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Underinsurance Caused by Uninsurable Losses in the Public Good and Personal Assets

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Abstract: A significant portion of flood damages were not covered by insurance, and policies are devised to promote insurance coverage. There are, however, rational reasons for why households may not purchase full insurance facing risks. We discuss optimal underinsurance when there are uninsurable losses in the public good or personal assets. In a first-best allocation, households will fully restore the damaged public good after a natural hazard and purchase full insurance. When public good restoration is not available, the Samuelson condition holds in expected utility, and households purchase insurance less than their wealth loss. Also, when there are uninsurable losses in personal assets, that optimal insurance purchase is less than the wealth loss. We provide a model based on households' choices of coverage and deductibles in insurance purchases. This model can be used to estimate households' risk preferences towards natural hazards.

Keywords: Underinsurance; Flood insurance; Public good and risk; Estimating risk preferences; Uninsurable loss

JEL Classifications: D81, H44, G22

1. Introduction

Empirical studies on the National Flood Insurance Program show that a large portion of flood damages are not covered by insurance. Households may not purchase full insurance against natural hazards. Mandatory insurance policies are imposed to help households alleviate risks. Policy design needs to take into account rational responses and incentives for household behavior. We provide partial explanations for why households do not purchase full insurance facing natural hazards. We demonstrate that lower-than-full insurance purchase can be a result of rational choice caused by uninsurable losses in the public good or personal assets. A distinct feature of natural hazards is that they bring uninsurable losses in the public good and personal assets that cannot, in contrast to financial losses, be fully compensated with money. Public infrastructure such as roads and bridges are subject to the damage from natural hazards. Floods often disrupt supply of public utilities such as water and electricity. Damages to a house are usually associated with losses in personal assets of emotional value. These losses in the public good and personal assets cannot be fully insured in the commercial insurance market. Therefore, we can only obtain optimality in the second best. With uninsurable losses, people will allocate less wealth in the state of loss. Consequently, the optimal purchase of insurance is less than full.

We demonstrate optimal underinsurance due to uninsurable losses with a model of two probability states: there is a high state without hazards and a low state where a natural hazard brings losses to household wealth and to the public good. An actuarially fair insurance is available to cover monetary losses. A public good is provided in a community which is financed by an equal-share tax. A restoration spending is available when the public good is damaged; it is also financed by an equal-share tax. The first-best optimization features the following: the Samuelson condition holds in each state separately; the public good is fully restored; households purchase full insurance that covers wealth loss and the restoration tax. The community, however, may not have the resources or fiscal tools to restore the public good to its undamaged level. When there are losses in some goods that cannot be insured or restored, their low state consumption is bound to be lower than that in the high state. This second-best optimization results in the following: When insurance does not cover the restoration tax, optimality means that the Samuelson condition holds in each state, the damaged public good will not be fully restored, and households purchase insurance fully covering wealth loss. When public good restoration is not available, the Samuelson condition holds in expected utility, households purchase insurance less than their wealth loss.

We also show, in a model without public good but with uninsurable losses in personal assets, that optimal insurance purchase is less than wealth loss. This model facilitates the estimation of households' risk preferences, which plays a crucial role in predicting households behavior facing natural hazards. To illustrate how to estimate with uninsurable loss, our model has households choosing over two variables, the deductible and the coverage, when purchasing (not actuarially fair) flood insurance for their houses. With uninsurable losses, the model demonstrates equilibrium under-purchase of insurance coverage. We, however, do not present an estimation here but rather provide a framework for future empirical research. Real world data show that a large portion of households do not purchase full insurance. Yet, basic models with risk-aversion preferences predict that full insurance is optimal. Even with actuarially unfair commercial insurance policies, the deviation to full insurance is minute. Our approach has an advantage that it predicts optimal underinsurance. Optimization conditions can pin down two parameters, one for risk preferences and one for uninsurable loss.

2. Literature Review

Households may not purchase full insurance against natural hazards with a few possible reasons; some are discussed in Kunreuther (1984). Empirical studies on the National Flood Insurance Program (NFIP) show that a large portion of flood damages are not covered by insurance; many households in flood prone areas purchase less than full flood coverage or do not purchase insurance at all (see Browne and Hoyt, 2000; Kriesel and Landry, 2004; and Michel-Kerjan and Kousky, 2010). To help households alleviate risks, mandatory insurance coverages are adopted. For example, Section B7-3-07 of Fannie Mae Selling Guide states "The minimum amount of flood insurance required for most first mortgages secured by one- to four-unit properties, individual PUD units, and certain individual condo units (such as those in detached condos, townhouses, or rowhouses) is the lowest of: 100% of the replacement cost of the insurable value of the improvements; the maximum insurance available from the NFIP, which is currently $250,000 per dwelling; or the unpaid principal balance of the mortgage."

