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The Government Sponsored Crop Insurance Program: Expected and Unexpected Consequences

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Synopsis

It is very popular for governments to use linear proportional premium subsidies to increase the insurance penetration in the agriculture production sector. This paper describes a case in which the affordability issue of agriculture insurance is induced by high fixed transaction cost. It is found irrespective of the independency of the risk government intervention helps farmers become better off, as long as the insurance company is certain about its portfolio risk. However, ambiguous information and spatial correlation of catastrophic risk make quite difficult for the insurance companies to estimate and price insurance lines correctly. Consequently, the unobservable high exposure and insolvent probability induced by the intervention could unconsciously hurt stakeholders involved.

Keywords: crop insurance; linear proportional subsidy; catastrophic risk; imperfect information

1. Introduction

The incompetence of insurance industry in coping with natural disaster risk has resulted in wide concerns of public-private partnership in the financial management of disaster risk. It is suggested that the government should use policy tools as well as fiscal instruments to intervene into the private disaster insurance market. In the past years, numbers of governmental programs have been developed either in the form of public insurance or government-sponsored private insurance, which have been developing with applauds and criticisms.

One of the most famous and long-lasting government sponsored private insurance programs is the agricultural insurance in the North America. The United States initialized its Federal Crop Insurance Program (FCIP) in the 1930s. With the 1980 Act it introduced premium subsidies to induce a higher participation rate (Barnett, 2000; Skees 2005). Due to the successful experience obtained in the past years, many developing countries follow the way of intervention in their insurance programs, among which China is a typical example. In China there was an experimental agriculture insurance program from 1987 to 1999 (Shi et al., 2007). However, this purely market based insurance program failed. On the one hand, claim ratio (the ratio of indemnity paid to premium revenue) was quite high. On the other hand, the participation rate was not desirable. As a matter of fact, the Chinese government decided to redesign the agriculture insurance program to protect the agriculture production (The State Council of China, 2006). In 2007, the China Agriculture Policy Insurance Program (CAPIP) was initialized. In the first phase of the program, 6 provinces (or equivalent) received the funding resources of a total of 1 billion RMB Yuan from the central government to operate experimental crop insurance programs. Features in common include: 1) multi-peril insurance lines for crop plantations against rainstorm, flood, inundation, strong wind, hail, frost and drought; 2) premium rates differ from 3% to 10% according to region, crops, and peril; 3) programs are operated at the provincial level; 4) the central government and provincial government subsidize 50% of the premium while local governments (city and county level) subsidize around 10~30%; 5) insurance lines include revenue coverage, yield coverage and cost coverage*.

There is one typical common feature of these sponsored insurance programs, the linear proportional premium subsidy. According to the policymakers, the purpose is to increase the participation rate so that more farmers and crops get hedged by insurance. This paper will mainly discuss in a theoretical way whether the government intervention could achieve such desirable purpose. Before making the judgment, we have to discuss one critical question: why farmers buy little insurance coverage? As we know, there could be plenty of reasons for that (Yokomatsu, 2006; Yokomatsu, 2007). It might because of irrationality that farmers wrongly perceive the risk they are facing, or they perceived the risk but are not aware of it. Alternatively, they do not know what is insurance. If farmers are rational, it could be attributed to many other reasons, e.g. poverty, fixed transaction cost, proportional transaction cost, and adverse selection. 1) Poverty: farmers need some minimum amount of consumption to survive and money to invest in cultivation. If their endowments are just enough or even insufficient to guarantee that, they cannot afford any insurance no matter it is cheap or expensive. 2) Fixed transaction cost: fixed transaction cost which could be denoted as a constant will have strong "income effect" on the consumption of insurance. If this transaction cost is too high, farmers with low endowment will not be able to afford any coverage. 3) Proportional transaction cost: The loading factor induced by proportional cost will not force poor farmers out of the market but force them to buy partial coverage. 4) Adverse selection: premium rate is generally priced according to a pooling strategy in which farmers at all risk levels are taken into a same pool. In that sense, low risk farmers will never be optimum to purchase full coverage since it is too expensive for them.

