On the Optimal Design of Disaster Insurance in a Federation

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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. We explore the optimal insurance scheme in a federal system, building on the model of Persson and Tabellini (1996). We begin with a simple set-up with 2 regional governments and a central government. Income contains both certain and uncertain components, with the latter subject to an i.i.d. shock (the disaster or terrorist attack). States can use certain income to invest in protective infrastructure (such as levies or police). By doing this, states will affect the probability that they end up in the high or low income state. We explore two distinct reasons why states might under-invest in infrastructure, and the optimal federal insurance policy in each case. First, to the extent that states can alter the probability of ending up in a low/high income state, there will be a moral hazard problem. While the central government will be unable to achieve a first-best (with no uncertainty) outcome, we explore the optimal contract that will get the state to invest the most under the constraints. Second, if the regional government is viewed as investing first in the expectation that the central government will compensate for losses incurred, a soft-budget constraint problem will arise. We discuss these results in light of disaster policy in the US.

I. Introduction

Chaos in New Orleans in the wake of Hurricane Katrina and the controversy that continues to swirl around the public sector response has 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).[1]

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, is the subject of the current study.

The federal government has taken an increasingly active role in providing ex post assistance to individuals and governments that experience disasters. Between fiscal years 1974 and 2005, Presidents declared over 1,200 disasters in the United States, and the federal government spent over $60 billion (constant FY 2005 dollars) on disaster relief.

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[1] Thomas (2005) provides an overview of events in the period immediately surrounding the breach of New Orleans' levees; neither federal nor state and local officials come out looking very good. See http://www.msnbc.msn.com/id/9287434.

Since 1990, as the annual number of declared disasters has risen, the cost per year has exceeded $3 billion (Bea 2005).

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. Since 1998, the Federal Emergency Management Agency (FEMA) has obligated an average of over $2 billion per year to public sector disaster assistance. Roughly one quarter of these expenditures have been designated for "protective measures" while the balance is designed for ex post emergency response and repair of public facilities.[2]

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.[3] 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 worse than those experienced in the second worst – implying that the most serious events may be expected to be extraordinarily costly.[4]

The possibility of natural disasters produces risks to income flows in particular places. There are substantial empirical and theoretical literatures examining the role that federalist institutions can play in insuring residents of a federation against this risk (von

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[2] These figures exclude the response to the September 11, 2001 terrorist attack. That event alone resulted in a $7 billion Congressional appropriation.

[3] See, for example, data on Presidentially declared disasters on the FEMA website http://www.fema.gov/news/disaster_totals_annual.fema; last accessed August 28, 2006.

[4] 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.

Hagen 1998 provides a useful review). This literature is based on the idea that, if all regions of a federation are unlikely to be hit with a negative shock simultaneously, 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). A large 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 estimate that central government redistribution offsets about 20% of shocks to personal income in four countries (France, the UK, the US and Canada). Within economically developed federations, central government insurance is thus an important resource for regions experiencing negative shocks.

While it is most common to model shocks as independent of the actions of individuals or regional governments, Persson and Tabellini (1996) relax this assumption and study the relationship between ex ante risk reduction and ex post insurance. 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. In Persson and Tabellini, as in our model, the focus

is on immobile governments – while residents may choose to relocate either before or after a disaster strikes, governments are 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 (2006) work on federal disaster insurance with mobile households.

The paper is organized as follows. Section II describes the economy we study, and lays out the basic model of federalism with uncertain incomes. This section also describes the model's comparative statics and shows that the Nash equilibrium is characterized by underinvestment in disaster protection. Section III contains our discussion of the optimal insurance scheme, and shows why the first-best solution is likely to be unobtainable. Section IV recasts the model as a soft budget constraint problem, and reinterprets the results in that context. Section V concludes with a discussion of what the model can teach us about the federal response to recent disasters and those yet to come.