The literature of general equilibrium financial markets points out that if there is a complete market of financial securities that can cover all possible losses, households will smooth out consumptions across different probability states of the world and eliminate risks (see, for example, McGill and Quinzii (1996)). In the real world, commercial insurers in the market sell insurance policies to households to cover specific property losses when damages occur. For the uninsurable loss issue at hand, we adopt the insurance model (for example, Raviv, 1979; and Shavell, 1979). Public good provision under risk and uncertain outcomes is also addressed, for example, by the following authors: Cornes and Silva (2000) found that, in a federation system with interregional insurance, incentive compatibility and participation constraint may not hold together. Keenan, Kim and Warren (2006) analyze private contribution to the public good when actions of other individuals are uncertain. Ihori and McGuire (2007) investigate optimal public goods for self-protection purposes that can reduce risks. Chambers and Melkonyan (2010) examine optimal regulatory design when there is scientific uncertainty about hazardous outcomes. Empirical estimation on risk preferences is important for the evaluation of policies, and risk preferences can be estimated from the choice of insurance coverage and deductibles as in Drèze (1981). Related empirical studies on insurance choice for automobiles can be found in Harel and Harpaz (2007), and Cohen and Einav (2007). Studies on housing insurance are few, and Sydnor (2009) is such an example, which estimates a utility parameter based on the prospect theory.

3. Uninsurable Loss in the Public Good

We examine two sources of uninsurable losses: the public good and personal assets. Public infrastructure like roads and bridges and public utilities such as water and electricity are subject to natural hazards. After a hurricane or flood, it takes local communities a long time to restore the neighborhood. During the recovery time, the public good are provided at a suboptimal level.

A community has *N* identical households, who consume a private good *x* and a public good *g*. Households have utility function $u(x, g)$ which satisfies standard concavity assumptions: $u_x, u_g > 0$, $u_{xx}, u_{gg} < 0$, and $u_{xg} > 0$. There are two states, high and low, which happen with probabilities $1 - p$ and p respectively. A natural hazard happens in the low state, causing damage to households' wealth and the public good. Wealth in each state is denoted by $w^h > w^l$ respectively (superscripts *h* and *l* denote the high and low states). A fair insurance policy is available in the market for households to purchase against risk. Premium *pc* is charged for coverage *c*. The public good level *g* is chosen across states (or chosen before the hazardous state realizes), and its cost is equally shared. In the low state, the natural hazard causes damage *d* to the public good. The community can also decide on an emergency spending $m \leq d$ financed through an equal-share tax *d/N* in the low state, to repair and restore public good up to its original level. The private good consumption is thus $x = w^h - \frac{g}{N} - pc$ in the high state and $w^l - \frac{(g+m)}{N} + (1-p)c$ in the low state.

The optimum is solved as the representative household choosing public good, insurance coverage, and restoration spending to maximize expected utility:

$$\text{Max}_{g,c,m} EU = (1-p)u\left(w^h - \frac{g}{N} - pc, g\right) + pu\left(w^l - \frac{g+m}{N} + (1-p)c, g-d+m\right),$$

The first order conditions are (Here $u_{x|h}$ denotes the value of function u_x in the high state.):

$$\frac{\partial EU}{\partial g} = (1-p)\left(-\frac{u_{x|h}}{N} + u_{g|h}\right) + p\left(-\frac{u_{x|l}}{N} + u_{g|l}\right) = 0,$$

$$\frac{\partial EU}{\partial c} = (1-p)p\left(-u_{x|h} + u_{x|l}\right) = 0,$$

$$\frac{\partial EU}{\partial m} = -\frac{u_{x|l}}{N} + u_{g|l} = 0.$$

In reality, a restoration spending may not be readily available for a community. The restoration tax is an extra spending in the low state which may not be covered by commercial insurance. Proposition 1 presents optimal allocations in the first best and also the above second best situations.

Proposition 1.

(i) *When public good restoration in the low state is available, the Samuelson condition holds in each state,*

$$u_{x|h} = Nu_{g|h} \text{ and } u_{x|l} = Nu_{g|l},$$

and there is a unique optimal policy choice of full restoration $m^* = d$ *and insurance* $c^* = w^h - w^l + \frac{d}{N}$.

(ii) *When public good restoration in the low state is available but insurance is capped at the wealth loss* $w^h - w^l$*, the Samuelson condition holds in each state, and the unique optimal choice is* $m^{*'} < d$ *and* $c^{*'} = w^h - w^l$.

