The Risk of Ever-Growing Disaster Relief Expectations

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Abstract
This paper analyzes the risk of the vicious cycle created by expectations of individuals that the federal government will always come to their rescue in the aftermath of a disaster, and more so, that they can always expect at least as much relief as was given to victims of previous catastrophes. As a result, elected officials might feel that they have no alternative than to provide even more relief the next time if they want to benefit politically from their actions… This cycle is happening in the United States.

While previous work has been done on the disincentive that relief creates for individuals to purchase proper insurance coverage (Buchanan, 1975; Coate, 1995), here we propose a more systematic political economic analysis of this escalating need for ever more relief and its impact on government revenues. We show that a government will benefit in the long run from simply capping relief payouts. However, this policy will prove more challenging to implement the longer one waits and eventually, it might be impossible politically for any new administration to do it. We show that the dominating strategy to limit government liability is to actually use *two* policy tools simultaneously: a publicly-known cap on relief payouts combined with the right level of public insurance subsidies (or, alternatively, insurance vouchers).

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"The most frequent argument against relief in petitions debated on the floor of either house of Congress between 1789 and 1870 was the fear that the appropriation would set a precedent that would obligate the federal government to provide relief in all analogous cases. (…) Furthermore, the need to adhere to a previously established precedent was the second most frequently offered reason for granting requested relief. "

Michele Landis. Disaster Relief and the Origins of the American Welfare State (1998)

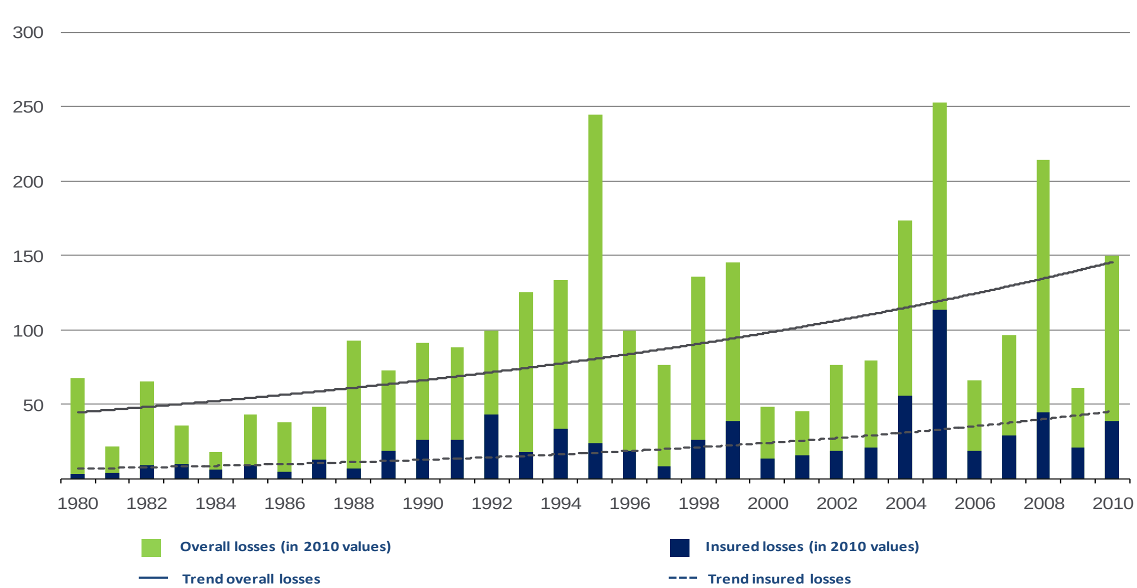
SECTION 1. MOTIVATION AND STRUCTURE OF THE PAPER

This paper analyzes the risk of the vicious cycle created by expectations of individuals that the federal government will always come to their rescue in the aftermath of a disaster, and more so, that they can always expect at least as much relief as was given to victims of previous catastrophes. As a result, elected officials in charge of providing this relief might have no alternative to providing even more relief if they want to benefit politically from their actions. While previous work has been done on the disincentive that relief creates for individuals to purchase proper insurance coverage (Buchanan, 1975; Coate, 1995), a more systematic political economic analysis of this escalating need for ever more relief and its impact on government revenue has not been undertaken, yet.

1.1. A New Era of Catastrophes

The accelerating rate at which disasters have unfolded in recent years, and the unprecedented levels of economic losses associated with them indicate we have entered a new era of catastrophes. Figure 1 depicts the evolution of the cost of natural disasters worldwide over the period 1980-2010. The trend towards much higher losses is clear.

Figure 1. Natural Catastrophes Worldwide 1980-2010. Overall and Insured Losses with Trend ($ billion)



Sources: Munich Re Geo Risks Research.

Hurricane Katrina, which hit Louisiana and Mississippi at the end of August 2005, killed 1,300 people and forced 1.5 million people to evacuate the area—a historic record for the country. Economic losses caused by Katrina are estimated at about $125 billion (White House, 2007). Another series of hurricanes in 2008 caused billions of dollars in direct economic losses along the Caribbean basin and in the United States. Outside of the U.S., 2010 was truly devastating, with two major earthquakes in Haiti and Chile, large-scale floods in China, Pakistan and Australia, which combined, cost over $100 billion.

These recent catastrophes highlight that the question before us today is not *whether* other large-scale catastrophes will occur, but *when* and *how frequent* they will be, and how extensive the damage—and numerous the fatalities—they will cause. And who will pay?

The population continues to grow rapidly and many more people now live in high-risk areas than in the past decades. We also witness hyper-concentration of assets in disaster-prone areas. Consider the United States: the population of Florida increased by 600% since 1950 to about 19.5 million today. Today there is nearly $10 trillion dollars of insured value located directly on the coasts from Texas to Maine. Much more exposure is not insured by either public or private insurance. (Kunreuther and Michel-Kerjan, 2009). Furthermore, the possibility of higher climate variability towards more extreme events is also worrisome. (Knutson et al., 2010). The U.S. National Hurricane Center at NOAA forecast in May that the 2011 hurricane season will have above-average activity in the Atlantic basin; early estimate of the cost of hurricane Irene in August are in the $7 to $10 billion range.

1.2. The Political Economy of Federal Disaster Relief

In the context of the increasing likelihood of extreme events, this paper investigates how governments are likely to manage (or mismanage) disaster financing. More specifically, we focus on government disaster relief and its impact on expectations of future federal payment to individuals living in hazard-prone areas. This has become an even more salient political economy issue as, in recent years, post-disaster government relief to aid the uninsured has risen to historical levels around the globe (Moss, 1999; Cummins and Mahul, 2008). In the United States, the American taxpayers paid $89 billion in relief in response to the 2005 hurricane season (2010 prices); that was more than private insurers paid for wind-related insured losses and what the federally-run National Flood Insurance Program paid for food insured losses, combined (Michel-Kerjan, 2010). In a recent study, Cummins, Suher, and Zanjani (2010) show that if this trend continues, the expected exposure of the U.S. government to natural and man-made disasters over the next 75 years could reach a staggering $7 trillion. According to the authors, this amount would be greater than the projected Social Security shortfall over the same period.

Since the seminal work by Buchanan (1975) and Coate (1995), economists have been interested in the balance between the social benefits associated with the government providing financial relief and the potential disincentives that this policy might create. In the context of government disaster relief, one might ask: Why should people invest in risk reduction measures or purchase insurance coverage if they expect to be bailed out anyway? (a form of "charity hazard" as described by Browne and Hoyt, 2000).

One solution would be not to provide any federal relief so people learn they need to take full responsibility and purchase insurance coverage on their own. Beyond the obvious equity issue such a strategy immediately raises (many people cannot afford to purchase actuarially fairly priced insurance if their income is low and they live in a high risk area), there is also a very pragmatic challenge here on the part of those who make the relief decision.

Indeed, experience shows that elected officials in government will have a hard time *not* being extremely generous when a disaster strikes. Media pressure to help the victims[3] and immediate demand from their constituencies is likely to be very high right after the disaster. Should they opt not to provide relief, they might run the risk of not being re-elected. For instance, there is clear evidence in the United States that, independently of what political party is in power, not only is the number of presidential disaster declarations higher during election years, but the federal government disaster payments are also significantly higher compared to non-election years (Garret and Sobel, 2003; Michel-Kerjan, 2010). This is the first element that motivates this paper: there will always be government disaster relief.

But the problem is actually worsened by the dynamic that is likely to develop over time. As Landis (1998, 1999) shows to be the case in America's history, any government disaster relief creates a precedent. Imagine now a new administration has just taken office. Not only are there expectations when a disaster strikes that relief is on the way, but in order to get maximum political reward for its action, the amount of relief that the new administration will push for most likely will be higher than that of the previous administrations for similar disasters. As such, there is the potential for a spiral of ever-growing expectations that more relief will always be provided, lowering the incentive for people to reduce their own exposure and/or purchase proper insurance coverage. We model this dynamic in this paper and show that it becomes more and more difficult for any new administration to actually stop it by reducing the level of relief as time passes: even though the country would be much better off in the long term, the short term political cost will make that decision very hard to make[4].

[3] Moss (2002; 2010) and Eisensee and Stromberg (2007) have shown the critical role played by increasing media coverage of disasters in increasing government relief in the United States.

[4] Note that to our knowledge there is no overarching monitoring system to clearly track how disaster relief is divided between the victims themselves and states/cities, where it is distributed, and who specifically receives what. In what we model in this paper, the expectation of relief is what matters. When people hear that Congress has given billions of dollars in relief, they may believe they will be receiving some. In this manner, it is not so much what individuals actually receive in relief, but what they expect they will receive that is important.

The increasing expectations of relief might explain why government relief in the United States has grown substantially in the past 75 years to reach historical highs in recent years.[5] As David Moss states:

> "*Congress provided assistance to the victims of a major fire in New Hampshire as early as 1803, and historians have counted 128 specific acts of Congress providing ad hoc relief for the victims of various disasters over the years 1803 to 1947. Nevertheless, disaster relief was not generally viewed as an ongoing federal responsibility in the United States until well into the twentieth century.*" (Moss, 2010, p. 152).

This view is also shared by Kunreuther and Miller (1985) who stated more than 25 years ago:

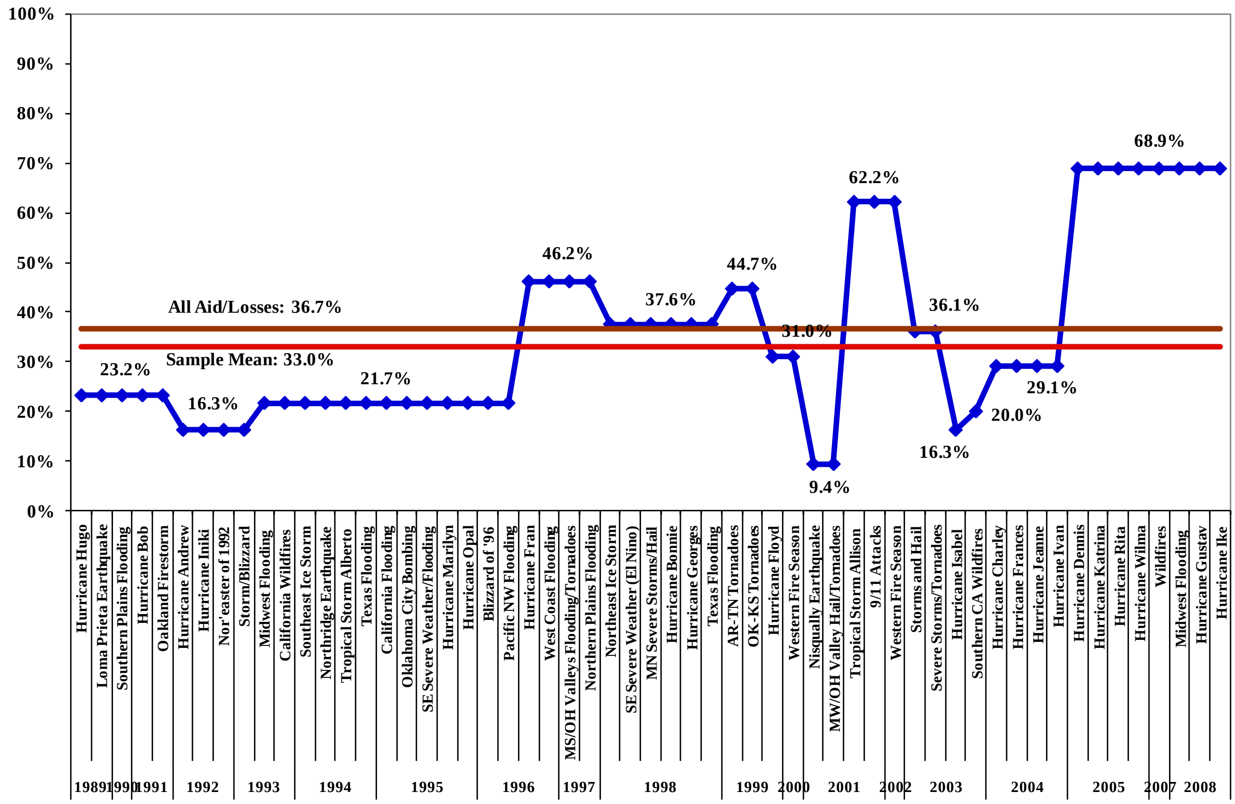
> *"The role of the federal government with respect to hazards has been changing over the past 30 years. Although Congressmen and federal agencies have become more concerned with finding way the help communities stuck by severe disasters, there has also been a realization that government has been viewed as the protector of risks in ways that would have been unthinkable 50 years ago."*

Indeed, one estimates that in the wake of Hurricane and Flood Diane in 1955, federal relief spending covered only 6.2 percent of total damages (Moss, 2010). More recently, Cummins, Suher and Zanjani (2010) have performed an extensive analysis of U.S. federal relief for large catastrophes over the period 1989-2008. Their findings provide striking evidence of how the proportion of federal disaster aid has increased radically in recent years (as a proportion of total economic losses).