II. Underinvestment with Moral Hazard

We begin with a simple model of a federation with two state-level governments. To differentiate the two states, variables for one of the states are denoted with asterisks. Each state's income has certain (subscripted with a one) and uncertain components. The uncertainty results from i.i.d. shocks. Uncertain income can be high with probability P or

low with probability (1 – P). A state can use some of its certain income to invest in protective infrastructure, I, (e.g. levies or police) and 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*))

States are assumed to be risk averse and risk sharing in the federation is accomplished through a set of transfers that depend on the uncertain income of both states, T(Y, Y*). For cases (i) and (iv) no transfers occur. For cases (ii) and (iii), income is transferred from the state that ends up with high income to the state that ends up with low income.

We now want to explore the investment decision of an individual state. How much protective infrastructure will a state provide? An individual state's maximization problem is:

$$\begin{aligned}
&\underset{I_1}{\text{Max}}\; Y_1 - I_1 \\
&+ P(I)P(I^*)\,(Y_H + T(Y_H, Y^*_H)) \\
&+ P(I)(1-P(I^*))(Y_H + T(Y_H, Y^*_L)) \\
&+ (1-P(I))P(I^*)\,(Y_L + T(Y_L, Y^*_H)) \\
&+ (1-P(I))(1-P(I^*))\,(Y_L + T(Y_L, Y^*_L))
\end{aligned}$$

The first order condition is:

$$\frac{\partial P}{\partial I}(Y_H + T(Y_H, Y^*_L)) - \frac{\partial P}{\partial I}(Y_L + T(Y_L, Y^*_H)) = 1$$

The right hand side is the direct marginal cost of greater investment which results in lower certain income and consumption. The two left hand side terms represent the net increase in 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 .

To see whether this results in underinvestment, consider as a benchmark the investment of a state that maximizes the sum of utilities of the two states:

$$\begin{aligned}
&\operatorname*{Max}_{I_1} Y_1 - I_1 + Y_1^* - I_1^* \\
&+ P(I)P(I^*)(Y_H + T(Y_H, Y^*_H)) \\
&+ P(I)(1-P(I^*))(Y_H + T(Y_H, Y^*_L)) \\
&+ (1-P(I))P(I^*)(Y_L + T(Y_L, Y^*_H)) \\
&+ (1-P(I))(1-P(I^*))(Y_L + T(Y_L, Y^*_L)) \\
&+ P(I)P(I^*)(Y^*_H + T^*(Y_H, Y^*_H)) \\
&+ P(I)(1-P(I^*))(Y^*_H + T^*(Y_H, Y^*_L)) \\
&+ (1-P(I))P(I^*)(Y^*_L + T^*(Y_L, Y^*_H)) \\
&+ (1-P(I))(1-P(I^*))(Y^*_L + T^*(Y_L, Y^*_L))
\end{aligned}$$

Assuming that the two states are symmetric, the first order condition is:

$$2\frac{\partial P}{\partial I}(Y_H + T(Y_H, Y^*_L)) - 2\frac{\partial P}{\partial I}(Y_L + T(Y_L, Y^*_H)) = 1$$

Comparing to the above problem, the two left hand side terms are multiplied by two. This is because one state's investment decision affects the probability of ending up in each of the four joint income possibilities. In other words, state 2 benefits from an increase in state 1's probability of ending up with Y_H (holding state 2's probabilities constant). State 1 ignores this benefit in its investment decision and invests too little in protective infrastructure from a social point of view. The same would hold for state 2 in a Nash equilibrium. Hence states will under-invest in protective infrastructure.