(iii) *When public good restoration is not available, the Samuelson condition holds in expected utility,*

$$\frac{1}{N}\left((1-p)u_{x|h} + pu_{x|l}\right) = (1-p)u_{g|h} + pu_{g|l},$$

and the optimal insurance is less than wealth loss $c^{**} < w^h - w^l$.

Proof.

(i) Three equalities, $\frac{\partial EU}{\partial m} = 0, \frac{\partial EU}{\partial g} = 0,$ and $\frac{\partial EU}{\partial c} = 0$, solve into $\frac{1}{N}u_{x|h} = u_{g|h} = u_{g|l} = \frac{1}{N}u_{x|l}$.

And we have the Samuelson condition holding in each state.

First, we notice that $m^* = d$ and $c^* = w^h - w^l + \frac{d}{N}$ is a solution to the above, since it equalizes consumption in both states to $\left(w^h - \frac{g}{N} + pc^*, g\right)$. To show uniqueness, we suppose there is another solution with $m' < d$. The public good in the low state is kept lower than that in the high state. From $u_{x|h} = u_{x|l}$, we need a higher private good in the high state, $w^h - \frac{g}{N} - pc > w^l - \frac{(g+m)}{N} + (1-p)c$, since $u_{xg} > 0$. A lower public good in the low state needs to pair with a lower private good consumption. This means the optimal insurance is $c' < w^h - w^l + \frac{m}{N}$. The consumption bundles are $\left(w^h - \frac{g}{N} + pc', g\right)$ in the high state and $\left(w^l - \frac{(g+m')}{N} + (1-p)c', g - d + m'\right)$ in the low state. Notice that the original choice m^* and c^* result in a bundle $\left(w^h - \frac{g}{N} + pc^*, g\right)$ in both states, which is larger than the high state consumption from choosing m' and c'. It yields a higher expected utility; a contradiction.

(ii) Equalities $\frac{\partial EU}{\partial m} = 0$ and $\frac{\partial EU}{\partial g} = 0$ solve into the Samuelson condition in each state:

$$u_{x|h} = Nu_{g|h} \; and \; u_{x|l} = Nu_{g|l},$$

The second derivative $\frac{\partial^2 EU}{\partial c^2} = (1-p)p\left(pu_{xx|h} + (1-p)u_{xx|l}\right) < 0$ holds for all values of g and m. So, the optimal constrained insurance choice is $c^{*\prime} = w^h - w^l$. This leads to a low state private consumption lower than that in the high state:

$$w^l - \frac{g+m}{N} + \left(w^h - w^l\right) - pc^{*\prime} = w^h - \frac{g+m}{N} - pc^{*\prime}.$$

The Samuelson condition in the high state is

$$u_x\left(w^h - \frac{g}{N} - pc^{*\prime}, g\right) = Nu_g\left(w^h - \frac{g}{N} - pc^{*\prime}, g\right).$$

since $u_{xx} < 0$ and $u_{xg} > 0$, $u_x(x - \Delta x, g) > Nu_g(x - \Delta x, g)$. To maintain the Samuelson condition in the low state, public good needs to be lower: $g - d + m^{*\prime} < g$, and thus $m^{*\prime} < d$.

(iii) The Samuelson condition comes from $\frac{\partial EU}{\partial g} = 0$. Condition $\frac{\partial EU}{\partial c} = 0$ implies $u_{x|h} = u_{x|l}$.

Notice that the public good is higher in the high state, and the marginal utility of *x* increases with the public good, $u_{xg} > 0$. To hold the above equality in the marginal utility of *x*, the private good consumption needs to be higher in the high state. This means

$$w^h - \frac{g}{N} - pc^{**} = w^l - \frac{g}{N} + (1-p)c^{**},$$

$$c^{**} < w^h - w^l. \blacksquare$$

When public good restoration is available, the optimal insurance coverage needs to equalize households' consumption in both states. Thus, it includes the tax share for restoration spending, and is larger than the loss in wealth. Unfortunately, commercial insurance policies usually only cover property values, and will not cover an intangible tax payment. This lack of coverage puts a cap on the optimal insurance and leads to a second-best restoration policy as well. The public good will not be restored to its original level. Moreover, when public good restoration is not available, optimal insurance coverage will be less than the wealth loss.

4. Uninsurable Loss in Personal Assets

We illustrate how risk preferences can be estimated with uninsurable loss in a model of flood insurance purchase. This a framework that we develop for computational purposes, with the utility function and loss distribution left unspecified. We present no analytical results due to the complex integrals encountered. The loss distribution of flood may be composed from real historical data in future research instead of an assumed form.