In this study, we will discuss on the issue that lots of farmers purchase no coverage rather than partial coverage. Then could we see how the government intervention increases the participation rate. With this purpose, the model will describe the low participation rate problem through the fixed transaction cost which keeps poor farmers completely out of the market. The fixed transaction cost consists of the cost in the operation of the business (C_o) and each policy (C_p). C_o is a fixed cost in the daily operating of business, no matter how many policies are sold. It would generate positive externality if the number of policyholders increases as they share this amount of cost. C_p is the fixed cost in each policy, e.g. delivery of insurance lines from cities to the rural areas, cost of underwriting, cost of inspection and indemnity auditing. Everyone will have to pay this amount irrespective of how many policyholders there are. This assumption is natural as in agricultural insurance the fixed transaction cost is significantly high particularly because of the delivery of insurance lines from cities to rural areas.

In the second part of this article, we give the hypothesis of why farmers do no purchase any crop insurance due to the existence of fixed transaction cost. Meanwhile, we shall discuss the budget of intervention as well as the market environment of the subsidized insurance. In section three, we discuss the effect of government intervention on individuals' welfare taking into account catastrophic feature of the disaster. Section 4 will expand the discussion on the pricing issue of insurance companies which could unconsciously make insurance companies highly exposed than expected. Table 1 shows a list of symbols used in this paper.

2. Hypothesis for the model

The affordability issue induced by fixed transaction cost

Proposition 1 Fixed transaction cost will force households with low endowments out of the market. In other words, when there is a fixed transaction cost incorporated in the contract, households with low

* Cost coverage is a type of insurance coverage sold in CAPIP. The insured object is the total capital cost in the cropping process, including the cost of seeds, fertilizer, pesticide, and so on. Cost in labor is not taken into account.

Table 1 List of symbols

Symbol	Meaning
μ	Probability of the event
ε	Undamaged proportion of crops
C_o	Fixed cost in business operation
C_p	Fixed cost in every policy sold
l	Area of land for cropping
w	Initial endowment/ cropping revenue
$\hat{w}$	Cropping revenue of the marginal farmer
m	Insurance coverage purchased
$\bar{m}$	Average insurance coverage
$\hat{m}$	Insurance coverage of the marginal farmer
M	Social demand of insurance coverage
n	Number of policyholders
v	Premium rate
γ	Standard coverage per unit area of land
A	Initial contingent reserve kept by the insurer
t	Lump-sum tax imposed
p	Proportional rate of subsidy
δ	Target insolvent probability
$\tilde{\delta}$	Parameter valued from the cumulative density function for given insolvent probability
$u(\cdot)$	Utility function
$V(\cdot)$	Optimized expected utility
$g(\cdot)$	Density function of the cropping revenue
$H(\cdot)$	Cumulative density functions of indemnity portfolio of insurance company
$\bar{\mu},\tilde{\mu}$	Mean of indemnity portfolio
$\bar{\sigma},\tilde{\sigma}$	Standard deviation of indemnity portfolio

endowments should not buy any insurance contracts.

We use a very simple model to prove. Suppose one household is going to get a return of w at the beginning of next period if no disaster occurs. However, if disaster strikes, the return would be discounted by the rate of ε. The household is risk averse and would like to purchase insurance coverage to reduce the variability of the revenue. Thus, the investment behavior of the household is given as

$$\max_m \ \mathrm{E}[u]=(1-\mu)u(w-v\cdot m) + \mu u(\varepsilon w - v\cdot m + m) \quad (1)$$

Subject to

$$\mathrm{E}[u] > V^0 = (1-\mu)u(w)+\mu u(\varepsilon w) \quad (2)$$

The inverse supply function of the insurance is given as $v = v(M, n, C_o, C_p)$, which depends on the total demand of insurance, number of policyholders, the transaction cost in operation and the transaction cost in each policy. In this sense, the budget constraint tells the affordability issue. As we know the premium paid is a certain loss. Once the household purchase coverage, even if it is a very small amount, it will have to pay the transaction cost embodied in the premium. In formulation, the premium paid could be decomposed as

$$vm = \tilde{v}m + C_o/n + C_p \quad (3)$$

Then the part $C_o/n + C_p$ will have a negative income effect as it subtracts from the endowment. The expected utility is actually a piecewise function as

$$\mathrm{E}[u] = \begin{cases} V^0 & m = 0 \\ (1-\mu)u(w - C - \tilde{v}\cdot m) + \mu u(\varepsilon w - C - \tilde{v}\cdot m + m) & m > 0 \end{cases} \quad (4)$$

in which $C = C_o/n + C_p$. In this sense, for those whose revenue is low, it will never be optimum to purchase any coverage as it cannot meet the second constraint. In order to show this issue visually, a simple numerical example is employed here. If we specify the utility function in Cobb-Douglas form with the supply function in a purely competitive market without any other loading factor,

$$vm = \mu m + C_o + C_p \tag{5}$$

and set parameter vector $(\mu, \varepsilon, C_o, C_p)$ as (0.1, 0.1, 0, 5), we could have the result as below:

We could see from fig. 1 that for given fixed transaction cost, for those who with low endowments, their optimum amount of coverage would be 0. as once $m > 0$, their expected utility will be strictly smaller than V^0.

