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Disaster Policies

Some Implications for Public Finance in the U.S. Federation

David E. Wildasin
University of Kentucky

Although major disasters like the 2005 Gulf Coast hurricanes are infrequent, they dominate empirical loss distributions, as illustrated by a statistical analysis of flood losses in Louisiana. Extraordinary Federal emergency assistance has shifted a large portion of the burden of the 2005 floods to the rest of society, relieving financial stress in the disaster-stricken region but raising serious questions about the incentives for subnational governments to implement costly but efficient disaster avoidance policies in the future. The Federal government cannot credibly commit not to insure losses from future disasters, nor can it efficiently assume responsibility for land use, economic development, and other state and local government policies that affect disaster risk. Mandatory disaster reserves provide an alternative policy option through which actuarially fair Federal insurance could credibly strengthen the incentives for efficient subnational government disaster policies.

Keywords: *intergovernmental fiscal relations; disaster policy; extreme value theory; state government finance*

1. Introduction

Disasters and catastrophes often result in policy responses by all levels of government in an affected society. In the U.S. context, the terrorist attacks of 9/11 and the Gulf Coast hurricane disasters of 2005 are recent examples of significant events that have presented a wide range of policy challenges for Federal, state, and local governments (Chernick 2001;

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Wildasin 2002; Chernick and Haughwout 2006). In a federal system, effective public-sector post-disaster relief and recovery efforts require management coordination and appropriate sharing of financial costs. The prospect of future catastrophes also engages all levels of government in disaster avoidance and preparedness, again requiring effective intergovernmental coordination. These two facets of disaster policy—the *ex post* response to disasters that have occurred, and the *ex ante* avoidance of and preparation for disasters that have yet to occur—are intimately related. *Ex ante* policies affect the likelihood and magnitude of future disaster losses. Equally important, anticipated *ex post* responses to disasters affect incentives for *ex ante* disaster-avoidance behavior.

This article examines the losses caused by the recent catastrophic hurricanes on the Gulf Coast, the policy responses to these catastrophes, and the implications of observed policy for *ex ante* disaster-avoidance incentives. These hurricanes caused exceptionally high property losses, principally from flooding, with total losses in the range of $100-125 billion. Equally exceptional has been the public-sector response, particularly on the part of the Federal government. Although the management of the Federal response has been the subject of considerable criticism, the magnitude of Federal financial assistance has been remarkably generous, with supplemental disaster relief funding now amounting to more than $110 billion. Clearly, much of the cost of these hurricanes has been shifted to the broader society, not only through private insurance and more routine forms of Federal government assistance, but through *ad hoc* financial relief provided by this special legislation, telling evidence of the Federal government's capacity and willingness to bring massive amounts of fiscal resources to bear in response to this crisis.

The Federal response to the Gulf hurricanes raises important questions about future disaster avoidance efforts on the part of private and public decision makers. Subnational governments have numerous instruments through which they can influence exposure to disaster risks. In particular, state and local land-use controls and economic development policies affect the spatial distribution of residential, commercial, and industrial activities and thus the hazards to life and property in floodplains, seismically active regions, and other locations susceptible to natural disasters. By insuring against localized disaster risks, Federal government disaster relief policies may adversely affect the incentives for subnational governments to undertake costly disaster-avoidance (and disaster-preparedness) efforts, a form of moral hazard.

It could be argued, of course, that the Federal response to the hurricanes of 2005 is highly exceptional. Because such large disasters are very rare, *ad hoc* Federal emergency assistance might have only negligible effects on subnational government behavior, since there may be no explicit assurance that regions afflicted with major disasters in the future will receive similar special assistance. However, such a supposition attaches great significance to the rarity of large disasters and possibly insufficient importance to their magnitudes. Taking the statistical properties of disaster loss distributions properly into account suggests that it is precisely the exceptionally large disasters that are of greatest importance for disaster policy.

To show this, section 2 below discusses some basic principles of extreme value theory (EVT), a methodology designed to facilitate the analysis of the tails of statistical distributions. EVT has proven to be a useful tool for climate scientists, hydrologists, insurance actuaries, and others concerned with infrequent but extreme natural events and their adverse consequences. A general lesson from EVT is that the behavior of the tails of statistical distributions cannot easily be inferred from the study of the masses of observations near their centers, and that for some purposes, such as insurance analysis, "outliers" should be viewed not as "exceptional cases" to be dismissed, but rather as the observations of utmost importance.

To illustrate this methodology, section 2 also presents an analysis of flood losses in Louisiana (to the author's knowledge, the first application of EVT to state-level economic data), confirming for that state an important empirical regularity that has been found in other flood-loss studies: infrequent but large floods account for a very large share of all flood losses. Since rare large floods account for the bulk of disaster losses, most disaster relief is also attributable to these infrequent but large events, and the main potential payoff from *ex ante* disaster policies arises from the mitigation of catastrophic losses. Thus, the policy responses of the Federal government to the Gulf Coast hurricanes, and their potential efficiency implications, constitute much more than an interesting special case. Federal, state, and local policies for dealing with rare major disasters are empirically the most important aspects of all disaster policy.

Section 3 examines the implications of Federal disaster policy from a federalism perspective. As noted above, Federal assistance to disaster-stricken regions offers a form of implicit insurance. Like other forms of insurance, this assistance offers potential benefits but it can also adversely affect incentives, including the incentives for state and local governments to implement efficient disaster-avoidance policies. Section 3 discusses the incentive problems raised by current policies, focusing on this issue in the context of fiscal federalism and intergovernmental fiscal and regulatory relations. It outlines some policy alternatives that may mitigate some of the adverse incentive effects of current policy while taking into account the fundamental commitment problem of the Federal government, which, it appears, cannot credibly deny *ex post* disaster relief to regions stricken with major disasters. Section 4 provides a concise summary.