When households purchase (actuarially unfair) flood insurance for their houses, they choose both deductible and coverage. With uninsurable losses, the model demonstrates equilibrium under-purchase of insurance coverage. Real world data show that a large portion of households do not purchase full insurance. Yet, basic models with risk-aversion preferences predict that full insurance is optimal. Even with actuarially unfair commercial insurance policies, the deviation to full insurance is minute. Our approach has an advantage that it predicts optimal underinsurance because of uninsurable loss. Optimization conditions can pin down two parameters, one for risk preferences and one for uninsurable loss. We are not looking to provide analytical results in this section, but rather illustrate an estimation strategy for general utility functions.

Personal assets that have emotional values are another possible source of uninsurable losses. When a house is flooded, items of family memories such as photos and paintings, may be destroyed with the house. We model this with a parameter e in the utility function $u(x, e)$. It is a state-dependent parameter that indicates a loss in the low state, $e^h > e^l$. We assume additionally $u_e,\ u_{xe} > 0$. Households maximize utility

$$\text{Max}_c EU = (1-p)u\left(w^h - pc, e^h\right) + pu\left(w^l + (1-p)c, e^l\right).$$

Optimization leads to

$$\frac{\partial EU}{\partial c} = -(1-p)p\left(-u_{x|h} + u_{x|l}\right) = 0.$$

Proposition 2. *When there is an uninsurable loss in personal assets, optimal insurance is less than wealth loss,* $c^* < w^h - w^l$.

Proof. Marginal utility is equalized in both states but $e^h > e^l$. Consumption need to be higher in the high state since $u_{xe} > 0,$ and $u_{xx} < 0$.

$$w^h - pc^* < w^l + (1-p)c^*.$$

This means $c^* < w^h - w^l$. ■

Risk preferences play a crucial role in households' choice against natural hazards, and empirical estimation on preferences is important for policy evaluations. Risk preferences can be estimated from households' behavior. Empirical studies, such as Harel and Harpaz (2007), and Cohen and Einav (2007), use the choice of coverage and deductibles in insurance purchases for automobiles and houses. We develop a model of flood insurance on house values that predicts underinsurance in equilibrium. Households choose two variables, coverage and deductible, and the model can be used to estimate two parameters, uninsurable loss and risk preferences, in the utility function. Our model with optimal underinsurance fits real world behavior better than a model predicting full insurance.

A representative household has wealth w and a house of valued H which is subject to flood damages. A flood happens with probability $1 - p$, it brings a potential property loss with different degrees of severity $l \in [0, \infty]$, and the probability distribution of loss l is $f(l)$. The actual property damage to the house is $\hat{l} = \max[H, l]$. Households can buy insurance against flood damages. An insurance policy is available with coverage *c* and deductible *d*. The insurer charges a premium schedule $M(c,d)$ with $M_c > 0,$ and $M_d < 0$. The premium is not necessarily actuarially fair, and it increases with coverage and decreases with deductible. There is a premium discount associated with a higher deductible. A simple example is $M(c,d) = m(c) - e(d)$ where $m(.)$ is the premium schedule according to coverage and e(.) is the schedule for premium discount. If a household buys coverage *c* and deductible *d*, $d < c \le H$, the policy will pay $min[l,c] - d$, which compensates any loss no greater than the coverage. There are four outcomes when a flood happens: (i) when $l < d$, a claim will not be filed; (ii) when $d \le l < c$, the insurance pays $l - d$ to compensate the loss minus deductible; (iii) when $c \le l < H$, the insurance pays *c* and the household suffers net loss $l - c$; and (iv) when $H \le l < \infty$, the household suffers loss $H - c$ with deductible.

The representative household has utility function $u(x,e;\alpha,\beta) = e^{-\alpha\hat{l}}u(w - \hat{l};\beta)$.