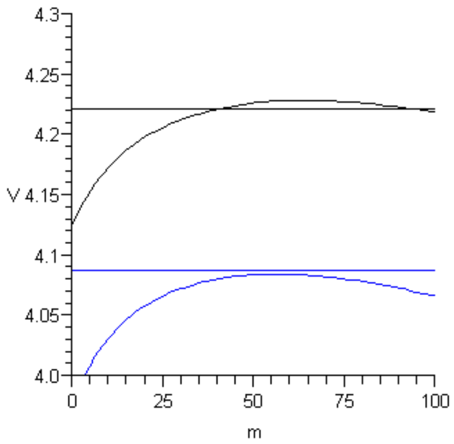


Fig. 1 Comparative statics of Expected Utility (V) respect to insurance coverage
The straight lines denote the EU without insurance while curves denote the EU when insurance coverage is purchased. Blue lines are where w=70 while black lines are where w=80.

The budget of intervention

Proposition 2 If the government is using lamp-sum tax revenue to subsidize households proportionally, it must not be a general equilibrium at the household level.

In other words, the total cost for subsidy must be larger than the tax revenue collected from the farmers. Government will have to either redistribute the tax revenue among households or use tax revenue from other sectors or urban households. Otherwise, the intervention will only make households worse off.

To prove this, first let us assume that the tax revenue comes only from the agriculture sector in the form of lump-sum taxation. Thus, the decision-making process of the representative farmer could be formulated as

$$\max_m \ \mathrm{E}[u] = (1-\mu)u\left[w - t - (1-p)v \cdot m\right] + \mu u\left[\varepsilon w - t - (1-p)v \cdot m + m\right] \tag{6}$$

Subject to

$$\mathrm{E}[u] > V^0 \tag{7}$$

Meanwhile, the budget constraint for the government is given as

$$0 \le pvm \le t \tag{8}$$

Firstly, the farmer will choose an optimum amount of coverage for given intervention strategy, $m^*(w;t,p)$. By observing the optimum choices of the representative farmer, the government could choose the optimum intervention strategy. Using envelop theorem, we know that $\frac{\partial V}{\partial t} < 0$, $\frac{\partial V}{\partial p} > 0$ (please turn to Appendix-1 for the proof). If the government wants to maximize the household's expected utility through intervention, the inequality binds. It says that the full tax revenue should be used to subsidize the farmer, $pvm = t$. By comparative statics (Appendix-2), it could be found that even if the government uses full tax revenue to subsidize, the expected utility is a non-increasing function of the subsidizing parameter, $\frac{\partial V}{\partial p} \le 0$, for $p \in [0,1)$. This result tells that in order to make farmers better off through such kind of intervention, the government has to make extra budget. The reason could be put in an intuitive way. Since farmers have already been choosing the best thing, this kind of tax-subsidy trick can only make them worse off since no extra endowment is given. Nevertheless, there could be plenty of discussion beyond this result as here we only formulated the representative households. If there are numbers of households, the government could pool the tax revenue and make discriminated taxation and subsidizing strategy. One way to redistribute wealth among farmers is to make the relatively richer farmers help the poorer ones. That kind of intervention is actually running in the form of "cross-subsidy" in some countries. However, generally the government should make the tax and subsidy ratio indifferent to all citizens. Meanwhile, whether to conduct discriminated subsidy depends on the criteria of defining the social welfare. In this simple model, we shall not go into depth on that issue but just assume the budget must come from cross-sector support. In other words, the tax revenue used to subsidize the premium paid by farmers could from other industrial sectors and other households living in urban areas. Therefore, in order to make the model simplified, we can further assume that the government exempts the lump-sum tax on farmers, t=0.

The environment of the disaster insurance market

Proposition 3 The environment of the market for the subsidized crop insurance must not be purely competitive. The principle for pricing the insurance lines is least profitable within the solvent constraint.