III. Optimal Transfers with Moral Hazard

We next consider how the central government can design a transfer system to get the states to invest in a high level of protective infrastructure at the lowest cost. Transfers will depend on observed income of the two states. The problem is to find the minimum transfer necessary to induce a certain level of protective infrastructure subject to (i) the participation constraint that utility of the state given the transfer is greater than a reservation utility level, and (ii) the incentive compatibility constraint that the level of utility of the state given that it chooses a high level of protective investment is greater than or equal to its level of utility if it chooses a low level of investment.

$$\underset{T(Y_i,\,Y^*_i)}{Min}\ (1-P(I))P(I^*)T(Y_L,Y^*_H)+P(I)(1-P(I^*))T(Y_H,Y^*_L)$$

$$s.t.$$

$$\begin{aligned}(1)\ & Y_{i1}-I^G_{i1}\\ &+P(I)P(I^*)\,u(Y_H\ +T(Y_H,Y^*_H))\\ &+P(I)(1-P(I^*)u(Y_H\ +T(Y_H,Y^*_L))\\ &+(1-P(S))P(S^*)\,u(Y_L\ +T(Y_L,Y^*_H))\\ &+(1-P(S))(1-P(S^*))\,u(Y_L\ +T(Y_L,Y^*_L))\geq u_0\end{aligned}$$

$$(2)\frac{\partial P}{\partial I}u(Y_H\ +T(Y_H,Y^*_L))-\frac{\partial P}{\partial I}u(Y_L\ +T(Y_L,Y^*_H))=1$$

It is useful to re-write this problem as follows. We define $t_{LH^*} = u(T(Y_L, Y_{H^*}))$ as the utility of the transfer T that is based on the state's observed income Y_L and the other state's observed income Y_{H^*}. Letting v be the inverse of u, the transfer paid to a state given the observation of income Y_L as a function of t_{LH^*} is $T(Y_L, Y_{H^*}) = v(t_{LH^*})$. Hence, as a function of the variables t_{ij}, the expected transfer the central government must pay if the state undertakes an investment level I is

$$(1-P(I))P(I^*)v(t_{LH^*})+P(I)(1-P(I^*))v(t_{HL^*})$$

This constitutes the objective function that the central government is trying to minimize.

The expected utility of transfers to the state given an investment level I and net of the state's investment is:

$$(1-P(I))P(I^*)\,u(v(t_{LH^*})) + P(I)(1-P(I^*)u(v(t_{HL^*})) - I$$
$$= (1-P(I))P(I^*)\,t_{LH^*} + P(I)(1-P(I^*)t_{HL^*} - I$$

The expected utility given transfers and investment is

$$(1-P(I))P(I^*)\,(y_L + t_{LH^*}) + P(I)(1-P(I^*)(y_H + t_{HL^*}) + u(Y) - u(I)$$

where y_i is the utility of income level i = H,L. For the first constraint, we must be sure that, given the level of investment, the state is at least as well off in expected value terms with the transfers than with no transfers:

$$(1-P(I))P(I^*)\,(y_L + t_{LH^*}) + P(I)(1-P(I^*)(y_H + t_{HL^*}) + u(Y) - u(I)$$
$$\geq (1-P(I))P(I^*)\,(y_L) + P(I)(1-P(I^*)(y_H) + u(Y) - u(I)$$
$$or$$
$$(1-P(I))P(I^*)\,t_{LH^*} + P(I)(1-P(I^*))t_{HL^*} \geq 0$$

For the second constraint, we must be sure that the state is better off with its chosen investment level I than with some other investment level. Since there is a continuum of investment levels, we follow the literature on incentives and reduce the infinite number of constraints to one by using the state's first-order condition for its investment level:

$$\frac{\partial P}{\partial I} t_{HL^*} - \frac{\partial P}{\partial I}\, t_{LH^*} = 1$$