2. Modeling Extreme Events: Flood Losses in Louisiana

The study of the risks from natural disasters must begin with an analysis of stochastic natural events such as storms, wind, and rainfall. These natural events, when combined with human action such as property development, give rise to economic losses. Subsection 2.1 briefly introduces some ideas from extreme value theory (EVT), a branch of statistical analysis devoted to the study of the extremes (maxima and minima) of statistical distributions. EVT has been fruitfully applied in climatic, hydrological, and insurance studies in which analysts are concerned with exceptionally high (or low) levels of rainfall, wind speeds, water levels, wave heights, and their economic consequences. To illustrate the application of EVT in a policy-relevant context, section 2.2 presents an analysis of flood losses in the state of Louisiana. As will become clear, data from the period 1955-2003 reveal a heavy-tailed loss distribution, an empirical regularity commonly encountered in storm loss data. Applying EVT methods to these data suggests that flood losses in Louisiana are dominated by rare but large flood events, emphasizing the importance of accurate estimation of the probabilities of these rare floods for planning and policy purposes.

The same analytical methods are then applied to the data when extended beyond the 1955-2003 sample period to include estimated flood losses for 2005. The losses from the Katrina disaster were so large that they significantly affect the estimated probability of large flood losses in Louisiana, a finding that highlights the challenges inherent in the statistical analysis of extreme values.

2.1 Modeling Disaster Losses

Hurricanes are by no means infrequent occurrences along the Atlantic and Gulf Coasts of the United States, and they commonly cause some economic losses, especially because of flooding. The experience of the major 2005 storms (Hurricanes Katrina, Rita, and Wilma) has shown that the economic damages of hurricanes are occasionally extraordinarily large. As discussed further in section 3, the prospect of such a major hurricane was not entirely unforeseen. Nevertheless, assessing the likelihood of major flood losses is a challenging statistical problem. Storms are random events whose adverse effects depend not only on their size, intensity, and duration, but also on whether their tracks bring them into close proximity to major population centers. Planning for hurricanes and other disasters is, of necessity, an exercise in decision making under uncertainty. As in all such contexts, it is important to understand the nature of the random variables in question.

Meteorological observations form an essential body of data for the statistical analysis of storms and storm damages. It is easy to see, however, that modeling the distribution of large storms, and the losses that they cause, presents somewhat unusual statistical challenges. Based in large part on normal distribution theory, much of classical statistical methodology focuses on the analysis of central tendencies. In a meteorological context, statistics such as mean monthly or daily rainfall, mean wind speed, mean wave height, or mean sea level lend themselves to modeling using traditional methods. Hurricanes or floods, however, are of interest and concern mainly because and to the extent that they diverge from meteorological norms; that is, in a statistical sense, they lie in the "tails" of the distributions of meteorological variables. For the analysis of hurricane flood risks in New Orleans, for instance, an accurate assessment of the mean New Orleans August rainfall, wind speed, or sea level is of little value. Rather, the random variables of greatest interest are the maximum rainfall, wind speed, or sea level, and the important problem is to understand the likelihood that these will exceed values that trigger floods or wind damage. Extreme value theory is concerned with the modeling of such comparatively unusual events.

A key theorem, analogous to the central limit theorem, characterizes the distribution of the extreme values of a random variable. Under suitable regularity conditions, the maximum value of a sample of independent and identically-distributed random variables asymptotically follows the generalized extreme value (GEV) distribution

$$G(z) = \exp\{-[1 + \xi((z - \mu)/\sigma)]^{-1/\xi}\}$$

where μ, σ, and ξ are, respectively, the location, scale, and shape parameters of this three-parameter distribution and where the support of the distribution satisfies $1 + \xi((z - \mu)/\sigma > 0$.[1] As examples, the maximum values of samples of normally and lognormally distributed random variables follow distributions in which the shape parameter $\xi = 0$, in which case the GEV distribution can be shown to reduce to the Gumbel distribution $\exp[-\exp\{-(z-\mu)/\sigma\}]$.

By observing the maxima of a large number of samples, it is possible to estimate the parameters of the GEV distribution. Such a procedure unfortunately requires very large amounts of data, highlighting a fundamental problem with the analysis of extreme values: the most important observations in a sample are not the numerous observations near the center of the sample, but the comparatively few observations near its upper (or lower) tails. Extreme values are by their nature comparatively rare and statistical inference thus faces the intrinsic challenge of sparse observations. There is no easy solution to this problem, but one useful method, known as the "peaks over threshold" approach, uses all of the observations in a sample that exceed a high threshold u. The "excess" of each observation x_i over this threshold value, $y = x_i - u$, also called an exceedance, can be shown to follow the generalized Pareto distribution (GPD)

$$H(y) = 1 - (1 + \xi y/\sigma')^{(-1/\xi)}$$

where ξ is the shape parameter for the corresponding GEV distribution and $\sigma' = \sigma + \xi(u - \mu)$ is a scale parameter whose value depends on the parameters of the corresponding GEV distribution and on the threshold value. The GPD is a two-parameter distribution that can be estimated from the sample of all observations in excess of a high threshold u. Threshold selection is a critical issue in this approach, as a high threshold is needed to justify the GPD approximation to the asymptotic distribution of exceedances but a high threshold also reduces the size of the available sample. The fact that the scale parameter depends linearly on the threshold, however, provides a useful diagnostic tool; in particular, estimation of the model for any threshold above a critical large value should display this property, which can alternatively be characterized by saying that a modified scale parameter $\sigma^* = \sigma' - \xi u$ should be independent of u.