The environment of the market determines the strategy of insurance companies to price their products. Meanwhile, as a government sponsored insurance program, the government expects the most cost-effective outcome and thus forces insurance companies to price their crop insurance lines least profitable as long as the program is sustainable. As we know, the least profitable situation is pure competitive market where insurance companies could earn 0 expected profits.

$$\left(1-\mu\right)\nu M+\mu\left(\nu M-M\right)=C_o+nC_p \tag{9}$$

Meanwhile, the sustainability constraint tells that insurance companies must keep the probability of business insolvency within a target value. If the cumulative density function (*c.d.f.*) of disaster indemnity is $H\left(x\right)$, this rule requires

$$\begin{gathered}\Pr\left\{x>A+\nu M-C_o-nC_p\right\}\le\delta\\ A+\nu M-C_o-nC_p\ge H^{-}\left(1-\delta\right)\end{gathered} \tag{10}$$

in which $H^{-}\left(1-\delta\right)$ refers to the inverse function of $H\left(x\right)$ valued at the point $\left(1-\delta\right)$. When the cumulative density function is given, it will be a threshold of liquid cash-in-hand (*c.i.h.*), $\tilde{\delta}$. As we know, when the total liability and number of policy changes, this threshold will also change according to the change in the *c.d.f.* Thus, the contingent reserve requested to reach the target *c.i.h.* becomes

$$A\ge\tilde{\delta}\left(M\right)-\mu M \tag{11}$$

In general, it holds that $\tilde{\delta}\left(M\right)\ge\mu M$, which implies that the initial reserve is an increasing function with respect to the liability of the company. As we shall prove later, there will be a rise in the demand of insurance when intervention is conducted. Obviously, not all insurance companies are able to prepare contingent reserve in a sufficient size. That is to say, the environment of the disaster insurance market cannot be purely competitive. Instead, it is likely that there are only several insurance companies are chosen by the government to run the program. The environment is neither monopoly nor oligopoly. Thus, a more practical criterion to price their insurance lines would be the "Probable Maximum Loss" (PML) rule (or insolvent principle). When reinsurance is not taken into consideration, the least profitable but sustainable pricing strategy would be:

$$\begin{gathered}\nu=\min\left\{\nu\mid 1-H\left(x\right)\le\delta\right\}\\ H\left(x\right)=\Pr\left\{x\le A+\nu M-C_o-nC_p\right\}\end{gathered} \tag{12}$$

3. The effect of government intervention in a crop insurance pool

Environment of the model

Suppose there are totally N farmers in this region. They are the same in terms of disaster risk but their areas of land for cultivating are different. Through cultivating, a farmer could harvest his crops and get revenue of $w(\cdot)$ if cropping is successful. Due to the focus of this study, we assume the output of land $w(\cdot)$ only depends on the area of land, l. Meanwhile, the productivity of land is homogeneous. We further assume the revenues of farmers follow a distribution $g(\cdot)$ on the interval of $[w_0, w_1]$. Crops have the same probability of getting damaged. If disaster strikes, only a small part of crops could be harvested. We assume if disaster strikes, the revenue would be discounted by the ratio of ε.

Insurance is the only financial instrument for farmers to manage their risk, as capital markets is far from mature to be available for farmers. In accordance to the discussion on the environment of market, there are only several insurers involved in the subsidized program. Nevertheless, their pricing strategies are strongly supervised according to the least profitable but solvent constraint. For the sake of simplicity, it is assumed there is only one insurer or a group of insurers providing the same products with identical premium rates. There is significant amount of fixed transaction cost in the operation of business and delivery of insurance policies. Due to the focus of the study, proportional transaction cost is not taken into account.

The government imposes a lump-sum tax and subsidizes farmers proportionally. As the budget constraint is not taken into account here, we assume the lump-sum tax is zero, or the cropping revenue is post-tax income.

Thus, the insurance purchasing behavior is given as

$$\begin{aligned}\max_{m}\ \mathrm{E}[u] &= (1-\mu)u\left[w-(1-p)\nu\cdot m\right] \\ &+\mu u\left[\varepsilon\cdot w-(1-p)\nu\cdot m+m\right]\end{aligned} \tag{13}$$

subject to

$$\begin{aligned}&\mathrm{E}[u] > V^0 = (1-\mu)u(w)+\mu u(\varepsilon w) \\ &m \le \gamma\cdot l\end{aligned} \tag{14}$$

Note that the budget constraint is different from the most general model in the previous section. The second item tells the unique feature of crop insurance: the maximum amount of coverage that a farmer could purchase dependes on the area of his land, l. Here γ is the insurance coverage per unit area of land determined by the insurance company. If w is in monetary unit, it could either denote revenue coverage or cost coverage, with γ denoting the revenue per unit area of land with instant market price and the average capital cost per unit area of land, respectively. If w is in weight or other units and γ denotes the expected yield per unit area, it is yield coverage with price standardized to 1. With this constraint, the individual demand of insurance is capped. If not there would be excessive coverage because of heavy subsidy, which is likely to happen in other insurance lines, e.g. healthy insurance (Selden, 1999).