To obtain more insight into the solution of this problem, we generalize this to consider the case in which uncertain income is drawn from a finite set $Y = \{Y_1, \ldots, Y_M\}$ for each state. We also simplify somewhat by assuming that a state can choose from finite set of investment levels $I = \{I_1, \ldots, I_N\}$ Given an investment level I_n, the probability that income level Y_m is produced is P_{nm} where $\sum_m P_{nm} = 1$ for each investment level. Now the objective function that the central government is trying to minimize (the expected transfer the central government must pay if the state undertakes an investment level I) is

$$\sum_{m^*} \sum_{m} P_{nm} P_{n^*m^*} v(t_{mm^*})$$

The first constraint becomes

$$\sum_{m^*} \sum_{m} P_{nm} P_{n^*m^*} t_{mm^*} \geq 0$$

and the second becomes

$$\sum_{m^*} \sum_{m} P_{nm} P_{n^*m^*} t_{mm^*} - I_n \geq \sum_{m^*} \sum_{m} P_{n'm} P_{n^*m^*} t_{mm^*} - I_{n'}, n' = 1, \ldots, N$$

The first order condition for t_{mm^*} is:

$$\frac{\partial v}{\partial t_{mm^*}} = \lambda + \sum_{n'} \Phi_{n'} \left(1 - \frac{P_{n'm} P_{n^*m^*}}{P_{nm} P_{n^*m^*}}\right)$$

where λ denotes the Lagrange multiplier on the first constraint and $\Phi_{n'}$ denotes the multiplier on the second constraint for n'.

This first order condition has an interesting interpretation. First, suppose that there are no incentive problems so that none of the relative incentive constraints (the second set of constraints) bind. This would be the case if, for instance, investment were observable. Then the first order condition reduces to

$$\frac{\partial v}{\partial t_{mm^*}} = \lambda$$

and the optimal transfer is constant in realized income. Thus, when there are no incentive problems and states are risk-averse, the lowest cost transfer is constant in income. Think of this as an initial or base payment.

Now consider what happens when there are incentive problems so that the relative incentive constraints bind. Then the second term on the right hand side of the first-order condition becomes relevant and the optimal transfer will vary with the probability of a particular income level occurring with a particular investment level of the state government.

To be concrete, suppose that the probability of a high income outcome when investment is high is greater than the probability of a high income outcome when investment is low (i.e. $P_{n'm} P_{n^*m^*} < P_{nm} P_{n^*m^*}$ where n represents high investment and n'

represents low investment). According to the first-order condition, the optimal transfer would be increased in the event of a high income outcome. This gives the state an incentive to undertake high investment. Conversely, suppose that the probability of a low income outcome when investment is high is less than the probability of a low income outcome when investment is low. In this case, the optimal transfer would penalize the low income outcome by giving less than the base transfer.

The problem for the central government, i.e. the reason that it cannot peg transfers to investment directly, is that a state's investment in protective infrastructure is by assumption unobservable or unverifiable. The central government can only try to infer the investment level of the state by observing the outcome. If greater investment in protective infrastructure reduces the probability of a disaster and the amount of investment is unobservable, the central government should design grants that give states greater transfers if they avoid disasters. Thus, there is a trade-off between the risk-sharing insurance provided by transfers and moral hazard. Incomplete risk-sharing that rewards good outcomes and penalizes bad ones will give incentives to states to invest more in protective infrastructure.

IV. The Soft Budget Constraint Case

A different and distinct reason for underinvestment in protective infrastructure is the anticipation by a state that the central government will come to the rescue with transfers if a shock occurs. The state sees a soft budget constraint and consequently underinvests in infrastructure. This soft budget constraint case does not depend on

uncertainty or asymmetric information, but rather results from the timing of decisions. To simply model this case, we consider the first problem above, but we do not allow state investment decisions to impact he probability of an event occurring.

Suppose first that the central government moves first and offers transfers of T. In this case, the state government's problem is:

$$\begin{aligned}\underset{I_1}{\text{Max}}\ & u(Y_1 - I_1) \\ & + PP^* v(Y_H + I + T) \\ & + P(1-P^*)v(Y_H + I + T) \\ & + (1-P)P^* v(Y_L + I + T) \\ & + (1-P)(1-P^*)\, v(Y_L + I + T)\end{aligned}$$

Since the state government moves second, it takes the transfer from the central government as fixed and the first order condition is:

$$\frac{\partial u}{\partial I} = E\left(\frac{\partial v}{\partial I}\right)$$

The state self-insures and equates the marginal utility of a foregone dollar of certain income with the expected marginal utility of that investment dollar as it is added to uncertain income.