The shape parameter ξ is of central interest in extreme value modeling. When this parameter is positive, the distribution of excesses is often characterized as "heavy tailed." If $\xi > 0$ the distribution of excesses is unbounded, the distribution has an infinite variance if $\xi > 1/2$, and it has an infinite mean if $\xi > 1$.[2] As noted above, the shape parameter is zero for distributions like the normal and lognormal.

To summarize, EVT focuses on the properties of the tails of statistical distributions. The GEV and GPD are the limiting distributions for sample maxima and for threshold exceedances; estimation of the parameters of these distributions, and of their shape parameter in particular, provides crucial information about the probability of large events and their "weight" in the distribution. A positive value of the shape parameter is indicative of a heavy-tailed distribution. If this parameter exceeds one, the distribution of exceedances has an unbounded mean.

The importance of these distributions for modeling disasters, and the economic losses associated with them, should be apparent. EVT models have been used (Embrechts, de Haan, and Huang 2000) to estimate the probability of extreme waves leading to failure for a dike along the Dutch seacoast, where a catastrophic flood occurred in 1953. As another illustration, the loss experience of private insurance companies will be determined by the distribution of losses in excess of policy deductibles. Empirical analysis frequently reveals that a large fraction of total losses results from a comparatively small number of major loss events; e.g., a Swedish insurance group experienced claims from forty-six major wind storm events over an eleven-year period, just one of which accounted for more than one-fourth of total losses over the period (Rootzen and Tajvidi 1997).

Estimation of the shape and other parameters of the GEV and GPD is difficult because it requires observations from the tails of the distribution of the underlying random variable. However, sparse though they are, these are the observations of critical importance for an analyst interested in modeling extreme values. In the context of economic losses from disasters, the rare extreme events at the upper tails of statistical distributions are precisely the events of greatest concern. To quote Schirmacher, Schirmacher, and Thandi (2005, 344) in the context of reinsurance, "In the past very large losses would be labeled as outlier observations, rationalized as extremely improbable, and sometimes even removed from the data set. For the reinsurance actuary these observations are likely to be the most important observations in the data set."

2.2 Flood Damages in Louisiana

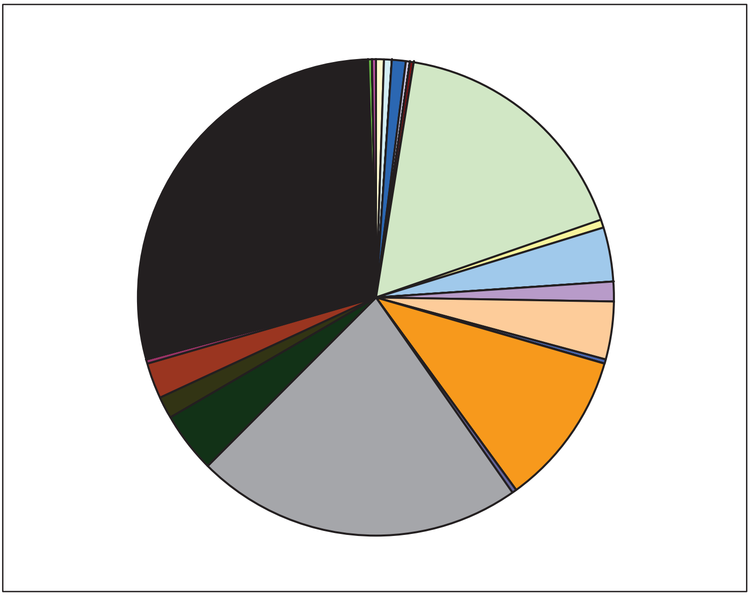
Let us now turn to the issue of flood losses in the state of Louisiana. Empirically, flooding in Louisiana is quite common, with non-negligible losses (greater than $1 million, in 1995 dollars) occurring in thirty-one of the forty-six years from 1955-2003 for which such data are available (Pielke, Downton, and Miller 2002; data collection was interrupted from 1980-1982). Although floods are frequent in Louisiana, the bulk of flood damage occurs in just a handful of years: the eight years with the greatest losses account for approximately 95 percent of total damages over the forty-six years. Preliminary data from Hurricane Katrina indicate that the losses from this one storm easily dwarf all previous losses (which total less than $8.5 billion 1995 dollars). One major private (re)insurer estimates total property losses from Katrina and Rita (in all states) at roughly $125 billion, of which about half were privately insured (MunichRe 2006). The Bureau of Economic Analysis (BEA) (2006) reports storm damages to fixed assets (i.e., property losses) at $70.1 billion during August-September 2005 (the Katrina and Rita months). A report to the President (GPO 2006) finds that Katrina alone resulted in $96 billion in property damages. These figures do not include non-property losses and do not break down losses by state, but, under reasonable assumptions, the 2005 losses suffered in Louisiana appear to be roughly *an order of magnitude larger* than the *cumulative* real damages of the previous half-century. This typifies a heavy-tailed loss distribution.