Figure 2 below provides a summary based on their analysis of fifty-seven catastrophes after correction for price-level changes and size of the housing stock, so the ratio is not overweighed by the most recent disasters. Hurricane Hugo in 1989 triggered federal aid equal to about 23 percent of the total losses. In comparison, when Hurricane Ike struck in 2008, federal aid represented about 69 percent of the total losses; that is a ratio three times larger.

[5] The bailout of large financial institutions in 2008-2009 might arguably have created unprecedented expectations that always more relief will come for anyone.

Figure 2. Federal Aid Ratio for U.S. Catastrophes – 1989-2008



Sources: Cummins, Suher and Zanjani (2010)

Despite this recent trend, there have been only a handful of contributions focusing on the economics of disaster relief. In addition to those we just introduced, some have focused on the disincentive of purchasing insurance that relief creates (Raschky and Weck-Hannemann, 2007) and others on the negative impact that foreign aid can have on economic development of the receiving country and lack of proper investments in disaster risk reduction measures *ex ante* (see Raschky and Schwindt, 2009, for a review).

This paper aims to contribute to this literature by analyzing the spiral we just described and ways it can be limited. Should the government stop federal relief entirely? Is this strategy even imaginable politically? Should they try to cap relief at a given level that is known to all? Should the government offer subsidized public disaster insurance to reduce its expenses post catastrophes by collecting some premiums *ex ante*? Could they adopt a mix of these strategies to reach a better outcome? We investigate and analyze such questions here.

The paper is organized as follows. **Section 2** introduces our insurance and government relief model. **Section 3** discusses several policy options a new government can adopt through two different policy tools: the level of federal relief in each time period, and the level of subsidy it provides to individuals in order to encourage them to purchase public disaster insurance even when they expect some relief post-disaster. We analyze the likely revenues (or expenses) of the government in these cases. **Section 4** compares each policy and discusses several combinations of these two policy tools. We find that capping relief payouts is the best policy option in the long run. Implementing this policy will prove more challenging the longer an administration waits, though. The more time that passes before utilizing this tool, the longer it will take for this policy to show its benefit relative to offering subsidized policies. An administration focused on the short-term will then find it easier not to try to reduce relief but simply to offer a more subsidized public insurance. The policy option that limits government expenses the most is both offering subsidies and capping relief payouts; this might take several administrations to accomplish. **Section 5** concludes the paper**.**

SECTION 2. INSURANCE MODEL WITH DISASTER RELIEF EXPECTATIONS

2.1. Setting for a One-Period Economy

Consider an economy where individuals are endowed with initial wealth $w_0 \geq 0$. The economy is prone to catastrophes so individuals face a monetary loss from a disaster, X, which occurs with probability p. An individual's preferences can be represented by a Bernoulli utility function, $u: \mathfrak{R}_+ \to \mathfrak{R}$, which we assume is increasing and concave, i.e. $u' > 0$ and $u'' < 0$.

The government will provide some federal relief after a disaster and this is the only source of relief available (i.e., we assume there is no other source of charity). Let $r_t \in (0, 1]$, represent the relief paid to those who do not have insurance in period t, where relief is defined as a proportion of the total loss incurred and therefore, relief paid at time t equals $r_t x$.

To reflect the increasing proportion of relief paid by the government per dollar damage over time as discussed in the previous section, we assume this proportion is increasing with time. That is, $r_{t+1} > r_t$ for all t, with $\lim_{t\to\infty} r_t = 1$.

There are two types of individuals in this economy. First, those who believe the government will provide relief if a disaster occurs and insurance has not been purchased; we denote such relief-expecting individuals with the subscript $i = R$. Second, there are those who do not expect government relief; they are either uncertain about whether such relief will actually be available to them so they simply assume it will not be, or they don't want to receive it anyway, because they believe in personal responsibility to adequately prepare for untoward events. This type of individual is denoted by subscript $i = NR$ to represent non relief-expecting individuals. The proportion of individuals that believe in relief in period t is given by $f(r_t) > 0$ and this proportion is increasing in the amount of relief paid. That is, $f'(r_t) > 0$; a higher level of relief after the previous disaster leads to a higher expectation that relief will come for the next disaster.

We assume there is a monopolistic public insurer that is risk-neutral and offers an indemnity contract with a premium equal to the expected indemnity plus a proportional loading factor λ.[6] Suppose the insurer offers a coinsurance contract with rates $\alpha \in [0, 1]$. The indemnity *I(.)* schedule is given by

$$I(x) = \alpha x$$

for realized loss $x \in \Re_+$. Premiums are therefore equal to

$$P\big(I(x)\big) = (1 + \lambda)E[I(X)] = (1 + \lambda)\alpha E[X]$$

where λ is the proportional loading factor. Lambda can be positive to reflect administrative costs and a profit margin, or negative should the public insurer chose to provide insurance at a subsidized rate.

We consider an equilibrium setting to determine the types of contracts that should be offered so that the public insurer maximizes profits and both types of individuals are willing to purchase the disaster insurance policies. A contract with premium and indemnity for an individual of type *i* is denoted by $C_i = (P_i, I_i)$. A zero insurance contract is given by $C^0 = (0,0)$. Note that in this setting, we assume there is full information and no moral hazard or adverse selection. Furthermore the public insurer solves this problem each period, and in this way, acts somewhat myopically.

The public insurer chooses the contract (premium and indemnity) to maximize its profits such that individuals participate. That is, the expected utility with insurance needs to be at least as great as the expected utility without insurance for each individual type (i.e. $C = (P_i, I_i) \geq C^0$) (Stiglitz, 1977). Profits at time t, π_t, equal premiums collected minus the expected indemnities that will be paid and can be represented as follows:

$$\pi_t = f(r_t)\big[P_{R,t} - pI_{R,t}\big] + \big(1 - f(r_t)\big)\big[P_{NR,t} - pI_{NR,t}\big]$$

At each time *t* the insurer solves the following problem:

$$\begin{aligned} &max_{P_R, I_R, P_{NR}, I_{NR}} f(r_t)\big[P_{R,t} - pI_{R,t}\big] + \big(1 - f(r_t)\big)\big[P_{NR,t} - pI_{NR,t}\big] \\ &s.t.\ V\big(C_{NR,t}\big|P_{NR,t}\big) \geq V\big(C^0_{NR,t}\big|P_{NR,t}\big) \\ &V\big(C_{R,t}\big|P_{R,t}\big) \geq V\big(C^0_{R,t}\big|P_{R,t}\big) \end{aligned} \tag{1}$$

[6] Given the reluctance of the insurance industry to provide coverage for certain type of catastrophe risks, several governments around the world have established public disaster insurance programs. This is for instance the case in the United States for most residential flood coverage (Michel-Kerjan, 2010; Michel-Kerjan and Kunreuther, 2011).

where

$$V\left(C_{NR,t}\middle|P_{NR,t}\right) = pu\left(w_0 - P_{NR,t} - X + I_{NR,t}\right) + (1-p)u\left(w_0 - P_{NR,t}\right),$$
$$V\left(C_{R,t}\middle|P_{R,t}\right) = pu\left(w_0 - P_{R,t} - X + I_{R,t}\right) + (1-p)u\left(w_0 - P_{R,t}\right),$$
$$V\left(C_{NR,t}^0\middle|P_{NR,t}\right) = pu(w_0 - X) + (1-p)u(w_0), and$$
$$V\left(C_{R,t}^0\middle|P_{R,t}\right) = pu(w_0 - (1-r_t)X) + (1-p)u(w_0).$$

In the following proposition we show that it is optimal for the insurer to offer full insurance policies to both types of individuals with premiums selected so that each agent is willing to buy the policy.

Proposition 1: The optimal contract is full insurance with pricing such that the participation constraint for each agent is binding. That is $I_{NR,t}^* = I_{R,t}^* = X$; $P_{NR,t}^*$ and $P_{R,t}^*$ are determined by the following: $V\left(C_{NR,t}^*\middle|P_{NR,t}^*\right) = V\left(C_{NR,t}^0\middle|P_{NR,t}^*\right)$ and $V\left(C_{R,t}^*\middle|P_{R,t}^*\right) = V\left(C_{R,t}^0\middle|P_{R,t}^*\right)$.
That is, $P_{NR,t}^*$ and $P_{R,t}^*$ are determined by:

$$u\left(w_0 - P_{NR,t}^*\right) = pu(w_0 - X) - (1-p)u(w_0)$$
$$u\left(w_0 - P_{R,t}^*\right) = pu(w_0 - (1-r_t)X) - (1-p)u(w_0)$$

Proof: See Appendix A.1.

Since in our theoretical economy the government is the sole provider of disaster insurance, they do not have to worry about competition. We also assume that they are aware that a proportion of society believes in government disaster relief and a proportion does not believe in it. As such, they can offer full insurance policies to all individuals and price the policies so that each type of agent is induced to purchase the policy.[7]

What price should the public insurer charge for such disaster coverage? As our proposition 2 below shows, the government will need to give discounts on some policies in order for relief-expecting individuals to buy disaster insurance.

Proposition 2: To *induce relief-expecting agents R to buy full disaster insurance policies, those agents will need to be offered a lower insurance rate relative to individuals of type NR without relief expectations; that is $\lambda^*_{R,t} < \lambda^*_{NR,t}$.. Furthermore, the amount of discount/subsidization needed to induce relief-expecting agents to buy full insurance policies is not as much as the expected government relief should they not buy the coverage; that is $\lambda^*_{R,t} > -r_t$.*

Proof: See Appendix A.2.

[7] Our Proposition 1 is similar to the well-known result that a monopolistic insurer should offer full insurance when there is full information (Dionne et al., 2000). We also considered the case where the government cannot distinguish between those who believe in relief and those who don't. In this case, the government assumes all individuals expect relief ($f(r_t) = 1$). The results regarding the ranking and preference of policy options remain the same.

Discounts or subsidization will need to be offered to induce those with relief expectations (R) to buy the disaster insurance coverage. Because expected utility without insurance for R individuals is higher than the expected utility without insurance for NR individuals, the government cannot charge R individuals as high a price as that charged to those who do not expect relief and still induce those who believe in relief to buy the policy. Consequently, the policies need to be discounted so that those who have relief expectations will still buy it.

While this proposition might lead to unwanted subsidization, the government will still be better off by levying some premiums rather than simply providing free post-disaster federal relief to those individuals without coverage. Indeed, Proposition 2 shows that the amount of discount and/or subsidization needed is not as much as the relief expected. The policy being offered is full insurance and hence such a policy eliminates the uncertainty associated with the potential loss that might occur.

Because individuals are risk averse, eliminating such uncertainty has substantial value, and therefore they do not need to be subsidized to the degree to which relief is expected in order to purchase the policy. That is, suppose the post disaster government relief is expected to be 20 percent of losses ($r_t = 0.20$). Then the discount that is needed to induce those who expect relief to purchase full insurance would be greater than -20% (since $\lambda^*_{R,t} > -r_t$). If subsidization was needed ($\lambda^*_{R,t} < 0$), the amount subsidized would be less than a 20% subsidy and hence, less than the relief paid ex-post.

An alternative to giving discounted/subsidized rates to those with relief expectations would be to give them an insurance voucher instead, as it has been recently proposed (Kunreuther and Michel-Kerjan (2009); Michel-Kerjan and Kunreuther (2011)). With this option, all individuals would pay premiums associated with policies given to NR individuals, but R individuals would receive an insurance voucher from the federal government. The voucher would reflect the discounted price needed to induce relief-expecting individuals to purchase insurance ex-ante.

2.2. Multi-Period Economy

To understand the dynamics of how insurance coverage and relief expectations work over time, we can solve the same maximization problem given in equation (1) for period $t+1$. By comparing results we gain a better understanding of how the optimal policies change with time.

The real difference between the two maximization problems is that the degree of relief will be greater ($r_{t+1} > r_t$) and consequently the proportion of R individuals who expect relief will be greater as well, since $f'(r_t) > 0$ (i.e. $f(r_{t+1}) > f(r_t)$).