If the number of farmers is large enough that we could treat the social demand using integral approach, the total premium revenue and the number of policyholders are denoted by

$$\begin{aligned}M &= \int_{\hat{w}}^{w_1} m(x)\cdot g(x)\,dx \\ n &= \int_{\hat{w}}^{w_1} g(x)\,dx\end{aligned} \tag{15}$$

The endowment of the marginal farmer who is just able to afford the insurance is

$$\hat{w} = \min\left\{w \mid V^*(w) \ge (1-\mu)u(w)+\mu u(\varepsilon w)\right\} \tag{16}$$

Independent risks

Independency of risk across agents is the most fundamental assumption of modern insurance theory. Although we know that disaster risk is not independent across agents, it is the best extreme we can assume and a good reference. To make the model simple, suppose there is only one type of disaster for all farmers. For individual risk at a certain instant, it is a Bernoulli trial with out come of {0, 1}, namely occur or not. Along the time horizon, it changes to a Binominal distribution when the number of time periods gets larger and finally converges to Poisson distribution $\pi(\mu)$, with expectation and variance equal to the probability of the event. Therefore, at each time point, the indemnity of the insurance company is a linear combination of Bernoulli random variables.

$$\mathbf{L} = m_1\mathbf{x}_1 + m_2\mathbf{x}_2 + \ldots + m_n\mathbf{x}_n \tag{17}$$

in which $\mathbf{x}_i$ denotes the Bernoulli random variable with same mean and variance. i here denotes different farmers. Thus,

$$\begin{aligned} E[\mathbf{L}] &= \mu\sum_{i=0}^{n} m_i = \mu M \\ \mathrm{Var}[\mathbf{L}] &= \sigma^2\sum_{i=0}^{n} m_i^2 = \mu(1-\mu)\sum_{i=0}^{n} m_i^2 \end{aligned} \tag{18}$$

According to the assumption of independency, the random variable $\mathbf{L}$ could be approximated by using Liapunov Theorem and it converges to the normal distribution,

$$\Pr\left\{\frac{\mathbf{L}-\mu_{\mathbf{L}}}{\sigma_{\mathbf{L}}} \le x\right\} \sim \Phi(x) \tag{19}$$

By applying the PML rule,

$$\Pr\left\{x > A + \nu M - C_o - nC_p\right\} \le \delta \tag{20}$$

Normalize the formulation to a standard normal distribution, we have

$$\frac{A + \nu M - C_o - nC_p - \mu M}{\sqrt{\mu(1-\mu)\sum_{i=0}^{n} m_i^2}} \ge \Phi^{-}(1-\delta) \tag{21}$$

By letting $\tilde{\delta} = \Phi^{-}(1-\delta)$, the pricing strategy is denoted as

$$\nu \ge \mu + \frac{1}{M}\left(\sqrt{\mu(1-\mu)\sum_{i=0}^{n} m_i^2}\cdot\tilde{\delta} - A\right) + \frac{nC_p + C_o}{M} \tag{22}$$

In the pricing equation, the first item on the right hand side is the true cost of insurance, the probability of the event. The second item denotes the loading factor to keep the portfolio meeting the solvent constraint. The third item is the transaction cost per unit policy. We know from (22) that the sign of $\frac{d\nu}{dM}$ depends on the relationship of the initial reserve and transaction cost. However, when n is large enough, ν would trends to a constant:

$$\lim_{n\to\infty}\nu = \mu + \sqrt{\mu(1-\mu)}\cdot\tilde{\delta} + \frac{C_p}{\bar{m}} \tag{23}$$