For analytical purposes, it is helpful to express these losses relative to the size of the state's economy rather than in absolute terms, since larger losses are to be expected over time because of population and economic growth.[3] Over the half-century prior to Katrina, mean annual flood damages were about 0.28 percent of state personal income (SPI), while the median was a much smaller 0.0008 percent, again indicating the importance of the upper tail. Flood damages exceeded 1 percent of SPI on four occasions prior to 2005, with a maximum value of 3.7 percent of SPI in 1992 (Hurricane Andrew). Figure 1 illustrates these losses for the period 1955-2003, showing that the four largest loss events dominate the data.

To take Katrina- and Rita-related losses into account is somewhat difficult given that official tabulations are not yet available, but it is clear that these losses may well amount to 40-60 percent of SPI; the following analysis assumes a value of 50 percent.[4] Inclusion of this crude estimate for 2005 flood losses raises mean flood losses in Louisiana from 0.28 percent to 0.38 percent of SPI, an impact dramatically illustrated by figure 2. It may be of interest to note that while average flood losses are fairly high in Louisiana by national standards, some other states, particularly North and South Dakota, have been much more severely affected by floods in relation to SPI (Wildasin forthcoming) because of the extreme flood event of 1997.

It is natural to apply EVT methods in estimating the probability of large flood losses in Louisiana. Table 1 presents peaks-over-threshold maximum likelihood estimates of the parameters of the GPD distribution, using the 1955-2003 data for Louisiana—i.e., excluding the estimated losses for 2005. For the sake of comparison, this table also presents

Figure 1
Annual Louisiana Flood Losses, as Percent of SPI, 1955-2003



estimates for the parameters of a lognormal distribution—an alternative and commonly used distribution with a moderately heavy upper tail, often used to describe skewed distributions. As remarked above, the lognormal corresponds to a maintained assumption that the shape parameter for the distribution of its extreme values is equal to zero. The GPD estimates exhibit some sensitivity to the choice of threshold, but the shape parameter is estimated to be fairly close to one for a wide range of threshold values and standard diagnostics (e.g., a QQplot) are acceptable. The standard errors for the GPD estimates, however, are quite large, so that values for ξ as low as zero and as high as two cannot be ruled out. Thus, in particular, the possibility that these losses are lognormally distributed cannot be ruled out, and indeed the lognormal distribution seems to provide a reasonably good fit to the data.

The estimates in table 1 can be used to calculate the estimated probabilities of large losses and to compare these with empirically observed losses.

Figure 2
Annual Louisiana Flood Losses, as Percent of SPI, 1955-2005

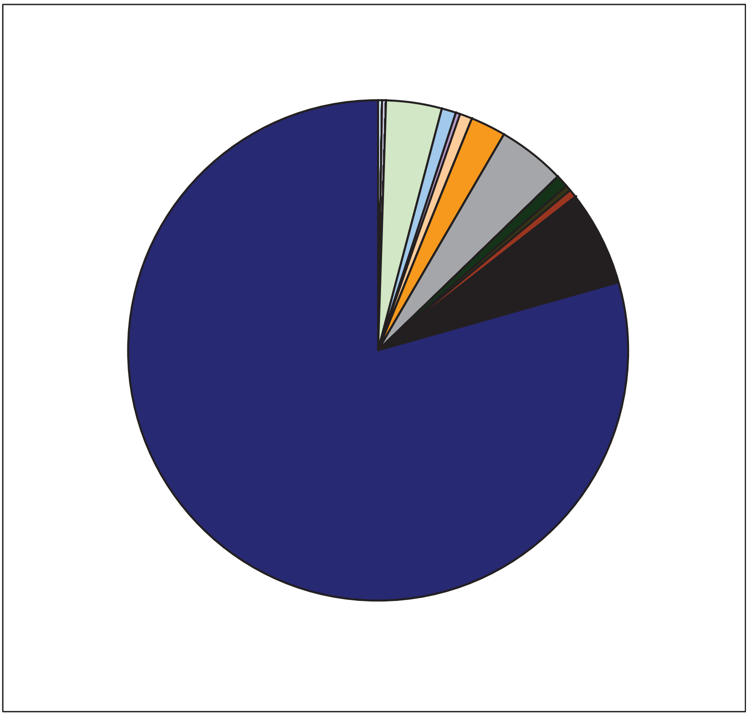


Table 2 shows, for example, that the GPD estimates in table 1 imply that a loss of one percent of SPI or greater in any year has a probability of 0.2. This point estimate is substantially higher than the value of about 0.07 implied by the lognormal estimates. The probability of still larger losses is again substantially higher for the GPD estimates than for those based on the assumption of a lognormal distribution, as is to be expected given the differences in the estimated and assumed values of the shape parameter for each. Note that the empirical frequency for losses in excess of 1 percent and 3.7 percent (the pre-Katrina maximum of Hurricane Andrew) are closer to those estimated under the assumption of lognormality than to the GPD estimates, which are substantially higher. Based on the data as

Table 1
Flood Damage as Percent of SPI, Louisiana, 1955-2003

Generalized Pareto		Lognormal	
Modified Scale	Shape	Mean (of log)	Standard Deviation (of log)
24601	1.020	5.28	2.68
(1500)	(0.618)	(0.43)	(0.30)

Notes: SPI = state personal income. Standard errors in parentheses. Data are rescaled by 10^6. Threshold for generalized Pareto distribution (GPD) estimates = 300; number of exceedances = 15. Lognormal estimated using all positive observations ($n = 39$).