Proposition 3 below shows that full insurance is optimal for both agents. We find that the expected utility values (both with and without insurance) for individuals who do not expect relief remains the same over time. Therefore, the optimal loading on policies for these individuals does not change, either. That is $\lambda_{NR,t} = \lambda_{NR,t+1}$ which holds for all t. Consequently, we drop the time subscript and denote the loading associated with policies for individuals of type NR as $\lambda_{NR.}$

The loading on disaster insurance policies for R agents who expect relief will have to decrease with time. That is, as the degree of relief expected rises with previous experience of disaster relief, the level of discount/subsidization on policies for these individuals will need to increase accordingly. We explain these results in the following proposition:

Proposition 3: *The optimal contract at time t+1 is full insurance with pricing such that each agent is just willing to buy the policy. That is* $I^*_{NR,t+1} = I^*_{R,t+1} = X$; $P^*_{NR,t+1}$ *and* $P^*_{R,t+1}$ *are determined by the following:* $V\left(C^*_{NR,t+1}\middle|P^*_{NR,t+1}\right) = V\left(C^0_{NR,t+1}\middle|P^*_{NR,t+1}\right)$ *and* $V\left(C^*_{R,t+1}\middle|P^*_{R,t+1}\right) = V\left(C^0_{R,t+1}\middle|P^*_{R,t+1}\right)$. *The loading on full insurance policies for non-relief-expecting agents remains the same over time (i.e.* $\lambda^*_{NR,t} = \lambda^*_{NR,t+1} = \lambda^*_{NR}$). *In order to participate, relief-expecting agents will need to receive an increasing discount/subsidy over time (i.e.* $\lambda^*_{R,t+1} < \lambda^*_{R,t} < \lambda^*_{NR}$).

Proof: See Appendix A.3.

As time proceeds and the government has provided more and more disaster relief to the uninsured, the public disaster insurer must lower the loading charged to relief-expecting individuals to induce them to continue to buy the disaster insurance policy. This pattern occurs because the amount of relief expected increases with time and hence, expected utility without insurance increases for such agents. The policy challenge is thus that, as time proceeds and more relief is given, relief-expecting individuals comprise a larger proportion of society who, if not charged lower premiums, will not buy the insurance.

As a result, the government faces an ever-growing risk of financial exposure. To reduce it the government needs to ensure that a maximum number of relief-expecting individuals still purchase insurance, even though the discounts/subsidies evolve at a growing rate. This still remains the best policy for the government since, as proposition 2 shows, the degree of subsidization needed is less than the degree of relief paid ex-post if insurance is not purchased.

Of course, in the real world, it might take a long time for this spiral to fully develop. Still, our discussion about the historical evolution of disaster federal relief in the United States shows that we might actually be pretty far down the road already. At this point, it is worth contemplating the different policy options available to a new administration and comparing the likely output and political feasibility of these options.

SECTION 3. ALTERNATIVE PUBLIC POLICIES FOR CATASTROPHE RISK FINANCING

As a new government contemplates what their disaster insurance policy should be, they might consider two policy tools: the level of insurance subsidy they will offer to some individuals, $\lambda_{NR,t}$, and the amount of disaster relief they will provide to the uninsured, r_t.

We thus consider four policy options (Table 1) and show the long term government revenues under each policy:

- (1) Acting only on the first tool by stopping all disaster insurance subsidies ($\lambda_{NR,t}$ charged on all policies) and letting the aforementioned dynamic of disaster relief take place with relief increasing over time;
- (2) Acting on both tools by stopping all disaster insurance subsidies ($\lambda_{NR,t}$ as the loading on all policies) and keeping relief payouts constant (that is, r_t remains the same as it was when the new administration took office at time t and thereby continues to be the same proportion of the total loss incurred) [8];
- (3) Offering discounted policies to reduce the need for relief and letting the dynamic of disaster relief take place
- (4) Offering discounted policies to reduce the need for relief and keeping relief payouts constant.

Table 1. The Four Policy Combinations under Study

	No disaster insurance subsidy	Disaster insurance subsidy
Letting relief dynamic take place	Case 1	Case 3
Keeping relief constant	Case 2	Case 4

3.1. Case 1: Full Insurance without Subsidization; Relief is Not Capped

The first policy option we put forth is for the government to offer full insurance contracts to all agents without any subsidized and/or discounted policies. Loadings on policies are such that non-relief expecting individuals will purchase the policy. If a disaster occurs, no changes are made to the loadings offered. That is, policies are offered with loading λ_{NR} each year. If a disaster occurs, relief is paid to those who did not purchase insurance. As assumed earlier, over time, the proportion of the loss paid in the form of relief increases and so does the proportion of people who have expectations of relief.

If the government offers full insurance contracts with a loading, λ_{NR}, then only individuals that do not expect relief will purchase the policy. Indeed, since policies are offered at

[8] It would not be a credible option for an administration to stop providing any type of relief to its citizens in need after a disaster, so we shall disregard the $r_{t+1} = 0$ option.

the rate given to those who do not expect relief, the policy appears too expensive for those who expect relief, and the relief-expecting agents do not purchase insurance.

Revenues will equal the revenue generated from those who purchase insurance (premiums minus expected indemnities) minus the expected relief payouts to the uninsured. Revenues of the government at time *t* are thus as follows:

$$\begin{aligned} Revenues_{t,Case1} &= \big(1 - f(r_t)\big)\big(P_{NR,t} - pI_{NR,t}\big) + f(r_t)\big[-r_t E[X]\big] \\ &= \big(1 - f(r_t)\big)\lambda_{NR}\, E[X] - f(r_t) r_t E[X] \\ &= \big[\big(1 - f(r_t)\big)\lambda_{NR} - f(r_t) r_t\big]\, E[X] \end{aligned}$$

As we show in the next proposition, revenues under this policy will continue to decline each period.

<u>Proposition 4a</u>: *Under the policy of full insurance with* ***no discounts/subsidization*** *and* ***without capping relief****, revenues will decrease with time;* $Revenues_{t+1,Case\ 1} < Revenues_{t,\ Case\ 1}$ *for all t. In the limit, the government will be paying out all expected losses (i.e.* $lim_{t\to\infty} Revenues_{t,Case1} = -E[X]$*).*

Proof: See Appendix A.4a.

As relief increases and the proportion of individuals that expect relief increases, the proportion of individuals that decide not to buy insurance increases as well. Policies are priced to induce those without relief expectations to purchase them and, therefore, appear too expensive to those who expect relief. With time, as relief increases and the proportion of those that expect relief increase, the proportion of people that don't expect relief decreases. As such, the proportion of those purchasing the full insurance policies decreases. With time, the public insurance program generates less and less revenue by insuring the risk and the government pays more in disaster relief ex-post then, and so on and so forth. Eventually, in the limit, no one buys insurance ex-ante and all individuals expect relief ex-post. Without any changes, in the limit, the government will end up paying all disaster losses.

3.2. Case 2: Full Insurance without Subsidization; Relief is Capped

In the second policy option we consider, the government again offers full insurance contracts to all agents without any subsidized and/or discounted policies. Loadings on policies are such that non-relief expecting individuals will purchase the policy, and if a disaster occurs no changes are made to the loadings offered. That is, policies are offered with loading λ_{NR} each year. When a disaster occurs, relief is paid to those who did not purchase insurance. In the policy option that we consider here, however, the government decides to stop the spiral of ever-growing relief expectation by keeping such relief constant. Ideally of course, the government would make the commitment not to provide any relief, so over time, people would realize no relief is to come anymore and they would be better off purchasing actuarially based insurance to protect themselves (since they are risk averse, buying full insurance should be appealing to them). In reality, however, we know it would be a political suicide for any administration not to provide relief after a disaster. The few examples we introduced in section 2 of the paper are quite illustrative here. So there will be relief, but the question is how much?

An option is thus for the new administration to cap the amount of relief at a given level (most likely what had been given to the population following the last disaster). Recall that relief payouts are a proportion of the loss that occurs. When the government maintains relief at a consistent level, they cap the proportion of the loss that would be paid through relief ex-post. For example, if relief is held constant at 20 percent and a homeowner that does not have insurance realizes a loss of $25,000, they will only receive $5,000 in relief. We denote this consistent relief level as $\overline{r_t}$ and the proportion of individuals expecting relief at this time as $f(\overline{r_t})$.

In this scenario, by holding relief constant the proportion of individuals expecting relief is held constant. We would expect to see a decline in government revenues until relief is held constant but after that revenues should hold steady.

<u>*Proposition 4b*</u>: *Under the policy of full insurance with* ***no discounts/subsidization*** *and* ***relief is capped*** *at time $\bar{t}$ and remains at that level thereafter, revenues will decrease every period until time $\bar{t}$, at which time they will remain at $Revenues_{t>\bar{t},Case2} = \left[\left(1 - f(\overline{r_t})\right)\lambda_{NR} - f(\overline{r_t})\overline{r_t}\right] E[X]$.*
Proof: See Appendix A.4b.

Under Case 1, there was a continual increase in those expecting relief and hence, a continual decrease in the number of individuals purchasing insurance ex-ante which leads to a decline in revenues with the government paying all expected losses in the limit (Proposition 4a). Instead, here revenues will remain flat in the long run at the level associated with the time at which relief is held constant.[9]

3.3. Case 3: Full Insurance with Subsidization; Relief is not Capped

Given that it might be politically difficult to cap relief payouts (i.e., make a stand that victims will not get more relief than that given for previous disasters even if there is strong political and media pressure in the few days after a disaster), another policy option we put forth is one in which the government offers full insurance contracts and offers subsidies/discounts to the individuals expecting relief. These subsidies are increased as needed, since relief expectations rise with time. When a disaster occurs, relief is paid to those who did not purchase insurance ex-

[9] Note that in this case, some individuals might not believe the government will hold relief constant at time $\bar{t}$. Therefore, some people might drop from purchasing insurance in the next few periods. As it becomes clear that relief is being held constant, the proportion of individuals purchasing insurance will return to $f(\overline{r_t})$.

ante. That is, full insurance policies are offered to all individuals with loadings λ_{NR} and λ_R for the proportion of people who do not and do expect relief ex-post, respectively.

In this case, all individuals are charged premiums so that they are willing to buy full disaster insurance. However, we again expect to see revenues decline with time. As relief expectations rise, the degree of subsidization needed to induce the purchase of insurance increases. Furthermore, the proportion of subsidized policies increases with time, too. In the next proposition, we describe how revenues change with time for this policy option and denote this scenario as Case 3.

Proposition 4c: Under the policy of full insurance with ***discounts/subsidization*** *to those expecting relief and* ***relief is not capped****, revenues will decline with time; i.e., $Revenues_{t+1,Case\ 3} < Revenues_{t,\ Case\ 3}$ for all t. In the limit, the government will pay a proportion of all expected losses; that is,* $\lim_{t\to\infty} Revenues_{t,Case3} = \left(\lim_{t\to\infty}\lambda_{R,t}\right) E[X]$.

Proof: See Appendix A.4c.

Note here that if the government continues to pay relief ex post and increases relief payouts every disaster period, ultimately all individuals expect relief. In the limit, the government offers subsidized policies to all individuals, and this is equivalent to the government paying a portion of the expected losses. As we show later in the paper, offering such subsidized policies to the entire population is still preferred by the government to offering full insurance policies without any discounts.

3.4. Case 4: Full Insurance with Subsidization; Relief is Capped

In the last case we consider, the government utilizes both policy tools: offering discounted/subsidized policies and capping relief payouts. That is, suppose subsidies/discounts have been offered on policies for those expecting relief with these subsidies increasing over time as relief payouts and hence relief expectations rise. Full insurance is offered to all individuals with loadings λ_{NR} and λ_R for the proportion of people who do not and do expect relief ex-post, respectively. As shown in Case 3, all individuals will purchase the insurance policies, but revenues will continue to spiral downward since the proportion of people that need to be offered discounted/subsidized policies increases over time as relief expectations continue to rise.

When a new administration enters, however, they could cap relief payouts at a given level (which would most likely be at the level of what had been given during the last disaster for equity reasons). The time at which relief is capped is denoted as $\bar{t}$, and the level at which relief is capped is given by $\overline{r_t}$. Because relief payouts are a proportion of the loss that occurs, when the government maintains relief at a consistent level, they cap the proportion of the loss that would be paid through relief ex-post. The proportion of individuals expecting relief once it is capped is represented by $f(\overline{r_t})$. In this case, we expect that once relief is held constant, the downward trend in revenues will stop and revenues will hold steady at the level associated with the time when relief was capped. Once relief payouts are capped, the proportion of people believing in relief will hold steady, and thus, the proportion of policies that need to be subsidized.