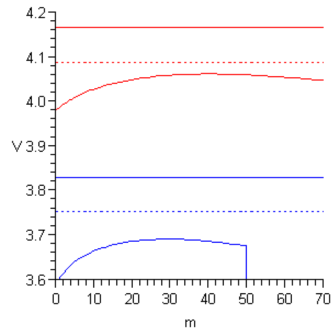
On the other hand, the number of policyholders will keep increasing with the increase in subsidy rate. Thus, there would be a significant increase in both the number of policyholders and social demand of insurance coverage. Now we would like to discuss the welfare of farmers. First we could construct the Lagrangian of the maximization problem with objective function (13) plus constraints (14), (15) and (16). Please turn to appendix-3 for details. According to the envelope theorem, the relationship between maximum expected utility and subsidy rate is given as

$$\left.\frac{dV}{dp}\right|_{p\in[0,1)} = \left.\frac{\partial \mathrm{L}}{\partial p}\right|_{p\in[0,1)} \ge 0 \tag{24}$$

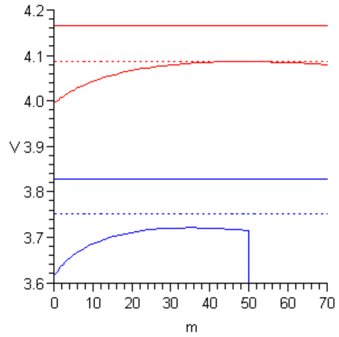
We see that the intervention helps farmers get better off. The expected result of the intervention is achieved. In order to show the comparative statics visually, we use a simplified model to derive the curves. Suppose all farmers are homogenous in terms of all aspects, including damage ratios, areas of land, and productivity of land. We specify the utility function in C-D form. Parameters are given as

{ $\mu = 0.1$; $\varepsilon = 0.2$; $C_o = 0$; $C_p = 10$; $l = 1$; $\gamma = w(l)/l$; $\tilde{\delta} = 2.326$ }. $\gamma = w(l)/l$ means the insurance company is providing full revenue coverage for the farmers. The value of $\tilde{\delta}$ represents approx. 1% exceedance probability on the standardized normal curve.

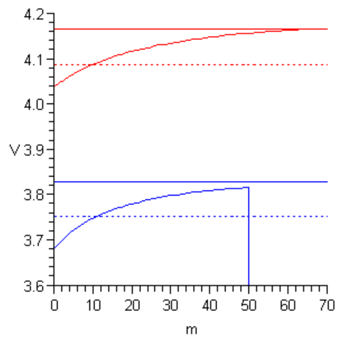
From fig. 2 we observe the effect of intervention. In panel A where there is no proportional subsidy, expected utilities of farmers are far below the ones when they could purchase fair insurance. Meanwhile, as the revenue given for two scenarios are too small compared to the transaction cost, farmers will not buy insurance. When the proportional subsidy comes, their maximum expected utility of purchasing insurance will increase. For the scenario in which w=70, when the subsidy rate is around 14% (panel B), farmers will be indifferent between purchasing and not purchasing. When the subsidy rate comes to 51% (panel C), the government subsidy actually diminishes the negative impact induced by the fixed transaction cost. We could also see that for the farmers in the scenario in which w=50, the critical subsidy rates are different from the scenario in which w=70. Moreover, the expected utility with insurance coverage will not increase dramatically but bounded even if the subsidy rate is too heavy. This is because the coverage is capped according to the area of the land.



A (*p=0*)



B (*p=0.14*)



C (*p=0.52*)

Fig. 2 Comparative statics of EU with respect to subsidy rate

The horizontal lines denote the expected utility when farmers purchase insurance with fair premium rate; horizontal dash lines denote the expected utility if they don't purchase any insurance; curves denote the expected utility when farmers purchase subsidized insurance whose premium rate is marked up by the transaction cost. We have two scenarios, the red with w=70 and the blue with w=50.

Dependent risks

The government intervention works in the previous section and it is the best situation we could assume: risks are independent of each other and the law of large numbers could be applied. However, as known by us, this assumption is not true in terms of natural disaster risk. Disaster risk is a kind of group risk or collective risk which correlates across households. Generally, insurance companies use statistical approaches to derive the density and distribution of the indemnity based on historical indemnity records. However, in that sense it is not easy for us to discuss on comparative statics about the intervention without analytical equations. When the number of policyholders is larger than two, it is difficult to use analytical approach to derive the density function, particularly when risk is interdependent. Therefore, here we just approach to the worst extreme: all risks are perfectly correlated with each other. In that sense the distribution function is:

$$F(x)=\begin{cases}0 & x<0\\ 1-\mu & 0\le x<M+C_o+nC_p\\ 1 & M+C_o+nC_p\le x\end{cases} \tag{25}$$