Table 2
Estimated Probability of Large Flood Damages in Louisiana

	Size of loss greater than or equal to (percent of SPI)			
	1%	3.7%	10%	50%
GPD, estimated probability	0.201	0.065	0.0253	0.0027
Lognormal, estimated probability	0.072	0.026	0.0101	0.0007
Empirical frequency (1955-2003 data)	0.086	0.022	0.0000	0.0000
Empirical frequency (1955-2005 data)	0.104	0.042	0.0210	0.0210

Notes: SPI = state personal income. Table entries show probability of loss greater than or equal to x% of SPI. Generalized Pareto distribution (GPD) and lognormal parameter estimates from table 1.

observed up to 2003, one is tempted to conclude that the GPD estimates put "too much" weight in the upper tail of the distribution and that a lighter-tailed distribution like the lognormal is preferable.

One can use the parameter estimates in table 1 to predict the likelihood of much larger damages than those observed in the data up through 2003. Table 2 shows that damages as high as 10 percent of GSP would be expected with a probability of about 0.025 using the GPD estimates but less than half as often—just 1 percent of the time—according to the lognormal estimates. An even larger loss, as high as 50 percent of SPI, only has a probability of 0.0007 (less than once per millennium, on average) under the lognormal estimates, but a much larger probability of 0.0027, using the GPD estimates. No losses of these magnitudes are observed in the 1955-2003 data. The empirical loss distribution inclusive of 2005 looks rather different, however, as shown in the bottom row of table 2. We now see that losses as large as 50 percent of SPI have occurred about 2

Table 3
Flood Damage as Percent of SPI, Louisiana, 1955-2005

Generalized Pareto		Lognormal	
Modified Scale	Shape (of log)	Mean (of log)	Standard Deviation
2118	1.660	6.33	2.47
(1341)	(0.708)	(0.43)	(0.30)

Notes: SPI = state personal income. Standard errors in parentheses. Data are rescaled by 10^6. Threshold for generalized Pareto distribution (GPD) estimates = 300; number of exceedances = 16. Lognormal estimated using all positive observations ($n = 40$).

Table 4
Re-Estimated Probability of Large Flood Damages in Louisiana

	Size of loss greater than or equal to (percent of SPI)			
	1%	3.7%	10%	50%
GPD, estimated probablity	0.269	0.129	0.0716	0.0180
Lognormal, estimated probablity	0.122	0.045	0.0180	0.0030
Empirical frequency (1955-2005 data)	0.104	0.042	0.0210	0.0210

Notes: SPI = state personal income. Table entries show probability of loss greater than or equal to x% of SPI, generalized Pareto distribution (GPD), and lognormal parameter estimates from table 3.

percent of the time. This frequency is an order of magnitude greater than implied by the GPD estimate of 0.0027, but two orders of magnitude greater than that implied by the lognormal distribution estimates. In view of the 2005 data, it would appear that the GPD estimates, based on the 1955-2003 data, may give a better picture of the likelihood of very large flood losses.

To assess the sensitivity of parameter estimates to a large loss observation like that of 2005, it is of interest to re-estimate the GPD and lognormal parameters by including 2004 (assumed to have a loss of zero) and 2005 (50 percent of SPI, as described above). Table 3 presents the results of this estimation, and table 4 shows the implied probabilities of large losses under each set of estimates.

As shown in table 3, the GPD shape parameter is now estimated to be considerably higher than that estimated using only the data through 2003, taking on a value of 1.66 as compared with the previous estimate of 1.02.

Now, the estimated value of the shape parameter is significantly greater than zero, thus rejecting (at a 95 percent level) the hypothesis of lognormality. It is interesting to note that the estimated value of the shape parameter exceeds the critical value of one, above which the mean of the loss distribution does not exist, although it is not significantly greater than one. Even though we can reject the hypothesis of lognormality, the parameter estimates based on the maintained assumption of a lognormal distribution still show a good fit and the estimated parameters of the lognormal distribution are not much affected by the inclusion of the data for 2005. This is perhaps not surprising given that the lognormal is estimated using forty observations, not just the fifteen that exceed the GPD threshold, and the weight attached to the addition of this one "outlying" datum is thus comparatively modest.

Table 4 shows that the GPD performs even more poorly than before, and continues to be outperformed by the lognormal, in estimating the probabilities of losses as large as 1 percent or 3.7 percent of SPI. As expected, including the data for 2004 and 2005 raises the estimated probability of losses as large as 50 percent of SPI: the lognormal estimate puts this probability at 0.003, about ten times larger than the table 2 calculation, and the GPD estimate is now 1.8 percent, also about an order of magnitude larger. Note that the GPD estimate of 1.8 percent is now very close to the empirical frequency of 2.1 percent, as compared with the lognormal estimate of only 0.3 percent.

What lessons can be drawn from this analysis of flood losses in Louisiana? First, it reveals that the flood loss distribution for this state, and presumably for most other states, is indeed heavy-tailed. The average flood inflicts only modest economic losses, whereas the average dollar of flood losses occurs in one of the comparatively few years in which there are large losses. Indeed, including the Katrina year of 2005, one can say that the average dollar of flood losses in Louisiana is the consequence of that one flood. Second, the empirical importance of extreme disasters puts a premium on statistical modeling that facilitates accurate assessment of the probabilities of these exceptional cases. Since observations in the tails of loss distributions are intrinsically sparse, EVT methods, which are designed explicitly to handle such problems, offer a promising approach to this inherently difficult modeling challenge. Third, from a policy viewpoint, it follows that disaster relief costs in Louisiana, and presumably in most states, are dominated by the costs of rare but extreme floods. Disaster avoidance policies that reduce the probability or magnitude of the worst floods can have large payoffs, while the benefits from policies that avert more commonplace floods are likely to be relatively modest. Policy responses to and preparations for extreme disasters are thus the most critical elements of overall disaster policy, and benefit-cost analysis of alternative policies should pay especially close attention to their consequences in extreme cases. To paraphrase Schirmacher, Schirmacher, and Thandi (2005), quoted earlier, to treat policies in extreme disasters as "outliers" to be dismissed as highly unusual is to dismiss the most important observations for policy analysis.