<u>Proposition 4d</u>: *Under a policy of full insurance with* ***discounts/subsidization*** *to those expecting relief and* ***capping relief*** *at time $\bar{t}$ with relief remaining at that level thereafter, revenues will decrease every period until time $\bar{t}$, at which they will remain at:*
$Revenues_{t>\bar{t},Case4} = \left[f(\overline{r_t})\lambda_{R,\bar{t}} + \left(1 - f(\overline{r_t})\right)\lambda_{NR}\right]E[X].$

Proof: See Appendix A.4d.

Prior to relief being capped, offering subsidized/discounted policies is the same equation as shown in the previous case. A continual increase in relief expectations causes a rise in the proportion of individuals that need to be offered discounted policies and therefore revenues decrease over time (proposition 4c). By capping relief, however, relief expectations stop increasing and therefore, the discount that need to be offered on policies to those who expect relief does not need to increase either. In this way, revenues hold steady at the level associated with the time at which relief is held constant. As we show in the next section, this case is actually the preferred case as all individuals buy insurance in this case, but revenues do not spiral downward since relief payouts are capped.

SECTION 4. WHICH POLICY OPTION IS PREFERRED?

Our four different policy options for ex ante disaster insurance and/or ex post disaster relief have now been suggested and examined. In this section, we compare the revenue the government should expect in the long run for each one of those options. Notably, we find that offering full insurance policies with actuarially fair loadings for all individuals is always dominated by at least one of the other three options.

<u>Proposition 5</u>: *Offering full insurance policies with* ***no discounts/subsidization*** *and* ***without caps on relief*** *is never an optimal policy option. That is, Case 1 is always dominated by Case 2, Case 3, or Case 4. Furthermore, the degree to which Case 3 dominates Case 1 increases with time.*

Proof: See Appendix A.5.

This result can be described intuitively as follows. As shown in the previous section, when full insurance policies are offered at rates for those who do not expect relief, revenues continue to decline with time. As each disaster period passes and relief payouts increase, more individuals believe in relief and do not purchase insurance. In the end, this policy leads the government to be exposed to paying out all disaster losses in the form of relief ex-post.

Capping relief would be a preferred policy option; once relief payouts are held constant, revenues are also held constant. This prevents revenues from having a continual decline as seen with full insurance policies offered at rates for non-expecting relief individuals. Prior to holding relief constant, the two policies are clearly identical. Once relief is held constant, however, the proportion of people believing in relief is held constant, and hence the proportion of individuals that both purchase insurance and do not purchase insurance (and will need relief ex-post) is held constant. Therefore, once relief is capped, revenues/government exposure are held constant (as shown in Proposition 4b).

Subsidizing policies for those who expect relief would also be preferred to offering full insurance policies at rates for those who don't expect relief**.** As shown in Proposition 2, due to risk aversion, the total amount of subsidization that is needed to induce relief-expecting individuals to purchase full insurance is less than the level of relief they expect. By purchasing full insurance, the uncertainty associated with the loss that might occur and the payout that households would have to make (even if they receive relief it will not be 100%) is eliminated. Therefore, people are willing to accept a subsidized rate that is less than the relief they expect in order to eliminate the uncertainty. As a result, the government can offer full insurance policies at a subsidized rate to those who expect relief, resulting in all individuals actually purchasing full disaster insurance. Because this subsidized rate is less than the relief expected, revenues from such a policy would be greater than one where only rates for those who do not expect relief are offered. Consequently, Case 3 always generates higher revenue for the government than it would receive in Case 1. Additionally, because the subsidization associated with Case 3 is less than relief expected, over time this difference accumulates and therefore the degree to which Case 3 is preferred to Case 1 increases with time.

Offering subsidized policies and capping relief would also be a better option for the government as it would reduce its financial liability. As discussed already, offering subsidized policies to those who expect relief is preferred to offering full insurance policies at rates for non-relief-expecting individuals. If the government also caps relief payouts, they will hold revenues constant at the level associated with the time relief was capped. This will prevent the continual decline in revenues if relief expectations rise and the proportion of individuals that need subsidization increases as well. Offering subsidies is already preferred to offering full insurance with no discounts/subsidies; therefore, offering subsidies to those that expect relief and capping relief payouts would be a preferred policy option as well.

If the government is not already offering discounts to those who expect relief payouts, utilizing both policy tools simultaneously by offering both discounted policies and capping relief payouts would be difficult to implement in practice. The choice of a preferred policy thus lies in the comparison between Cases 2 (capping relief) and 3 (offering discounts/subsidies), which we examine in the next proposition.

<u>Proposition 6</u>: *For $t \leq \bar{t}$, offering subsidized full insurance policies to those who expect relief (Case 3) is preferred to offering full insurance policies but holding relief constant (Case 2).*
For $t > \bar{t}$, if

$$\frac{f(r_{t>\bar{t}})}{f(\bar{r}_t)} > \frac{\lambda_{NR}+\bar{r}_t}{\lambda_{NR}-\lambda_{R,t>\bar{t}}}, \tag{2}$$

then holding relief constant (Case 2) is preferred to offering subsidized policies to those who expect relief (Case 3). Otherwise, offering subsidized policies (Case 3) is still preferred.

Proof: See Appendix A.6.

Prior to relief being held constant, revenues from that policy option (Case 2) are identical to that associated with offering all individuals full insurance at rates associated with non-relief-expecting individuals (Case 1). As shown in Proposition 5, due to risk aversion, offering subsidized rates to those who expect relief (Case 3) generates greater revenues than offering rates associated with non-relief-expecting individuals to all and then paying relief ex-post to those who expect relief since they will not purchase the policies ex-ante (Case 1). Therefore, prior to relief being held constant, offering subsidized rates (Case 3) is the preferred policy option. Since Case 3 is preferred to Case 1 and prior to relief being held constant, Case 2 equals Case 1, then Case 3 is preferred to Case 2 prior to $\bar{t}$.

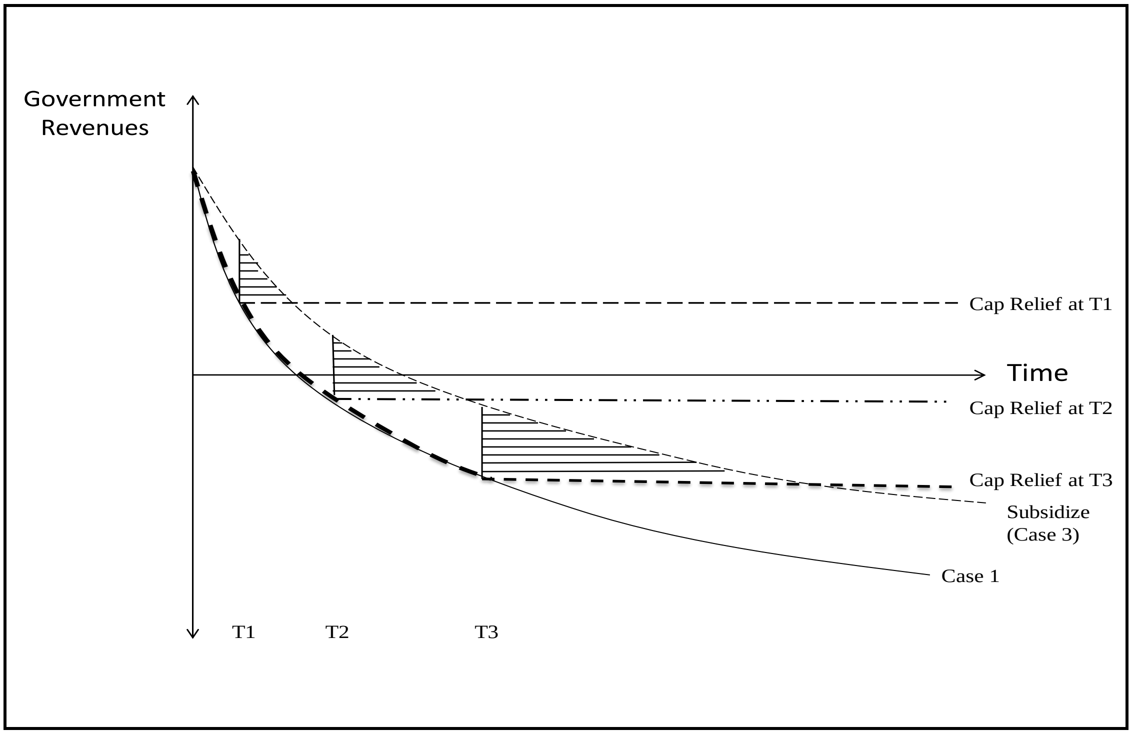
After relief is held constant ($t > \bar{t}$), understanding the preferred policy option (whether capping relief or offering subsidized rates) depends on the degree of subsidization needed at that point in time ($\lambda_{R,t>\bar{t}}$), the proportion of people who expect relief when relief is capped ($f(r_{t>\bar{t}})$), and the level of relief when it was capped ($\bar{r}_t$), as described in equation (2).

As relief payouts increase with time, the proportion of people who believe in relief also increases over time (i.e. $(r_{t>\bar{t}}) > f(\bar{r}_t)$) making the left hand side of equation (2) greater than one. At the time relief is capped, the amount of subsidization needed to induce relief-expecting individuals to buy full insurance is less than the relief that would have to be paid ex-post to those who do not purchase insurance (i.e. $-\lambda_{R,\bar{t}} < \bar{r}_t$ as shown in Proposition 2). With time, this subsidy level increases, though (Proposition 3). If the amount of subsidization needed has increased so much that it is becomes more expensive than paying the capped level of relief ex-post (i.e. $-\lambda_{R,t>\bar{t}} > \bar{r}_t$), then the preferred policy option is to cap relief (Case 2) rather than subsidize policies. In this situation, the right hand side of equation (2) will be less than 1, and therefore, equation (2) holds.

On the other hand, if the amount of subsidization needed has not increased so much that it is more than paying the capped level of relief ex-post (i.e. $-\lambda_{R,t>\bar{t}} < \bar{r}_t$), then offering subsidized rates to relief-expecting individuals might still be optimal. This will depend on how quickly the proportion of people believing in relief has increased, though. If the proportion of individuals expecting relief has increased so much relative to that proportion expecting relief when relief was capped (i.e. $f(r_{t>\bar{t}})\, vs.\, f(\bar{r}_t)$) so as to outweigh the benefit that offering subsidized rates ex-ante gives over paying relief ex-post ($-\lambda_{R,t>\bar{t}} < \overline{r_t}$), then offering subsidized rates will not be optimal. Capping relief payouts (Case 2) would be the best policy option under these circumstances. That is, the subsidized rate might still be cheaper when compared to the capped relief amount, but when multiplied by the number of people to whom that the subsidy would have to be offered, it might not be cheaper. If the proportion of those believing in relief is not too high so as to outweigh the benefit of subsidized rates over paying relief, then offering subsidized rates would be the preferred policy (Case 3).

The results so far from this section can be explained by Figure 3 which plots government revenues (which become liability when negative) over time for three of the policy options considered: **Cases 1, 2, and 3.** When the government offers full insurance policies at rates associated with those who do not expect relief and there are no discounts and/or subsidization (Case 1) revenues decline with time. This case is depicted by the solid line.

Figure 3. Graphical Representation of Government's Revenues under Different Policy Options and Over Time



As relief payouts increase with time, ultimately no one purchases insurance and the government pays out all expected losses. The thicker dashed lines (dashed curves that become straight) depict revenues when the government puts a cap on the relief payouts at some time, $\bar{t}$. Prior to relief being held constant, revenues are identical to that in Case 1, but once relief payouts are capped, revenues are held constant as well. Therefore, once relief is capped, this policy option (Case 2) is preferred to that of offering full insurance at rates for non-relief-expecting individuals to all people (Case 1).

As explained in Proposition 4c, offering subsidized policies to those who have relief expectations (Case 3) always generates higher revenues than offering rates associated with those who do not expect relief to all individuals (Case 1). Because individuals are risk averse, the discount demanded to induce those individuals who have relief expectations to buy insurance is lower than the level of relief expected. This policy option would generate more revenue because by offering them discounted policies, the individuals obtain full insurance; otherwise, they will not buy insurance and relief will need to be paid to them ex-post. This relief payout is greater than the subsidy that would have been necessary ex-ante. The policy option for offering subsidized policies to the proportion of people who have relief expectations is depicted by the thinner dotted line (curved line). As shown in Figure 3, revenues for this case are always greater than that for Case 1.

In comparing whether capping relief or offering subsidized rates is preferred, as shown in Figure 3, prior to relief being held constant, offering subsidized rates is the best policy option. Once relief is held constant, however, there is a time period for which subsidized rates are still preferred. Over time, the level of subsidization needed increases; that is, the amount of discounts that the government needs to offer to induce those with relief expectations to purchase full insurance (Case 3) increases with time. As we explained earlier, at any time *t*, the amount of subsidization needed at that time is less than the relief expected. Under Case 2, relief is capped. Initially the subsidization needed will still be less than this relief payout. Hence, offering subsidized rates will still be the preferred policy option. As relief payouts increase and the proportion of people expecting relief increases beyond time $\bar{t}$ in Case 3, the amount of subsidization needed multiplied by the higher number of individuals expected relief will continue to increase. At some point it will equal the payouts associated with the constant proportion of relief-expecters multiplied by the capped relief payouts as in Case 2. At this point, the revenue lines for Case 2 (capping relief) and Case 3 (subsidized policies) cross each other. After this point in time, the policy option of capping relief is preferred. Beyond this point in time, the subsidization needed in combination with the number of people that need to be subsidized is more than the capped amount of relief that would be paid ex-post under Case 2. In other words, capping federal disaster relief might not prove to be the best policy option in the short-run, but it is likely to be so in the long term.