Now suppose that the central government moves after the state government decides how much to invest and declares that it will use risk sharing transfers. We defer the central government's problem for now, but denote T* as the solution to the central government's problem. The arguments of the function T* and its value depend on the

objective of the central government. Suppose, though, that the central government undertakes transfers that are related to the investment decision of the state, as would be the case if the central government is insuring against the shock. To the extent that the state government itself undertakes the investment to self-insure, the central government does not have to, so in this case T* would be a negative function of I. In its decision, the state would predict what the central government would do and would invest less than if there were no transfers. This is easily seen by solving:

$$\begin{aligned}
&\underset{I_1}{\text{Max}}\, u(Y_1 - I_1) \\
&+ PP^* v(Y_H + I + T^*) \\
&+ P(1-P^*)v(Y_H + I + T^*) \\
&+ (1-P)P^* v(Y_L + I + T^*) \\
&+ (1-P)(1-P^*) v(Y_L + I + T^*)
\end{aligned}$$

The first order condition is:

$$\frac{\partial u}{\partial I} = E\left(\frac{\partial v}{\partial I} + \frac{\partial v}{\partial T^*}\frac{\partial T^*}{\partial I}\right)$$

As T* is negatively related to I, the state will underinvest relative to the decentralized equilibrium.

V. 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 state government protective effort is unobservable, federal disaster insurance will result in underinvestment in pre-disaster protective investment. Unfortunately, we believe that unobservability is empirically relevant. Information about local vulnerability – and which investments actually reduce this vulnerability - is likely to be most easily available to state officials, providing them an informational advantage over the federal level. A second approach to the problem, ex post commitment of federal resources to cover state government budget shortfalls, leads to a similar conclusion. Again, this situation is empirically relevant in the US and elsewhere (Goodspeed 2002).

Matters are improved when the federal government either pre-commits to a level of interregional transfers, inducing states to self-insure in the soft budget constraint view, or rewards successful avoidance of disasters so as to avoid moral hazard by state governments. As in Persson and Tabellini (1996), centralization of the provision of protective infrastructure would eliminate inefficiency by eliminating the moral hazard. Yet since local officials have an informational advantage in determining vulnerability and how to minimize it, this solution is likely to raise other problems. Steinberg (2000, pp 103-111) describes one such situation in some detail. In 1968, the Federal government adopted the National Flood Insurance Program, which offered insurance to residents of 100-year floodplains at a subsidized rate. In exchange, local officials were to enforce regulations requiring that new structures be built above the 100-year flood level. Yet in

the interest of economic development, officials in some locations granted 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 three. All of these extensions may add some richness to the findings reported here, but we believe that none is likely to reverse our main conclusions.

We model state 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.

Second, we model federal disaster aid as a lump-sum transfer, and exclude treatment of both direct federal protective spending and federal-state grants to reduce the cost of protective infrastructure. Yet about a quarter of federal government disaster spending is designed to reduce losses ex ante. With effective use of this tool, the federal government may be able to improve upon the results we report. But the example of the National Flood Insurance Program is not encouraging.

A final extension concerns the independence of shocks across regions. 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 to shocks to income, regardless of their probability and magnitude, are difficult to solve. We find that in a simple set-up with the potential for moral hazard at the state level and lump-sum transfers from the central government, disaster protection will be underprovided. Nonetheless, creative use of federalist institutions may yield outcomes superior to those available in a unitary system. The challenge is to provide appropriate incentives for local protective actions, whether regulatory or structural. This is a difficulty that has bedeviled disaster policy makers for generations. We do uncover one possibility – rewarding successful *avoidance* of disasters. The politics of such a program, however, like much else to do with disasters, are likely to be difficult.

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