3. Challenges for Federalism in the Wake of 9/11 and Katrina: Institutions, Incentives, and the Economic Incidence of Disasters

Let us now turn to issues of disaster policy. As noted in the introduction, recent exceptionally damaging natural and man-made disasters—specifically, the 9/11 terrorist attacks and Hurricane Katrina—have given rise to exceptional policy responses. Most notably, the Federal government has undertaken massive financial relief for the states affected by these disasters. Special legislation has awarded some $110B of Federal assistance to the states affected by the 2005 storms, with most of this assistance flowing to Louisiana (Murray and Bea 2007). This relief is additional to the customary relief mechanisms provided by existing programs like the National Flood Insurance Program and the implicit and automatic relief that is provided by the personal and corporation income tax systems and a wide range of means-tested cash and in-kind benefit programs which increase Federal transfers to and reduce taxes collected from a disaster-stricken region.[5] Some of this Federal assistance takes the form of explicit intergovernmental transfers to affected state and local governments. Federal transfers to households and businesses provide significant indirect fiscal relief to state and local governments since these transfers positively affect state and local tax revenues and obviate the need for some types of state and local expenditures. The magnitude of these direct and indirect transfers is difficult to estimate, but the fiscal circumstances of Louisiana, at least, appear to have been substantially eased as a result since Katrina struck. It seems quite possible that total Federal relief for the 2005 storms, as measured by the explicit and implicit costs to Federal taxpayers, will approach or even exceed the total damages incurred.

Would (or will) the Federal government provide similar assistance when the next great disaster occurs? The 9/11 attacks and the flooding in

New Orleans were undoubtedly somewhat unique events that elicited somewhat unique Federal government responses. Other, seemingly similar cases that may arise in the future, such as the devastation of Memphis or San Francisco from a large earthquake, the flooding of other major cities as a result of tsunamis or major storms, or the radioactive contamination of a major city center by a terrorist attack, may fail to elicit a comparable Federal response. More plausibly, however, the recent disasters have exposed a significant feature of the contemporary American fiscal system, namely, that the responsibility for financing the *ex post* recovery from "local" disasters rests, to a large degree, with the Federal government. Like consumers whose preferences are revealed by the choices they make in the marketplace, recent disasters have "revealed" an important but hitherto implicit underlying institutional structure in which, to put it succinctly, the Federal government is the insurer of regional disaster risks. The remaining discussion examines some of the implications of this "revealed institutional structure" of the American fiscal system and its *ex post* disaster-response mechanisms.

3.1 The Assignment of Disaster Relief and Avoidance Responsibilities in the American Federation

The "assignment problem" is a classical issue in fiscal federalism. Traditionally, subnational governments are thought to have a comparative advantage over central governments in the performance of allocative functions whose benefits and costs accrue primarily to households residing within their boundaries. Central governments, by contrast, are better able to undertake redistributive policies, with smaller efficiency costs, than state or local governments.

The massive Federal financial relief for the Gulf Coast hurricanes is easily understood as a form of *ex post* redistribution or as the *ex post* execution of a social insurance contract: the marginal utility of income rises sharply for households in a region that has been struck by a disaster, and *lump-sum non-distorting transfers* from the rest of society to that region would raise utilitarian social welfare or, equivalently expressed, average or *ex ante* expected utility (Varian 1980; Caplan, Cornes, and Silva 2000). The normative case for such assistance may strike many as self-evident, and the substantial Federal aid that has been directed to New York and to the Gulf Coast is a convincing demonstration of the political appeal of such policies. The assignment of responsibility for this insurance or redistributional function to the Federal government appears to be generally consistent with classical federalism principles.

Like other forms of insurance, however, Federal disaster relief can adversely affect disaster avoidance incentives. In particular, from a fiscal federalism viewpoint, *ex post* central government disaster assistance weakens the incentives for subnational governments to undertake costly disaster avoidance policies. The assignment of disaster relief responsibility to the Federal government, coupled with significant subnational government responsibility for disaster avoidance policy, creates a potentially serious misalignment of incentives in the U.S. federation.

To appreciate the nature of this problem, note first that classical federalism arguments provide a strong presumption for the decentralization of much if not all responsibility for disaster avoidance. The most important costs of many disasters accrue, in the first instance, to those in the immediate vicinity of major storms, earthquakes, or other disasters. Compared to the national population as a whole, local citizens and policymakers are typically well aware of major hazards and of the benefits and costs of possible hazard mitigation policies. (In New Orleans, for instance, local residents and policymakers have long been aware of flood risks.[6]) The local payoff from the utilization of this information in development, zoning, infrastructure, and other local policymaking takes the form of reduced disaster losses. Federal emergency relief in recent disasters reduces this payoff, however. For instance, if state and local authorities had in the past pursued policies to limit development in those portions of the New Orleans metropolitan area at greatest flood risk, the damages from Katrina, and thus the costs of Federal disaster relief, would have been reduced. A large portion of the benefits of such disaster avoidance efforts would thus have accrued to Federal taxpayers, that is, primarily to households not residing in New Orleans or Louisiana, whereas the costs of these policies would fall on local residents and landowners. The assignment of responsibility for *ex post* disaster relief policies to the Federal government implies that a large portion of the benefits of *ex ante* disaster avoidance efforts undertaken by subnational governments spill out to the broader society, giving rise to a classical externality problem.[7]