Initially, offering subsidized/discounted policies seems like the better policy option, as explained above; but in the long run, capping relief is actually preferred. As we show in Figure 3, though, as governments wait longer and longer to implement one of these policies tools, the longer it will take to prove that capping relief is actually better than offering discounted/subsidized policies to those who expect relief. This result can be demonstrated by the shaded triangles. Suppose the government decides to cap relief at time T1. The triangle represents the gain in revenue that subsidizing policies has initially relative to capping relief. By capping relief at time T1, it does not take too long to show that this policy option is ultimately the preferred option. Suppose the government continues on a trajectory of offering full insurance without any discounts and continually increasing relief payouts (Case 1) until we are at time T3 though. At this point, the government decides to either cap relief payouts or offer discounted policies to those who expect relief. As shown in Figure 3, capping relief will ultimately be the preferred policy. However, the difference between offering subsidies and capping relief at this time is quite large (furthest triangle to the right) and it will take more time for one to see that capping relief is the preferred option. It will therefore take more political leadership to implement a policy of capping relief; the payoff from such a policy will not be made evident for quite some time. That is, for a good amount of time offering discounted policies will seem better and many might question the policy of capping relief payouts. Although capping relief is the preferred policy option in the long run, it will realistically be difficult to prove this fact when one waits longer to implement this policy. That is, it is easier to cap relief earlier in time. As successive governments continue to increase disaster relief payouts it becomes more and more difficult for a new one to implement a policy that caps relief. This is because, as time progresses, it takes longer and longer for capping relief to prove to be preferred to offering subsidized/discounted policies. A short-term focused administration is, therefore, unlikely to implement such policy.

Is offering discounts/subsidies or capping relief payouts the best the government can do? Suppose the government has decided to offer discounted/subsidized policies to those who expect relief (as capping relief may be difficult to do politically as explained). Can they still do better? The next proposition shows that the fourth policy option put forth is actually the optimal one. That is, it is best for a new government to use **both** policy tools at the same time: offering full insurance with discounts/subsidization to those who expect relief and capping relief. This will indeed limit the government's exposure the most. That is, Case 4 dominates Case 1, Case 2, and even Case 3.

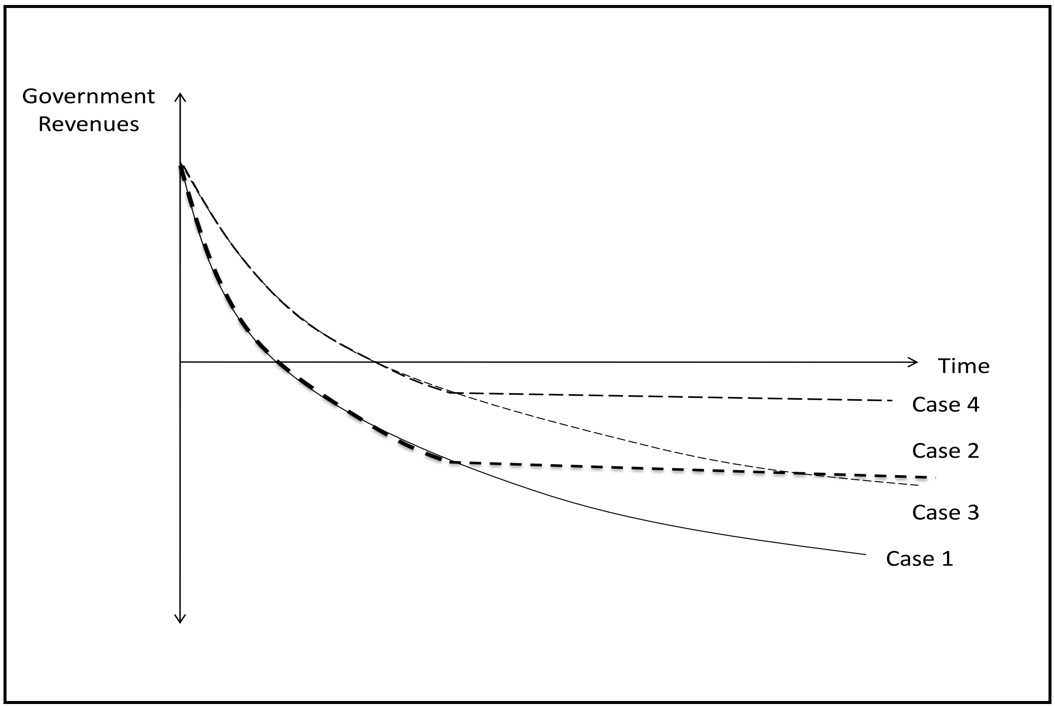
Proposition 7**: Offering full insurance policies with discounts/subsidization and capping relief is the optimal policy option. That is, Case 4 dominates Cases 1, 2, and 3.**

Proof: See Appendix A.7.

As discussed earlier, offering discounts/subsidies (Case 3) is preferred to offering full insurance without discounts or without capping relief (Case 1) since the subsidy/discount needed is less than the relief expected. If the government also caps relief to hold revenues constant in addition to offering these discounted policies, this policy option would also be preferred to a downward trend in revenues where relief payouts increase and ultimately no one buys insurance ex-ante. Because the discount/subsidy that the public insurer would have to offer to induce relief-expecting individuals to buy insurance is less than the relief expected, at the time relief is capped offering subsidies/discounts is also preferred to capping relief (Case 2, Proposition 6). By offering subsidies, the public insurer is able to have all individuals buy insurance ex-ante.

If the government can then also hold revenues steady at this level by capping relief payouts (Case 4) then this would be preferred as well. Capping relief without any subsidies (Case 2) stops the continual decline in revenues as relief expectations hold constant, but still leaves a proportion of the population not buying insurance and receiving relief after a disaster. By offering subsidies/discounts and capping relief, all individuals are insured. Since relief is capped, relief expectations no longer increase, and consequently the subsidies/discounts offered on policies to those who expect relief do not increase over time. In this way, offering subsidies/discounts to those who expect relief and capping relief payouts is preferred to offering subsidies/discounts without capping relief (Case 3).

Figure 4. A Mixed Disaster Policy Dominates



All four policy options discussed are depicted in Figure 4 above. Offering full insurance without discounts/subsidization and without capping relief leads to a continual decline in revenues as relief payouts increase and more individuals do not purchase insurance (sold line, Case 1). If relief is capped, revenues will be held constant as the proportion of individuals that expect relief is frozen (thick dashed line, Case 2). Still, not all individuals will be insured in this case. Because individuals are risk averse, the public insurer can offer discounted/subsidized policies to those who expect relief and this discount will be less than the relief expected.

In this scenario, all individuals purchase insurance, but relief expectations continue to rise with time and therefore the subsidies/discounts also need to increase. Revenues will decrease with time (dotted line, Case 3) but not as much as they did without any discounts/subsidies and without capping relief. The last policy option considered involved offering both discounted/subsidized policies and capping relief (thinner dashed line, Case 4). As seen in

Figure 4, prior to relief being capped, revenues are equal to offering subsidized/discounted policies to those who expect relief (Case 3). Once relief is capped, however, relief expectations are held constant, and the proportion of people who believe in relief stops increasing. Revenues hold steady since the discounts offered no longer need to increase in proportion with rising relief expectations. Because discounts/subsidies are offered to those who expect relief, all individuals purchase full insurance ex-ante.

The discount the public insurer needs to offer to induce individuals to buy the policy is not as high as the relief expected, making revenues in this case higher than the case where those who expect relief do not purchase insurance because there are no discounts (Case 2). Figure 4 shows that capping relief and offering discounted/subsidized policies to those who expect relief limits the public insurer's exposure the most; it shall be the preferred policy option.

Before we conclude, note that our model is based on the assumption that the government knows who expects relief and who does not. Undertaking surveys of people living in exposed areas might be useful here (Kunreuther et al. (1978)). In reality, there will always be individuals that do not believe they will receive relief ex-post and will protect themselves ex-ante. Therefore, what matters more is that he government understand the proportion of individuals that believe in relief in a given period. However, even if the government cannot distinguish between those who have relief expectations and those that do not, and consequently, has to assume all individuals have relief expectations, the main result of the paper still remains.

SECTION 5. CONCLUSION

Evidence shows that we are in a new era of catastrophes with costly disasters occurring more often and at a larger scale. History also shows that relief payouts are continually given after each disaster as a precedent has been set and these payouts are becoming larger and larger. As populations start to expect relief payouts, it becomes more difficult to manage the risk and encourage individuals to purchase protection ex ante through insurance.

In this paper, we have examined how a new government entering office could utilize two different policy tools to manage catastrophe risk through a public insurance scheme when individuals have expectations of relief: either adjusting the level of disaster relief given or offering discounts/subsidies on catastrophe insurance policies.

We find that if the previous governments have not implemented either tool, a new government can limit future expenses by officially capping relief payouts. This policy is preferred to offering subsidies on policies in the long run, but we are also fully aware that this will be difficult to implement politically. Additionally, the longer the wait to implement this policy, the more challenging it will be do so. As time progresses, it will take a longer period of time for the benefit from capping relief payouts to be shown relative to offering discounted/subsidized policies. Therefore an administration focused on the short term will most likely find it easier to solely offer subsidized policies, which is still preferred to doing nothing. The optimal policy is to utilize both tools available simultaneously: offer subsidized policies and cap relief payouts. This policy option induces all individuals to buy insurance protection ex ante and generates the highest revenues (or lowest governmental expenses). It might take several administrations to reach such a plan for catastrophe risk management, however, due to political short-termism we discussed in this paper. Results obtained here can add value in different areas. Natural applications include public disaster insurance programs, such that the National Flood Insurance Program and the crop insurance program, which provide subsidized coverage to millions of residents and farmers across the United States every year.

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Appendix

A.1 Proof of Proposition 1

Given the maximization problem defined in (1), set up Lagrangian as follows: (we use k_R and k_{NR} as the Lagrange multiplier associated with the participation constraint for individual type R and NR respectively.

$$\mathcal{L}(P,I,k) = f(r_t)\left[P_{R,t} - pI_{R,t}\right] + \left(1 - f(r_t)\right)\left[P_{NR,t} - pI_{NR,t}\right]$$
$$+k_R\left[pu\left(w_0 - P_{R,t} - X + I_{R,t}\right) + (1-p)u\left(w_0 - P_{R,t}\right) - pu(w_0 - (1-r_t)X) - (1-p)u(w_0)\right]$$
$$+k_{NR}\left[pu\left(w_0 - P_{NR,t} - X + I_{NR,t}\right) + (1-p)u\left(w_0 - P_{NR,t}\right) - pu(w_0 - X) + (1-p)u(w_0)\right]$$

The first order conditions are therefore:

(1) $\frac{\partial \mathcal{L}}{\partial P_{R,t}} = 1 - k_R\left[pu'\left(w_0 - P_{R,t} - X + I_{R,t}\right) + (1-p)u'\left(w_0 - P_{R,t}\right)\right] = 0$

(2) $\frac{\partial \mathcal{L}}{\partial I_{R,t}} = -f(r_t)p + k_R pu'\left(w_0 - P_{R,t} - X + I_{R,t}\right) = 0$

(3) $\frac{\partial \mathcal{L}}{\partial P_{NR,t}} = 1 - k_{NR}\left[pu'\left(w_0 - P_{NR,t} - X + I_{NR,t}\right) + (1-p)u'\left(w_0 - P_{NR,t}\right)\right] = 0$

(4) $\frac{\partial \mathcal{L}}{\partial I_{NR,t}} = -\left(1 - f(r_t)\right)p + k_{NR} pu'\left(w_0 - P_{NR,t} - X + I_{NR,t}\right) = 0$

(5) $\frac{\partial \mathcal{L}}{\partial k_R} = pu\left(w_0 - P_{R,t} - X + I_{R,t}\right) + (1-p)u\left(w_0 - P_{R,t}\right) - pu(w_0 - (1-r_t)X) - (1-p)u(w_0) = 0$

(6) $\frac{\partial \mathcal{L}}{\partial k_{NR}} = pu\left(w_0 - P_{NR,t} - X + I_{NR,t}\right) + (1-p)u\left(w_0 - P_{NR,t}\right) - pu(w_0 - X) + (1-p)u(w_0) = 0$

Equation (2) implies

$$pf(r_t) = k_R pu'\left(w_0 - P_{R,t} - X + I_{R,t}\right)$$
$$\Rightarrow k_R = \frac{f(r_t)}{u'\left(w_0 - P_{R,t} - X + I_{R,t}\right)} > 0$$

which means the participation constraint for individual of type R is binding. Substituting equation (2) into equation (1) we find:

$$0 = k_R u'\left(w_0 - P_{R,t} - X + I_{R,t}\right) - k_R\left[pu'\left(w_0 - P_{R,t} - X + I_{R,t}\right) + (1-p)u'\left(w_0 - P_{R,t}\right)\right]$$

$$(1-p)k_R u'\left(w_0 - P_{R,t} - X + I_{R,t}\right) = k_R(1-p)u'\left(w_0 - P_{R,t} - X + I_{R,t}\right)$$
$$u'\left(w_0 - P_{R,t} - X + I_{R,t}\right) = u'\left(w_0 - P_{R,t} - X + I_{R,t}\right)$$

The last equation implies that marginal utility for individuals of type R is equal in states where there is a loss and in states where there is not a loss. This implies that wealth with no loss equals wealth when there is a loss; that is, full insurance is optimal.