Still we assume the population has the same size and endowment distribution as described in (15). Thus, the pricing strategy is to make the probability of insolvency smaller than a target value. As the cumulative distribution function is discontinuous here, there are only three values to specify as target probability. A reasonable solution is to assume the company wants to keep itself completely solvent, which means

$$\begin{gathered}\Pr\left\{x>A+\nu M-C_o-nC_p\right\}=0\\ A+\nu M-C_o-nC_p\ge M\end{gathered} \tag{26}$$

So the premium rate is given as

$$\nu\ge 1-\frac{A-C_o-nC_p}{M} \tag{27}$$

Again we could discuss the effect of government intervention by using the envelop theorem. We can find that the derivative of expected utility with respect to the intervention parameter is the same and the intervention does help farmers again. We have the same result as in (24). Actually, the effect has nothing to do with the distribution of the indemnity of the insurance company.

4. Discussion

From the previous section, we see that if the insurance company can price the crop insurance lines correctly according to the *c.d.f.* of indemnity, the government intervention will always help farmers become better off. Unfortunately, in reality the insurance companies are not able to do so due to the ambiguous information on the catastrophic risk. The reasons are as follows. Generally insurance companies do not have long historical indemnity records to generate a good Exceedance Probability (*EP*) curve. Even if they did that, the dramatic change in the demand induced by the intervention could make the original "perfect" *EP* curve a wrong one. They are likely to underestimate the coming consequence of natural disaster and under pricing their products.

Assuming independency among risks

For a newly established insurance company, or for insurance companies which do not have enough records to estimate the *EP* curve, they might assume risks are independent and use the general normal distribution to make their pricing. The result would be horrible. One vivid example could be generated by just using the result from the two cases we formulated above. If the risks are so highly correlated that could be treated as one risk but the insurance company is using the pricing for independent risks, the insolvent probability will become

$$EP\left(\mu M+\sqrt{M\mu(1-\mu)}\cdot\tilde{\delta}\right)=\mu \tag{28}$$

This means that the probability of insolvent is the same as the probability of the disaster! Although this pricing strategy is comparing between two extreme cases, the essential is the same. It is sure that the insurance product will be underpriced if they are pricing it by assuming independency, as independency is another extreme, the best extreme we could have expected.

Using the original EP curve

Suppose the insurance company estimated the distribution of indemnity from historical indemnity records, with a standardized distribution function of $H(x)$ with parameter $\left(\bar{\mu},\bar{\sigma}^2\right)$. Thus, this company would like to price its insurance lines using

$$\nu\ge\frac{1}{M}\left[\bar{\mu}+\bar{\sigma}\cdot H^{-}(1-\delta)-\left(A-C_o-nC_p\right)\right] \tag{29}$$

After the intervention, the demand of insurance is likely to increase. Meanwhile, the distribution function would change to $\tilde{H}(x)$ with parameter $\left(\tilde{\mu},\tilde{\sigma}^2\right)$. However, the insurance company could not observe this unless enough indemnity records emerge after the intervention. For positively correlated risks, we will have

$$\tilde{H}^{-}\left(1-\delta\right) > H^{-}\left(1-\delta\right), \quad \tilde{\mu} > \overline{\mu}, \text{ and } \tilde{\sigma} > \overline{\sigma} \tag{30}$$

Obviously, if the company is still using the old *EP* curve to price its products, the desirable insolvent probability could not be achieved. If the company requires same solvent probability, the premium collected must meet

$$EP\left(\overline{\mu},\overline{\sigma}\right) = \tilde{EP}\left(\tilde{\mu},\tilde{\sigma}\right) \\ \tilde{\mu} + \tilde{\sigma}\cdot\tilde{H}^{-}\left(1-\delta\right) + \tilde{n}C_p \geq \overline{\mu} + \overline{\sigma}\cdot H^{-}\left(1-\delta\right) + \overline{n}C_p \tag{31}$$

However, as the company is actually pricing with the original EP curve and thus the required premium is underestimated, finally we will have

$$\tilde{EP}\left(\overline{\mu} + \overline{\sigma}\cdot H^{-}\left(1-\delta\right) + \tilde{n}C_p\right) \\ \geq \tilde{EP}\left(\tilde{\mu} + \tilde{\sigma}\cdot\tilde{H}^{-}\left(1-\delta\right) + \overline{n}C_p\right) \tag{32}$$

Thus, the insolvent probability would be higher than the desirable one.