3.2 Moral Hazard and Policy Options for Disaster Relief and Avoidance

The externalities arising from the current assignment of disaster policy responsibilities can be viewed as a moral hazard problem of the type commonly found in insurance analysis. One apparently simple solution to this problem would be for the Federal government not to offer *ex post* relief to disaster-stricken regions, that is, to (re)assign responsibility for disaster relief to subnational governments. This solution would be unattractive to many on normative grounds, and is open to the objection that it is not a feasible policy because the Federal government cannot credibly commit to it. Recent experience has shown that the Federal government is willing and able to intervene with massive financial assistance, if necessary on an *ad hoc* basis, following major disasters.

A second possible solution to the moral hazard problem would be for the Federal government to assume full responsibility for disaster avoidance activities, assuming control of economic development and land-use policies that influence exposure to disaster risks. Leaving aside possible constitutional objections to Federal encroachment on state government powers, such a solution would entail extremely high costs. Expressed in terms of insurance contracting, it may be excessively costly or impossible to eliminate informational asymmetries between subnational and national governments, so that complete centralization of disaster avoidance policy is either very inefficient or simply infeasible.[8] Expressed in terms of federalism, the upward reassignment of responsibility for all disaster avoidance policy would sacrifice the efficiency gains from decentralized local policymaking.

As these remarks make clear, current disaster policy is characterized by a mismatch between the responsibility for *ex ante* disaster avoidance, on the one hand, and the financial burden of *ex post* disaster relief, on the other hand. Increased Federal government control of subnational government policymaking aimed at hazard mitigation is likely to be very costly, but failure to exercise such control may result in insufficient hazard mitigation. There is no simple solution to this policy dilemma.

On the other hand, if private insurance contracting can be used as a guide, there may be ways in which to minimize the costs of imperfect disaster policies. In the private insurance context, insurers often utilize some combination of deductibles and coinsurance to enhance the incentives for efficient risk avoidance by insurees. Analogous arrangements are possible in the federalism context, even taking into account the fundamental constraint that the Federal government may not credibly be able to "refuse" to provide *ex post* disaster relief. Given this constraint, the challenge is to find mechanisms through which the benefits of costly disaster avoidance efforts can accrue to subnational governments.

One way to do so would be for the Federal government to mandate the establishment of disaster contingency reserves (e.g., "rainy day" funds) by subnational governments, assumed here to be the state governments. Under such a plan, each state would be required to contribute to a fund from which it would receive disaster relief, in accordance with applicable Federal regulations, in the event of a Federally declared disaster. Although distributions of disaster relief from such "mandatory disaster reserves" (MDRs) would be controlled by Federal regulations, the funds in each state's reserve would nevertheless remain the property of that state in the sense that the assets in each MDR would not be used to provide disaster relief for other states or for any other purpose.

The MDRs would help to finance disaster relief but the Federal government could augment MDR distributions with additional assistance. If carefully formulated, the rules governing distributions from MDRs and the provision of additional Federal assistance would make it possible to reduce, though not to eliminate entirely, the moral hazard problems associated with current policy. Note first that regulations could require the entirety of all disaster losses, up to some level D, to be paid entirely from MDRs, with no Federal assistance. In effect, states would thus be self-insured for all disaster losses of an amount $L \leq D$. When larger disasters occur, the Federal government could assist the disaster-stricken state by paying for some fraction f of disaster losses in excess of D, with the remaining fraction of losses to be paid from the accumulated MDR fund. In the event of very large losses, the MDR fund would be entirely depleted and the Federal government would then have to pay for the entirety of any remaining disaster relief. If R denotes the size of the mandated reserve, then depletion would occur for any L such that $R \leq D + (1 - f)(L - D)$, i.e., for $L \geq D + (R - D)/(1 - f)$.

Such a system of MDRs would increase the stake of a state government in disaster avoidance because its MDR is at risk in the event of a disaster. Just as in private insurance contracts, the policy parameter D is recognizable as a deductible, and the parameter $(1 - f)$ is a coinsurance rate for losses in excess of the deductible, up to a maximum loss for the insured state of an amount equal to its MDR. Importantly, the MRD reserve level R should reflect the loss experience of each individual state, so that the benefits of favorable loss experience, attributable to avoidance efforts, accrue to the jurisdiction that incurs those costs. In particular, the reserve levels should be selected so that the expected net Federal transfer to each jurisdiction would be zero. In this way, no jurisdiction's taxpayers would be required to cross-subsidize the losses incurred in other jurisdictions.

By comparison, existing policies effectively set some relatively low positive value of D (the level that triggers a Presidential Disaster

Declaration) together with a value of f that is close to one and a value of $R = 0$. As discussed more fully in Wildasin (forthcoming), actuarially fair reserve funds would vary substantially among the states because they face differential disaster risks. Focusing only on flood risks, crude estimates of MDR levels based on historical loss experience would be well below one percent of SPI for low risk states but would be as high as approximately nine percent of SPI for North Dakota, the state with the most unfavorable loss experience. Ideally, MDR reserves would be calculated using sophisticated actuarial techniques, for example using EVT methods as described in section 2, but it should be noted that the establishment of such a reserve system would be expected to affect disaster avoidance behavior and thus the actual loss experience.