Equation (4) implies

$$p\left(1 - f(r_t)\right) = k_{NR} pu'\left(w_0 - P_{NR,t} - X + I_{NR,t}\right)$$
$$\Rightarrow k_{NR} = \frac{1 - f(r_t)}{u'\left(w_0 - P_{NR,t} - X + I_{NR,t}\right)} > 0$$

which means the participation constraint for individual of type NR is binding. Substituting equation (4) into equation (3) we find:

$$0 = k_{NR}u'\left(w_0 - P_{NR,t} - X + I_{NR,t}\right) - k_{NR}\left[pu'\left(w_0 - P_{NR,t} - X + I_{NR,t}\right) + (1-p)u'\left(w_0 - P_{NR,t}\right)\right]$$
$$(1-p)k_{NR}u'\left(w_0 - P_{NR,t} - X + I_{NR,t}\right) = k_{NR}(1-p)u'\left(w_0 - P_{NR,t} - X + I_{NR,t}\right)$$
$$u'\left(w_0 - P_{NR,t} - X + I_{NR,t}\right) = u'\left(w_0 - P_{NR,t} - X + I_{NR,t}\right)$$

The last equation implies that marginal utility for individuals of type NR is equal in states where there is a loss and in states where there is not a loss. This implies that wealth with no loss equals wealth when there is a loss; that is, full insurance is optimal.

The optimal contract for agents of each type is full insurance, I_i*= X (I_{NR} =X and I_R =X) where the premium, P*, is determined by

$$V\left(C^*_{NR,t}\middle|P_{NR,t}\right) = V\left(C^0_{NR,t}\middle|P_{NR,t}\right)\ and\ V\left(C^*_{R,t}\middle|P_{R,t}\right) = V\left(C^0_{R,t}\middle|P_{R,t}\right)$$

A.2 Proof of Proposition 2

From Proposition 1, we know the optimal premium (P*) is determined by:

For individual type R:

$$u\left(w_0 - P^*_{R,t}\right) = pu(w_0 - (1-r_t)X) - (1-p)u(w_0)$$
$$u\left(w_0 - \left(1+\lambda_{R,t}\right)E[X]\right) = pu(w_0 - (1-r_t)X) - (1-p)u(w_0)$$

For individual type NR:

$$u\left(w_0 - P^*_{NR,t}\right) = pu(w_0 - X) - (1-p)u(w_0)$$
$$u\left(w_0 - \left(1+\lambda_{NR,t}\right)E[X]\right) = pu(w_0 - X) - (1-p)u(w_0)$$

For individuals not expecting relief, the premium and hence the loading, λ_{NR}, is chosen such that

$$u\left(w_0 - \left(1+\lambda_{NR,t}\right)E[X]\right) = pu(w_0 - X) - (1-p)u(w_0)$$

By the concavity of u( ), we know

$$u(p(w_0 - X) + (1-p)w_0) >\ pu(w_0 - X) - (1-p)u(w_0)$$
$$u(w_0 - pX) >\ pu(w_0 - X) - (1-p)u(w_0)$$

which implies

$$u\left(w_0 - \left(1+\lambda_{R,t}\right)E[X]\right) <\ u(w_0 - px)$$
$$w_0 - \left(1+\lambda_{NR,t}\right)E[X] < w_0 - pX$$
$$\left(1+\lambda_{NR,t}\right) > 1$$
$$\lambda_{NR,t} > 0$$

In a competitive market, expected profits would be zero, implying that an actuarially fair premium would be charged (λ=0). In a monopoly setting, this is not necessarily so. For individuals expecting relief, the premium and loading are such that

$$u\left(w_0 - \left(1+\lambda_{R,t}\right)E[X]\right) = pu(w_0 - (1-r_t)X) - (1-p)u(w_0).$$

By the concavity of the utility function,

$$u(p(w_0 - (1-r_t)X) + (1-p)w_0) >\ pu(w_0 - (1-r_t)X) - (1-p)u(w_0)$$

$$u(w_0 - p(1-r_t)X) > \; pu(w_0 - (1-r_t)X) - (1-p)u(w_0)$$

which implies

$$u(w_0 - p(1-r_t)X) > \; u\big(w_0 - (1+\lambda_{R,t})E[X]\big)$$
$$w_0 - p(1-r_t)X > w_0 - (1+\lambda_{R,t})E[X]$$
$$(1-r_t) < 1 + \lambda_{R,t}$$
$$\lambda_{R,t} > -r_t$$

Contracts for agents who expect relief might need to be subsidized. Although the degree of subsidization will not be as much as the relief paid out due to the agent's risk aversion. Also, since $r_t > 0$ we know that

$$pu(w_0 - X) - (1-p)u(w_0) < \; pu(w_0 - (1-r_t)X) - (1-p)u(w_0)$$

which from above implies

$$u\big(w_0 - (1+\lambda_{NR,t})E[X]\big) < u\big(w_0 - (1+\lambda_{R,t})E[X]\big)$$
$$(1+\lambda_{NR,t}) > (1+\lambda_{R,t})$$
$$\lambda_{NR,t} > \lambda_{R,t}$$

The loading for policies offered to those who belief in relief is lower than the loading for policies offered to individuals that don't believe in relief. That is, discounts will need to be offered or subsidization may be needed to induce those with relief expectations to buy the insurance policy.

A.3 Proof of Proposition 3

At time *t+1*, the insurer's maximization problem is:

$$max_{P_R, I_R, P_{NR}, I_{NR}} f(r_{t+1})\big[P_{R,t+1} - pI_{R,t+1}\big] + \big(1 - f(r_{t+1})\big)\big[P_{NR,t+1} - pI_{NR,t+1}\big]$$
$$s.t.\; V\big(C_{NR,t+1}\big|P_{NR,t+1}\big) \; \geq V\big(C^0_{NR,t+1}\big|P_{NR,t+1}\big)$$
$$V\big(C_{R,t+1}\big|P_{R,t+1}\big) \geq \; V\big(C^0_{R,t+1}\big|P_{R,t+1}\big)$$

where

$$V\big(C_{NR,t+1}\big|P_{NR,t+1}\big) = pu\big(w_0 - P_{NR,t+1} - X + I_{NR,t+1}\big) + (1-p)u\big(w_0 - P_{NR,t+1}\big),$$
$$V\big(C_{R,t+1}\big|P_{R,t+1}\big) = pu\big(w_0 - P_{R,t+1} - X + I_{R,t+1}\big) + (1-p)u\big(w_0 - P_{R,t+1}\big),$$
$$V\big(C^0_{NR,t+1}\big|P_{NR,t+1}\big) = pu(w_0 - X) + (1-p)u(w_0), and$$
$$V\big(C^0_{R,t+1}\big|P_{R,t+1}\big) = pu(w_0 - (1-r_{t+1})X) + (1-p)u(w_0).$$

Set up the Lagrangian as follows: (we use k_R and k_{NR} as the Lagrange multiplier associated with the participation constraint for individual type R and NR respectively.

$$\mathcal{L}(P,I,k) = f(r_{t+1})\big[P_{R,t+1} - pI_{R,t+1}\big] + \big(1 - f(r_{t+1})\big)\big[P_{NR,t+1} - pI_{NR,t+1}\big]$$
$$+k_R\big[pu\big(w_0 - P_{R,t+1} - X + I_{R,t+1}\big) + (1-p)u\big(w_0 - P_{R,t+1}\big) - pu(w_0 - (1-r_{t+1})X) - (1-p)u(w_0)\big]$$
$$+k_{NR}\big[pu\big(w_0 - P_{NR,t+1} - X + I_{NR,t+1}\big) + (1-p)u\big(w_0 - P_{NR,t+1}\big) - pu(w_0 - X) + (1-p)u(w_0)\big]$$

The first order conditions are therefore:

(1) $\frac{\partial \mathcal{L}}{\partial P_{R,t+1}} = 1 - k_R\big[pu'\big(w_0 - P_{R,t+1} - X + I_{R,t+1}\big) + (1-p)u'\big(w_0 - P_{R,t+1}\big)\big] = 0$

(2) $\frac{\partial \mathcal{L}}{\partial I_{R,t+1}} = -f(r_{t+1})p + k_R pu'\big(w_0 - P_{R,t+1} - X + I_{R,t+1}\big) = 0$

(3) $\frac{\partial \mathcal{L}}{\partial P_{NR,t+1}} = 1 - k_{NR}\big[pu'\big(w_0 - P_{NR,t+1} - X + I_{NR,t+1}\big) + (1-p)u'\big(w_0 - P_{NR,t+1}\big)\big] = 0$

(4) $\frac{\partial \mathcal{L}}{\partial I_{NR,t+1}} = -\big(1 - f(r_{t+1})\big)p + k_{NR}pu'\big(w_0 - P_{NR,t+1} - X + I_{NR,t+1}\big) = 0$

(5) $\frac{\partial \mathcal{L}}{\partial k_R} = \; pu\big(w_0 - P_{R,t+1} - X + I_{R,t+1}\big) + (1-p)u\big(w_0 - P_{R,t+1}\big) - pu(w_0 - (1-r_{t+1})X) - (1-p)u(w_0) = 0$

(6) $\frac{\partial \mathcal{L}}{\partial k_{NR}} = pu\big(w_0 - P_{NR,t+1} - X + I_{NR,t+1}\big) + (1-p)u\big(w_0 - P_{NR,t+1}\big) - pu(w_0 - X) + (1-$
puw0=0

Equation (2) implies

$$pf(r_{t+1}) = \; k_R pu'\big(w_0 - P_{R,t+1} - X + I_{R,t+1}\big)$$
$$\Rightarrow k_R = \frac{f(r_{t+1})}{u'\big(w_0 - P_{R,t+1} - X + I_{R,t+1}\big)} > 0$$

which means the participation constraint for individual of type R is binding. Substituting equation (2) into equation (1) we find:

$$0 = k_R u'\big(w_0 - P_{R,t+1} - X + I_{R,t+1}\big) - k_R\big[pu'\big(w_0 - P_{R,t+1} - X + I_{R,t+1}\big) + (1-p)u'\big(w_0 - P_{R,t+1}\big)\big]$$

$$(1-p)k_R u'\big(w_0 - P_{R,t+1} - X + I_{R,t+1}\big) = k_R(1-p)u'\big(w_0 - P_{R,t+1} - X + I_{R,t+1}\big)$$
$$u'\big(w_0 - P_{R,t+1} - X + I_{R,t+1}\big) = u'\big(w_0 - P_{R,t+1} - X + I_{R,t+1}\big)$$

The last equation implies that marginal utility for individuals of type R is equal in states where there is a loss and in states where there is not a loss. This implies that wealth with no loss equals wealth when there is a loss; that is, full insurance is optimal.

Equation (4) implies

$$p\big(1 - f(r_{t+1})\big) = \; k_{NR}pu'\big(w_0 - P_{NR,t+1} - X + I_{NR,t+1}\big)$$
$$\Rightarrow k_{NR} = \frac{1 - f(r_{t+1})}{u'\big(w_0 - P_{NR,t+1} - X + I_{NR,t+1}\big)} > 0$$

which means the participation constraint for individual of type NR is binding. Substituting equation (4) into equation (3) we find:

$$0 = k_{NR}u'\big(w_0 - P_{NR,t+1} - X + I_{NR,t+1}\big) - k_{NR}\big[pu'\big(w_0 - P_{NR,t+1} - X + I_{NR,t+1}\big) + (1-p)u'\big(w_0 - P_{NR,t+1}\big)\big]$$
$$(1-p)k_{NR}u'\big(w_0 - P_{NR,t+1} - X + I_{NR,t+1}\big) = k_{NR}(1-p)u'\big(w_0 - P_{NR,t+1} - X + I_{NR,t+1}\big)$$
$$u'\big(w_0 - P_{NR,t+1} - X + I_{NR,t+1}\big) = u'\big(w_0 - P_{NR,t+1} - X + I_{NR,t+1}\big)$$

The last equation implies that marginal utility for individuals of type NR is equal in states where there is a loss and in states where there is not a loss. This implies that wealth with no loss equals wealth when there is a loss; that is, full insurance is optimal.

