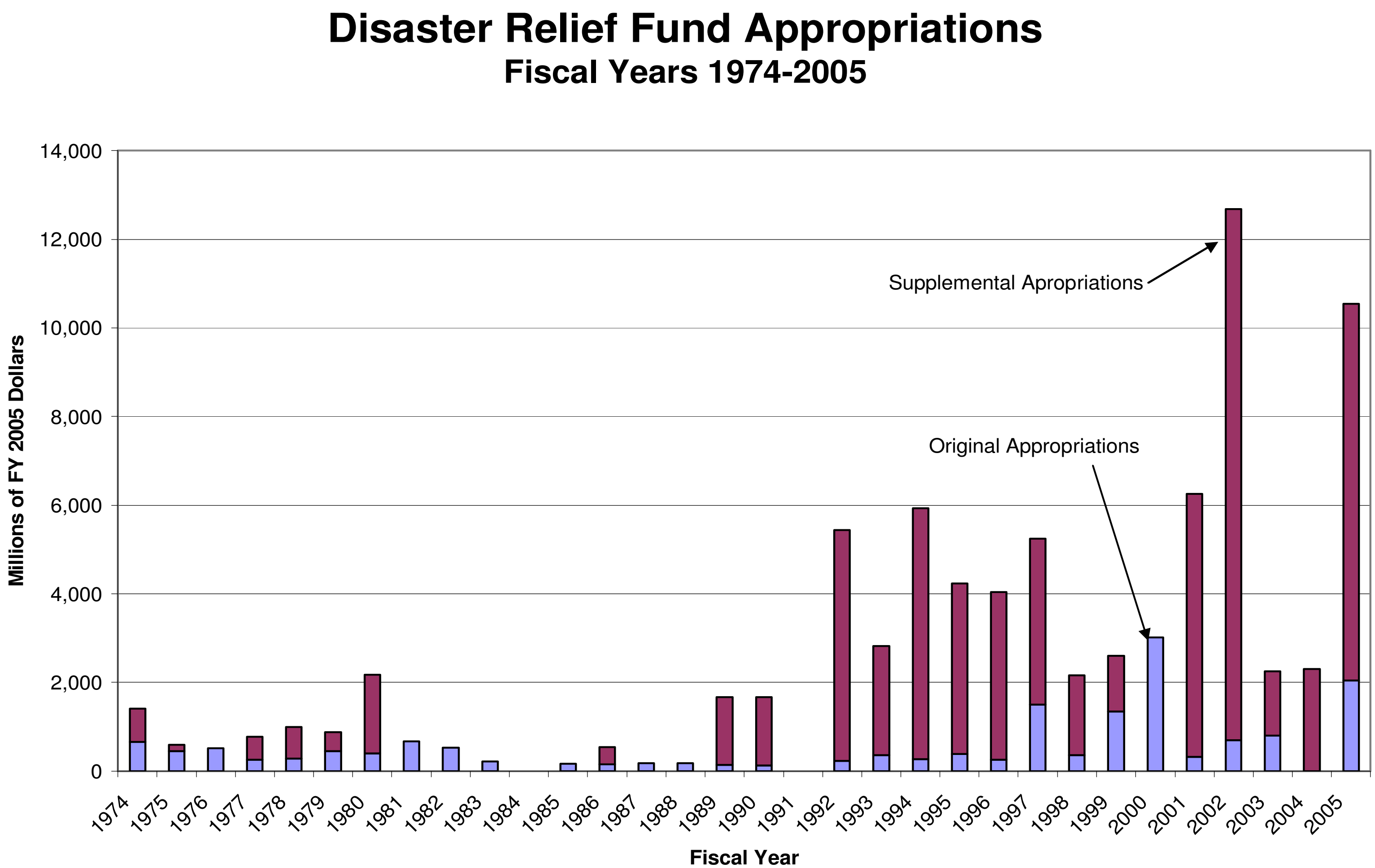


Chart 1



Source: Bea (2005). Note: Data exclude effects of Hurricane Katrina

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