Private consumption is denoted by $x = w - \hat{l}$, which is wealth minus loss. When there is actual flood damage $\hat{l}$, the loss term $e^{-\alpha\hat{l}}$ in the utility function captures an uninsurable loss that causes a decrease in utility. It is assumed to be separable for simplicity. The uninsurable loss is assumed to be correlated with the actual damage inflicted. Parameter β can indicate risk preferences, but for the simplicity of expression, we suppress parameter β in the following. The household with insurance policy (c,d) has expected utility:

$$\begin{aligned} EU = {} & pu(w + H - M(c,d)) + (1-p)[\int_0^d e^{-\alpha l}u(w + H - l - M(c,d))f(l)dl \\ & + \int_d^c e^{-\alpha l}u(w + H - d - M(c,d))f(l)dl \\ & + \int_c^H e^{-\alpha l}u(w + H - d - l + c - M(c,d))f(l)dl) \\ & + \int_H^\infty e^{-\alpha H}u(w + c - d - M(c,d))f(l)dl]. \end{aligned}$$

Optimization over *c* and *d* leads to[1]

$$\begin{aligned} 0 = \frac{\partial EU}{\partial c} = {} & -pu'(w + H - M)M_c + (1-p)[-M_c\int_0^d e^{-\alpha l}u'(w + H - l - M)f(l)dl \\ & - u'(w + H - d - M)M_c\int_d^c e^{-\alpha l}f(l)dl + u(w + H - d - M)e^{-\alpha c}f(c) \\ & + (1 - M_c)\int_c^H e^{-\alpha l}u'(w + H - l - d + c - M)f(l)dl \\ & - e^{-\alpha c}u(w + H - d - M)f(c) + e^{-\alpha H}u'(w + c - d - M)(1 - M_c)\int_H^\infty f(l)dl], \end{aligned}$$

and

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[1] In the following, we used the Leibniz integral rule,

$$\frac{\partial}{\partial z}\int_{a(z)}^{b(z)} f(x,z)dx = \int_{a(z)}^{b(z)} \frac{\partial f(x,z)}{\partial z}dx + f(b(z),z)\frac{\partial b}{\partial z} - f(a(z),z)\frac{\partial a}{\partial z}.$$

$$0=\frac{\partial EU}{\partial d}=-pu'(w+H-M)M_d+(1-p)[-\int_0^d e^{-\alpha l}u'(w+H-l-M)(1+M_d)f(l)dl$$
$$+e^{-\alpha d}u(w+H-d-M)f(d)-u'(w+H-d-M)(1+M_d)\int_d^c e^{-\alpha l}f(l)dl$$
$$-u(w+H-d-M)e^{-\alpha d}f(d)$$
$$-\int_c^H e^{-\alpha l}u'(w+H-l-d+c-M)(1+M_d)f(l)dl$$
$$-e^{-\alpha H}u'(w+c-d-M)(1+M_d)\int_H^\infty f(l)dl].$$

The above can be simplified to

$$pM_c\bar{u}_0-(1-p)[-M_c(\bar{u}_1+\bar{u}_2)+(1-M_c)(\bar{u}_3+\bar{u}_4)]=0,$$
$$pM_d\bar{u}_0+(1-p)(1+M_d)[\bar{u}_1+\bar{u}_2+\bar{u}_3+\bar{u}_4]=0,$$

where $\bar{u}_0=u'(w+H-M), \bar{u}_1=\int_0^d e^{-\alpha l}u'(w+H-l-M)f(l)dl,$

$$\bar{u}_2=u'(w+H-d-M)\int_d^c e^{-\alpha l}f(l)dl\,,\bar{u}_3=\int_c^H e^{-\alpha l}u'(w+H+c-l-d)f(l)dl,$$

$$\bar{u}_4=u'(w-M+c-d)e^{-\alpha H}\int_H^\infty f(l)dl.$$

The expo-power function proposed by Saha (1993) is a good candidate for the utility function:

$$u(w)=\theta-\exp(-\tau w^\sigma).$$

This utility function is general in the form of risk preferences. It exhibits both absolute and relative risk aversion separately, controlled by two parameters respectively. Parameter σ shows increasing or decreasing absolute risk aversion, and τ shows increasing or decreasing relative risk aversion. Only one of the two parameters would be used in our model as parameter β and the other fixed as given. We do not aim to obtain analytical results in this paper. Actual estimation is left for future research with better data. For example, the loss distribution $f(l)$ can be computed non-parametrically from historical data.

5. Conclusion

This paper offers partial explanations for why households do not purchase full insurance facing natural hazards. Policy design needs to take into account households' rational responses and incentives. When there are uninsurable losses in the public good or personal assets, underinsurance is optimal. This result may fit data better than a model predicting full insurance. The reason for underinsurance is that a low consumption due to uninsurable losses in the low state forces a low consumption in another good in order to equate marginal utility levels across states.

An estimatable model of flood insurance is developed, where households maximize expected utility choosing insurance coverage and deductibles when purchasing (not actuarially fair) flood insurance for their houses. There is no public good in the model, but households have uninsurable losses to personal assets. The model demonstrates equilibrium under-purchase of insurance coverage. We propose this framework for future empirical research. Our approach has an advantage that it predicts optimal underinsurance.

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