Of course, the foregoing remarks merely sketch a menu of possible disaster policy options. To develop these options further, several crucial issues need to be addressed. First, and most importantly, how responsive is state government disaster avoidance to the incentives provided by Federal disaster relief policy? Adjusting the "co-insurance rate" f is analogous to controlling a tax rate: effort that reduces disaster losses by one dollar would save f dollars of state government resources. Analysis of the determinants of state (and local) disaster avoidance efforts could shed light on the elasticity of these efforts to the parameters of an MDR distribution policy. Coupled with a model of endogenous disaster losses, knowledge of this elasticity would make it possible to determine how alternative MDR distribution policies would affect disaster loss distributions and thus how to structure these policies so as to achieve more efficient levels of disaster avoidance. The use of EVT methods, as described in section 2, would presumably be an important element in the modeling of these endogenously determined loss distributions.

4. Conclusion

The statistical modeling of losses from floods and other disasters, discussed in section 2 and illustrated by an analysis of flood losses in Louisiana, shows that rare but exceptionally large disasters typically account for a very large share of all disaster losses. As discussed in section 3, Federal government policy responses to recent extreme disasters, especially Hurricane Katrina, indicate that much of the financial burden of relief from major disasters, and thus the main burden of disaster relief overall, now rests in the hands of the Federal government. This creates a potential misalignment of incentives in the U.S. federal system, in which state and local governments play a crucial role in disaster-avoidance policy. Assignment of responsibility for *ex post* disaster relief to the Federal government, coupled with subnational government responsibility for *ex ante* disaster avoidance, creates a misalignment of incentives because the main benefits from costly disaster-avoidance efforts spill out from the state or locality incurring these costs to the Federal government, and thus to Federal taxpayers and the broader society, in the form of reduced *ex post* disaster relief expenditures. This misalignment of incentives can be viewed as a form of moral hazard, attributable to the Federal provision of insurance to disaster-stricken regions.

Such a misalignment of incentives is likely to produce larger disaster losses in the future. To avoid this outcome, the Federal government could conceivably refuse to assist regions stricken by major disasters. This prospect is unlikely, however. Alternatively, the Federal government could assume increased responsibility for disaster-avoidance efforts.

Centralization of responsibility for many disaster-related policies, including local public safety, land use control, public health, transportation, and economic development policies, would constitute a radical departure from historical practice in the United States and would necessitate a major overhaul of the constitutional structure of the nation. It would also forgo the benefits of decentralized decision making in these areas of policy.

Other policy alternatives can be designed, however, that, like other imperfect insurance mechanisms, preserve some of the incentives for loss-avoidance behavior by subnational governments without forgoing completely the insurance benefits of Federally funded disaster relief. In particular, a system of actuarially fair mandatory disaster reserves, funded by contributions from subnational governments, would offer a mechanism through which these governments make *ex ante* experience-rated insurance payments that are used to offset future disaster losses.

Notes

1. The main results of EVT summarized here can be found in Coles (2001). See Embrechts, Klueppelberg, and Mikosch (1997) for a more advanced treatment of the subject.

2. More generally, the rth moment does not exist if $\xi > 1/r$.

3. For simplicity, the following analysis treats the distribution of flood losses, relative to state income, as exogenous. Of course, the true distribution is endogenous, depending, among other things, on policies that affect economic growth and also on state, local, and Federal disaster policies.

4. The Louisiana gross state product for 2005 was approximately $166 billion, and hence 50 percent of GSP corresponds to a loss of about $80 billion. It may be worth noting here that

the quality of flood damage data is generally poor, especially for *small* floods (Pielke, Downton, and Miller 2002): "When damage in a state is estimated to be greater than $500 million (1995$), disagreement between estimates from NWS and other sources are relatively small (40% or less)."

5. See Chernick (2001) and Chernick and Haughwout (2006) for careful analysis of the fiscal impact of the 9/11 terrorist attacks on New York City. As these studies show, New York benefited significantly from the implicit relief provided by means-tested fiscal policies.

6. Flooding in the Gulf Coast counties of Louisiana and Texas during the period 1983-1997 resulted in numerous Presidential disaster declarations (Downton and Pielke 2001), well known to state and local policymakers, analysts, private insurers, and others. Numerous pre-Katrina studies drew attention to the potential impact of a major hurricane strike on New Orleans, with findings that were widely reported in the popular press (e.g., *The Times-Picayune* 2002).

7. Federal government flood control projects in the 1960s (including levees that later failed) encouraged development in high-risk areas of New Orleans. Without these projects, ironically, the losses from Hurricane Katrina would have been far smaller, since high-risk areas would not have been developed. The disaster losses from Katrina may thus reflect a different kind of malassignment of responsibilities for disaster policy, arising from Federal government involvement in local flood control projects. A straightforward solution to this problem is to leave responsibility for flood control in the hands of local authorities. Unfortunately, this solution ignores the interstate externalities associated with riverine flooding which played a major role in the development of Federal water control policies throughout the entire Mississippi River system following devastating floods, affecting downstream states, in the 1930s.

8. Recent federalism literature has focused increasing attention on the problems of "bailouts" and moral hazard in federations, and associated institutional design problems, to which the reader is referred for more detailed discussion of the issues raised in this paragraph. For example, see Inman (2003), Wildasin (2004), and Oates (2005, 2006) for surveys and references to a rapidly growing literature, and Besfamille and Lockwood (2005) and Espino (2005) for recent theoretical analyses.

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David E. Wildasin is endowed professor of public finance in the Martin School of Public Policy and professor of economics at the University of Kentucky. Much of his research is concerned with the analysis of public economics issues in international, regional, and urban contexts.