The optimal contract for agents of each type is full insurance, I_i*= X (I_{NR} =X and I_R =X) where the premium, P*, is determined by

$$V\big(C^*_{NR,t+1}\big|P_{NR,t+1}\big) = V\big(C^0_{NR,t+1}\big|P_{NR,t+1}\big) \; and \; V\big(C^*_{R,t+1}\big|P_{R,t+1}\big) = \; V\big(C^0_{R,t+1}\big|P_{R,t+1}\big)$$

The above implies the following:

For individual type R:

$$u(w_0 - P^*_{R,t+1}) = pu(w_0 - (1 - r_{t+1})X) - (1 - p)u(w_0)$$
$$u(w_0 - (1 + \lambda_{R,t+1})E[X]) = pu(w_0 - (1 - r_{t+1})X) - (1 - p)u(w_0)$$

For individual type NR:

$$u(w_0 - P^*_{NR,t+1}) = pu(w_0 - X) - (1 - p)u(w_0)$$
$$u(w_0 - (1 + \lambda_{NR,t+1})E[X]) = pu(w_0 - X) - (1 - p)u(w_0)$$

For individuals not expecting relief, the premium and hence the loading, $\lambda_{NR,t+1}$, is chosen such that

$$u(w_0 - (1 + \lambda_{NR,t+1})E[X]) = pu(w_0 - X) - (1 - p)u(w_0).$$

Note that this equation is the same as shown in Proposition 1 for period t, where $P^*_{NR,t}$ was determined by

$$u(w_0 - (1 + \lambda_{NR,t})E[X]) = pu(w_0 - X) - (1 - p)u(w_0).$$

Therefore, $\lambda^*_{NR,t} = \lambda^*_{NR,t+1}$ for all t. We denote the loading for NR agents at any time *t* to be $\lambda^*_{NR,t} \equiv \lambda^*_{NR}$.

Also, since $r_{t+1} > 0$ we know that

$$pu(w_0 - X) - (1 - p)u(w_0) < pu(w_0 - (1 - r_{t+1})X) - (1 - p)u(w_0)$$

which from above implies

$$u(w_0 - (1 + \lambda_{NR,t+1})E[X]) < u(w_0 - (1 + \lambda_{R,t+1})E[X])$$
$$(1 + \lambda_{NR,t+1}) > (1 + \lambda_{R,t+1})$$
$$\lambda_{NR,t+1} > \lambda_{R,t+1}$$

and discounts are offered to R type agents.

Based on the optimal premium at time t we know:

$$u(w_0 - (1 + \lambda_{R,t})E[X]) = pu(w_0 - (1 - r_t)X) - (1 - p)u(w_0)$$

Based on the optimal premium at time t+1 we know:

$$u(w_0 - (1 + \lambda_{R,t+1})E[X]) = pu(w_0 - (1 - r_{t+1})X) - (1 - p)u(w_0)$$

Since $r_{t+1} > r_t$, we know

$$pu(w_0 - (1 - r_{t+1})X) - (1 - p)u(w_0) > pu(w_0 - (1 - r_t)X) - (1 - p)u(w_0)$$

which implies

$$u(w_0 - (1 + \lambda_{R,t+1})E[X]) > u(w_0 - (1 + \lambda_{R,t})E[X])$$
$$(1 + \lambda_{R,t+1}) < (1 + \lambda_{R,t})$$
$$\lambda_{R,t+1} < \lambda_{R,t}$$

Therefore, for all t, we have

$$\lambda_{R,t+1} < \lambda_{R,t} < \lambda_{NR}$$

A.4a Proof of Proposition 4a

Under Case 1, revenues at time *t* are given by:

$$Revenues_{t,Case1} = (1 - f(r_t))(P_{NR,t} - pI_{NR,t}) + f(r_t)[-r_t E[X]]$$
$$= [(1 - f(r_t))\lambda_{NR} - f(r_t)r_t]\, E[X]$$

In the next period, with no changes, revenues will be:

$$Revenues_{t+1,Case1} = [(1 - f(r_{t+1}))\lambda_{NR} - f(r_{t+1})r_{t+1}]\, E[X]$$

Because $r_{t+1} > r_t$ and $f(r_{t+1}) > f(r_t)$ then $Revenues_{t+1,Case1} < Revenues_{t,Case1}$. We can also see this by considering:

$$Revenues_{t,Case1} - Revenues_{t+1,Case1} = \begin{pmatrix} \left[\left(1 - f(r_t)\right)\lambda_{NR} - f(r_t)r_t\right] E[X] \\ -\left[\left(1 - f(r_{t+1})\right)\lambda_{NR} - f(r_{t+1})r_{t+1}\right] E[X] \end{pmatrix}$$
$$= \left[\left(f(r_{t+1}) - f(r_t)\right)\lambda_{NR} + f(r_{t+1})r_{t+1} - f(r_t)r_t\right] E[X]$$
$$> 0$$

In fact revenues will become negative when the following holds:

$$\left[\left(1 - f(r_t)\right)\lambda_{NR} - f(r_t)r_t\right] E[X] < 0$$

which implies revenues are negative when

$$\left(1 - f(r_t)\right)\lambda_{NR} - f(r_t)r_t < 0$$
$$\Rightarrow \lambda_{NR} < f(r_t)(\lambda_{NR} + r_t)$$
$$\Rightarrow f(r_t) > \frac{\lambda_{NR}}{\lambda_{NR} + r_t}$$

As t → ∞, $r_t \to 1$and $f(r_t) \to 1$ which implies

$$\lim_{t\to\infty} Revenues_{t,Case1} = \lim_{t\to\infty}\left[\left(1 - f(r_t)\right)\lambda_{NR} - f(r_t)r_t\right] E[X] = -E[X].$$

A.4b Proof of Proposition 4b

Until relief is held constant at time $\bar{t}$, the policy option under case 2 is exactly the same as the revenues under case 1. At time $\bar{t}$, as shown previously revenues will be:

$$Revenues_{t,Case2} = \left[\left(1 - f(r_t)\right)\lambda_{NR} - f(r_t)r_t\right] E[X]$$

If the government does not increase relief payouts for time $\bar{t} + 1$, then the proportion believing in relief will not increase either. Revenues at time $\bar{t} + n$ for n ≥ 1 will therefore be given by:

$$Revenues_{\bar{t}+n,Case2} = \left[\left(1 - f(\overline{r_t})\right)\lambda_{NR} - f(\overline{r_t})\overline{r_t}\right] E[X]$$

This result follows because as t → ∞, $\overline{r_t}$and $f(\overline{r_t})$ remain constant. Therefore revenues will remain constant at this level.

A.4c Proof of Proposition 4c

Under a policy of full insurance with subsidization for those expecting relief, revenues at time t will be given by:

$$Revenues_{t,Case3} = f(r_t)\left(P_{R,t} - pI_{R,t}\right) + \left(1 - f(r_t)\right)\left(P_{NR,t} - pI_{NR,t}\right)$$
$$= f(r_t)\left(\left(1 + \lambda_{R,t}\right)E[X] - E[X]\right) + \left(1 - f(r_t)\right)\left((1 + \lambda_{NR})E[X] - E[X]\right)$$
$$= \left[f(r_t)\lambda_{R,t} + \left(1 - f(r_t)\right)\lambda_{NR}\right] E[X]$$

Revenues at time t+1 will be given by:

$$Revenues_{t+1,Case3} = f(r_{t+1})\left(P_{R,t+1} - pI_{R,t+1}\right) + \left(1 - f(r_{t+1})\right)\left(P_{NR,t+1} - pI_{NR,t+2}\right)$$
$$= f(r_{t+1})\left(\left(1 + \lambda_{R,t+1}\right)E[X] - E[X]\right) + \left(1 - f(r_{t+1})\right)\left((1 + \lambda_{NR})E[X] - E[X]\right)$$
$$= \left[f(r_{t+1})\lambda_{R,t+1} + \left(1 - f(r_{t+1})\right)\lambda_{NR}\right] E[X]$$

Consider

$$Revenues_{t,Case3} - Revenues_{t+1,Case3}$$

$$= \left[f(r_t)\lambda_{R,t} + \left(1 - f(r_t)\right)\lambda_{NR}\right] E[X] - \left[f(r_{t+1})\lambda_{R,t+1} + \left(1 - f(r_{t+1})\right)\lambda_{NR}\right] E[X]$$
$$= \left[f(r_t)\lambda_{R,t} - f(r_{t+1})\lambda_{R,t+1} + \left(f(r_{t+1}) - f(r_t)\right)\lambda_{NR}\right] E[X]$$

Since $\lambda_{R,t} > \lambda_{R,t+1}$we know the above is

$$> \left[f(r_t)\lambda_{R,t+1} - f(r_{t+1})\lambda_{R,t+1} + \left(f(r_{t+1}) - f(r_t)\right)\lambda_{NR}\right] E[X]$$
$$= \left[\left(f(r_{t+1}) - f(r_t)\right)\left(\lambda_{NR} - \lambda_{R,t+1}\right)\right] E[X]$$
$$> 0.$$

The last inequality follows since $f(r_{t+1}) > f(r_t)$ and $\lambda_{NR} > \lambda_{R,t+1}$. Therefore, $Revenues_{t,Case3} > Revenues_{t+1,Case3}$ for all *t*; revenues decrease over time.

Since $\lim_{t\to\infty} f(r_t) = 1$ we find that as t → ∞

$$\lim_{t\to\infty} Revenues_{t,Case3} = \lim_{t\to\infty}\left[f(r_t)\lambda_{R,t} + \left(1 - f(r_t)\right)\lambda_{NR}\right] E[X] = \left(\lim_{t\to\infty}\lambda_{R,t}\right) E[X]$$

A.4d Proof of Proposition 4d

Until relief is held constant at time $\bar{t}$, the policy option under case 4 is exactly the same as the revenues under case 3. At time $\bar{t}$, as shown previously revenues will be:

$$Revenues_{t,Case4} = \left[\left(1 - f(r_t)\right)\lambda_{NR} + f(r_t)\lambda_{R,t}\right] E[X].$$

If the government does not increase relief payouts for time $\bar{t} + 1$, then the proportion believing in relief will not increase either. Revenues at time $\bar{t} + n$ for n ≥ 1 will therefore be given by:

$$Revenues_{\bar{t}+n,Case4} = \left[\left(1 - f(\overline{r_t})\right)\lambda_{NR} + f(\overline{r_t})\lambda_{R,\bar{t}}\right] E[X].$$

This result follows because as t → ∞, $\overline{r_t}$and $f(\overline{r_t})$ remain constant. If subsidies are offered, $\lambda_{R,\bar{t}}$ will hold steady and therefore, revenues will remain constant at this level.

A.5 Proof of Proposition 5

Recall that at any time *t*, revenues for Case 1 are:

$$Revenues_{t,Case1} = \left(1 - f(r_t)\right)\left(P_{NR,t} - pI_{NR,t}\right) + f(r_t)\left[-r_t E[X]\right]$$
$$= \left[\left(1 - f(r_t)\right)\lambda_{NR} - f(r_t)r_t\right] E[X]$$

Prior to relief being held constant, revenues for Case 2 are the same as that for Case 1 since the policies are identical until relief is held constant. Therefore, if $\bar{t}$ is the time at which relief is held constant in case 2, then

$$Revenues_{t,Case1} = Revenues_{t,Case2}\ for\ t \le \bar{t}.$$

At $t = \bar{t} + n$ for all n≥1, we have

$$Revenues_{\bar{t}+n,Case2} = \left[\left(1 - f(\overline{r_t})\right)\lambda_{NR} - f(\overline{r_t})\overline{r_t}\right] E[X]$$
$$Revenues_{\bar{t}+n,Case1} = \left[\left(1 - f(r_{\bar{t}+n})\right)\lambda_{NR} - f(r_{\bar{t}+n})r_{\bar{t}+n}\right] E[X].$$

Comparing the two cases, we have

$$Revenues_{\bar{t}+n,Case2} - Revenues_{\bar{t}+n,Case1}$$
$$= \left[\left(1 - f(\overline{r_t})\right)\lambda_{NR} - f(\overline{r_t})\overline{r_t}\right] E[X] - \left[\left(1 - f(r_{\bar{t}+n})\right)\lambda_{NR} - f(r_{\bar{t}+n})r_{\bar{t}+n}\right] E[X]$$
$$=\left[\left(f(r_{\bar{t}+n}) - f(\overline{r_t})\right)\lambda_{NR} - (f(\overline{r_t})\overline{r_t} - f(r_{\bar{t}+n})r_{\bar{t}+n})\right] E[X]$$
$$>0.$$

The last line follows since $f(r_{\bar{t}+n}) > f(\overline{r_t})$so the first term in the brackets is positive; also, the second term in the brackets is negative since $f(r_{\bar{t}+n}) > f(\overline{r_t})$ and $r_{\bar{t}+n} > \overline{r_t}$. Therefore the brackets have a positive term minus a negative term, making it positive and causing $Revenues_{\bar{t}+n,Case2}$>$Revenues_{\bar{t}+n,Case1}$ for all $t > \bar{t}$.

We can also examine revenues for the two cases in the limit. In the limit, revenues for Case 2 are:

$$\begin{aligned}\lim_{t\to\infty} Revenues_{t,Case\ 2} &= \left[\left(1 - f(\overline{r_t})\right)\lambda_{NR} - f(\overline{r_t})\overline{r_t}\right]E[X] \\ &> \left[\left(1 - f(\overline{r_t})\right)\lambda_{R,t} - f(\overline{r_t})\overline{r_t}\right]E[X] \\ &> \left[\left(1 - f(\overline{r_t})\right)(-\overline{r_t}) - f(\overline{r_t})\overline{r_t}\right]E[X] \\ &= -\overline{r_t}E[X] \\ &> -E[X] \\ &= \lim_{t\to\infty} Revenues_{t,Case1}\end{aligned}$$

The last inequality follows since r < 1 and therefore –r > -1.
To compare Case 3 with Case 1, recall that at any time t, revenues for Case 3 are

$$Revenues_{t,Case3} = \left[f(r_t)\lambda_{R,t} + \left(1 - f(r_t)\right)\lambda_{NR}\right] E[X].$$

Consider the following:

$$\begin{aligned}Revenues_{t,Case3} - Revenues_{t,Case1} &= \left[f(r_t)\lambda_{R,t} + \left(1 - f(r_t)\right)\lambda_{NR}\right] E[X] - \left[\left(1 - f(r_t)\right)\lambda_{NR} - f(r_t)r_t\right] E[X] \\ &= \left[f(r_t)\left(\lambda_{R,t} + r_t\right)\right] E[X] \\ &> 0.\end{aligned}$$

The last line follows since $f(r_t) > 0$; also, even if $\lambda_{R,t}$ is less than zero (subsidization), we know that $\lambda_{R,t} > -r_t$ which implies that even if we subsidize, the subsidization needed is less than the relief paid. Therefore the term is brackets is positive.

Comparing the two cases in the limit, we know that for Case 3:

$$\begin{aligned}\lim_{t\to\infty} Revenues_{t,Case3} &= \lim_{t\to\infty}\left[f(r_t)\lambda_{R,t} + \left(1 - f(r_t)\right)\lambda_{NR}\right] E[X] \\ &= \lim_{t\to\infty}\lambda_{R,t}E[X] \\ &> -E[X] \\ &= \lim_{t\to\infty} Revenues_{t,Case1}\end{aligned}$$

We know from previous analysis that $\lambda_{R,t} > -r_t$ implying that $\lim_{t\to\infty}\lambda_{R,t} > \lim_{t\to\infty} - r_t = -1$. Therefore, $\lim_{t\to\infty}\lambda_{R,t}E[X] > -E[X]$ and $\lim_{t\to\infty} Revenues_{t,Case3} > \lim_{t\to\infty} Revenues_{t,Case1}$.

Furthermore, consider

$$\begin{aligned}\frac{\partial}{\partial t}\left(Revenues_{t,Case3} - Revenues_{t,Case1}\right) &= \frac{\partial}{\partial t}\left[f(r_t)\left(\lambda_{R,t} + r_t\right)\right] E[X] \\ &= \left[f(r_t)\left(\frac{\partial}{\partial t}\lambda_{R,t} + \frac{\partial}{\partial t}r_t\right) + \left(\lambda_{R,t} + r_t\right)f'(r_t)\right] E[X] \\ &> 0\end{aligned}$$

The second term in brackets is positive since $\left(\lambda_{R,t} + r_t\right)$ is positive as shown above and $f'(r_t) > 0$ since $f(r_t)$ is increasing with time. The first term inside the brackets is also positive since $f(r_t)$ is positive; also the decrease in loading to those expecting relief is not as much as the increase in relief expected with each period thereby making $\left(\frac{\partial}{\partial t}\lambda_{R,t} + \frac{\partial}{\partial t}r_t\right) > 0$.

To compare Case 4, recall that prior to relief being held constant, revenues for Case 4 are equal to those for Case 3. Since Case 3 always dominates Case 1, then Case 4 dominates Case 1 prior to relief being held constant. Once relief is held constant, we have

$$Revenues_{t>\bar{t},Case4} = \left[\left(1 - f(\overline{r_t})\right)\lambda_{NR} + f(\overline{r_t})\lambda_{R,\bar{t}}\right] E[X]$$

Comparing with Case 1 revenues we find

$$\begin{aligned}
&Revenues_{t>\bar{t},Case4} - Revenues_{t>\bar{t},Case1} \\
&\quad = \left[\left(1 - f(\overline{r_t})\right)\lambda_{NR} + f(\overline{r_t})\lambda_{R,\bar{t}}\right] E[X] - \left[\left(1 - f(r_{t>\bar{t}})\right)\lambda_{NR} - f(r_{t>\bar{t}})r_{t>\bar{t}}\right] E[X] \\
&\quad = \left[f(r_{t>\bar{t}})r_{t>\bar{t}} + f(\overline{r_t})\lambda_{R,\bar{t}} + f(r_{t>\bar{t}})\lambda_{NR} - f(\overline{r_t})\lambda_{NR}\right]E[X] \\
&\quad = \left[f(r_{t>\bar{t}})(r_{t>\bar{t}} + \lambda_{NR}) - f(\overline{r_t})\left(\lambda_{NR} - \lambda_{R,\bar{t}}\right)\right]E[X] \\
&\quad > 0
\end{aligned}$$

The difference is positive since $f(r_{t>\bar{t}}) > f(\overline{r_t})$ and $-\lambda_{R,\bar{t}} < r_t < r_{t>\bar{t}}$.

Therefore, Case 2 is preferred to Case 1 once relief is held constant, and Case 3 and Case 4 are always preferred to Case 1.

A.6 Proof of Proposition 6

Recall that prior to relief being held constant, revenues in Case 2 are equivalent to revenues in Case 1. In Proposition 7, we showed that Case 3 revenues are always greater than Case 1 revenues. Therefore,

$$Revenues_{Case\ 3} > Revenues_{Case\ 2}\ for\ t \leq \bar{t}.$$

Once relief is held constant,

$$Revenues_{t,Case\ 2} = \left[\left(1 - f(\overline{r_t})\right)\lambda_{NR} - f(\overline{r_t})\overline{r_t}\right]E[X]$$

$$Revenues_{t,Case3} = \left[f(r_t)\lambda_{R,t} + \left(1 - f(r_t)\right)\lambda_{NR}\right] E[X]$$

Comparing the two cases for $t > \bar{t}$,

$$\begin{aligned}
&Revenues_{t>\bar{t},Case3} - Revenues_{t>\bar{t},Case\ 2} \\
&\quad = \left[f(r_{t>\bar{t}})\lambda_{R,t>\bar{t}} + \left(1 - f(r_{t>\bar{t}})\right)\lambda_{NR}\right] E[X] - \left[\left(1 - f(\overline{r_t})\right)\lambda_{NR} - f(\overline{r_t})\overline{r_t}\right]E[X] \\
&\quad = \left[f(r_{t>\bar{t}})\left(\lambda_{R,t>\bar{t}} - \lambda_{NR}\right) + f(\overline{r_t})(\lambda_{NR} + \overline{r_t})\right] E[X]
\end{aligned}$$

The above term is positive if

$$\left[f(r_{t>\bar{t}})\left(\lambda_{R,t>\bar{t}} - \lambda_{NR}\right) + f(\overline{r_t})(\lambda_{NR} + \overline{r_t})\right] > 0.$$

Rewrite the above as

$$\left[\left(f(r_{t>\bar{t}}) - f(\overline{r_t})\right)\left(\lambda_{R,t>\bar{t}} - \lambda_{NR}\right) + f(\overline{r_t})\left(\lambda_{R,t>\bar{t}} + \overline{r_t}\right)\right].$$

The first term is negative since $\lambda_{R,t>\bar{t}} < \lambda_{NR}$. If loadings on policies are such that those believing in relief need to be subsidized more under Case 3 than the constant relief level paid ex-post in Case 2 ($\lambda_{R,t>\bar{t}} \leq -\overline{r_t}$), then the second term is negative as well and Case 2 has higher revenues.

The two cases have equal revenues when

$$f(r_{t>\bar{t}})\left(\lambda_{R,t>\bar{t}} - \lambda_{NR}\right) + f(\overline{r_t})(\lambda_{NR} + \overline{r_t}) = 0$$

$$-f(r_{t>\bar{t}})\lambda_{R,t>\bar{t}} - \left(f(\overline{r_t}) - f(r_{t>\bar{t}})\right)\lambda_{NR} = f(\overline{r_t})\overline{r_t}$$

$$\overline{r_t} = -\frac{f(r_{t>\bar{t}})}{f(\overline{r_t})}\lambda_{R,t>\bar{t}} + \frac{f(r_{t>\bar{t}}) - f(\overline{r_t})}{f(\overline{r_t})}\lambda_{NR}$$

$$\overline{r_t} = \frac{f(r_{t>\bar{t}})}{f(\overline{r_t})}\left(\lambda_{NR} - \lambda_{R,t>\bar{t}}\right) - \lambda_{NR}$$

Case 3 revenues continue to be greater than Case 2 revenues as long as the relief level when it is held constant (for case 2) is greater than:

$$\overline{r_t} > \frac{f(r_{t>\bar{t}})}{f(\overline{r_t})}\left(\lambda_{NR} - \lambda_{R,t>\bar{t}}\right) - \lambda_{NR}$$

or alternatively when

$$\frac{f(r_{t>\bar{t}})}{f(\overline{r_t})} < \frac{\lambda_{NR} + \overline{r_t}}{\lambda_{NR} - \lambda_{R,t>\bar{t}}}.$$

A.7 Proof of Proposition 7

- 4 preferred to 1: As shown in Proposition 5, Case 4 dominates Case 1.
- 4 preferred to 2: Prior to capping relief, we know that Case 2 equals Case 1. Since Case 4 dominates Case 1 then prior to capping relief, Case 4 also dominates Case 2. At the time relief is capped, Case 4 equals Case 3 and then remains at this capped level forever. As shown in Proposition 6, Case 3 dominates Case 2 at the time relief is capped. Since Case 4 revenues remain at this level, then Case 4 dominates Case 2 for all t>$\bar{t}$.
- 4 preferred to 3: Prior to relief being capped, Case 4 equals Case 3. Once relief is capped, revenues hold constant at

  $$Revenues_{t>\bar{t},Case4} = \left[\left(1 - f(\overline{r_t})\right)\lambda_{NR} + f(\overline{r_t})\lambda_{R,\bar{t}}\right] E[X]$$

  Revenues for Case 3 are given by

  $$Revenues_{t>\bar{t},Case3} = \left[f(r_{t>\bar{t}})\lambda_{R,t>\bar{t}} + \left(1 - f(r_{t>\bar{t}})\right)\lambda_{NR}\right]\ E[X]$$

  Comparing the two we have

  $$\begin{aligned} & Revenues_{t>\bar{t},Case4} - Revenues_{t>\bar{t},Case3} \\ &= \left[\left(1 - f(\overline{r_t})\right)\lambda_{NR} + f(\overline{r_t})\lambda_{R,\bar{t}}\right] E[X] - \left[f(r_{t>\bar{t}})\lambda_{R,t>\bar{t}} + \left(1 - f(r_{t>\bar{t}})\right)\lambda_{NR}\right]\ E[X] \\ &= \left[f(\overline{r_t})\lambda_{R,\bar{t}} - f(r_{t>\bar{t}})\lambda_{R,t>\bar{t}} + f(r_{t>\bar{t}})\lambda_{NR} - f(\overline{r_t})\lambda_{NR}\right]E[X] \\ &= \left[f(r_{t>\bar{t}})\left(\lambda_{NR} - \lambda_{R,t>\bar{t}}\right) - f(\overline{r_t})\left(\lambda_{NR} - \lambda_{R,\bar{t}}\right)\right]E[X] \\ &> 0 \end{aligned}$$

  The term in brackets is positive since $f(r_{t>\bar{t}}) > f(\overline{r_t})$. Furthermore, we know that $\left(\lambda_{NR} - \lambda_{R,t>\bar{t}}\right) > \left(\lambda_{NR} - \lambda_{R,\bar{t}}\right)$. Both $\lambda_{R,t>\bar{t}}$ and $\lambda_{R,\bar{t}}$ are less than λ_{NR} but $\lambda_{R,t>\bar{t}} < \lambda_{R,\bar{t}}$ since the discounts/subsidies increase with time as relief expectations rise.
  Therefore, once relief is capped, Case 4 is still preferred to Case 3.

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