In the above two ways, insurance companies could be "cheated" by their basis for pricing. The most explicit consequence is the insurance companies will not be sufficiently prepared to the coming disaster. Consequently, liquidity crisis or even bankruptcy would happen. Finally, all stakeholders, the farmers, the insurers and the government get hurt.

5. Conclusions

It is a very popular government intervention approach to proportionally subsidize in premiums paid by policyholders to increase the participation rate of private insurance programs. This study has made an attempt to answer how such kind of government intervention is expected to work and help farmers. It modeled the situation that poor farmers are not able to afford crop insurance because of high fixed transaction cost in the operation of insurance business. Meanwhile, discussion on the micro structure of the intervention says the government will have to use tax revenues besides agricultural sector. In order to make the program solvent, insurers need to be allowed to receive some positive expected profit. The government will request the insurers to price insurance lines least profitably within solvent constraint.

As long as the insurance company can observe the *c.d.f.* of indemnity liability and price insurance lines correctly, the government intervention could achieve desirable outcomes irrespective of independency of the risk. This is because in this linear proportional subsidizing system, the subsidy in premium is some "extra income" which can only be consumed on insurance. It allows farmers to afford more insurance coverage. Meanwhile, more farmers could overcome the threshold induced by high transaction cost and get covered. One important difference with other types of subsidized insurance is the coverage of crop insurance is capped according to the area of the land.

Unfortunately, the program will fail to meet the essential mechanism, i.e., pricing of insurance lines. If insurance companies wrongly estimate the *c.d.f.* of indemnity and under-estimate their exposure, the *c.i.h.* will not be sufficient for the coming events, because of the imperfect information on the disaster risk itself. Insurance companies generally have very limited samples compared to the entire population. In this sense, catastrophic risk modeling is urged to help insurers understand and estimate their portfolio risk. In some situations, insurers are not allowed to rate by themselves. Then the government has to invest on insurers to cope with the extra exposure induced by the intervention. It will take the forms of special reinsurance program, disaster reserve, or liability exemption (capping of loss).

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Appendix-1

The Lagrangian could be constructed as

$$\begin{aligned}\mathrm{L} &= (1-\mu)u\big(w-t-(1-p)vm\big) \\ &\quad +\mu u\left[\varepsilon w-t-(1-p)vm+m\right] \\ &\quad -\lambda\begin{pmatrix}V^0-(1-\mu)u\big(w-t-(1-p)vm\big) \\ -\mu u\left[\varepsilon w-t-(1-p)vm+m\right]\end{pmatrix} \\ \lambda &\ge 0\end{aligned}$$

According to the envelop theorem,

$$\begin{aligned}\frac{dV}{dt} &= \frac{\partial \mathrm{L}}{\partial t} \\ &= -(1+\lambda)\begin{bmatrix}(1-\mu)u'\big(w-t-(1-p)vm\big) \\ +\mu u'\big(\varepsilon w-t-(1-p)vm+m\big)\end{bmatrix} \\ &\le 0\end{aligned}$$

$$\begin{aligned}\left.\frac{dV}{dp}\right|_{p\in[0,1)} &= \left.\frac{\partial \mathrm{L}}{\partial p}\right|_{p\in[0,1)} \\ &= (1+\lambda)vm\begin{bmatrix}(1-\mu)u'\big(w-t-(1-p)vm\big) \\ +\mu u'\big(\varepsilon w-t-(1-p)vm+m\big)\end{bmatrix} \\ &\ge 0\end{aligned}$$

Appendix-2

When the budget constraint binds, $t(p) = pvm$.

Thus for $p \in [0,1)$,

$$\begin{aligned}\frac{dV}{dp} &= \frac{\partial V}{\partial t}\frac{dt}{dp}+\frac{\partial V}{\partial p} \\ &= -(1+\lambda)\begin{bmatrix}(1-\mu)u'\big(w-t-(1-p)vm\big) \\ +\mu u'\big(\varepsilon w-t-(1-p)vm+m\big)\end{bmatrix}\cdot\left(vm+\frac{d(vm)}{dp}\right) \\ &\quad +(1+\lambda)vm\begin{bmatrix}(1-\mu)u'\big(w-t-(1-p)vm\big) \\ +\mu u'\big(\varepsilon w-t-(1-p)vm+m\big)\end{bmatrix} \\ &= -(1+\lambda)\begin{bmatrix}(1-\mu)u'\big(w-t-(1-p)vm\big) \\ +\mu u'\big(\varepsilon w-t-(1-p)vm+m\big)\end{bmatrix}\frac{d(vm)}{p} \\ &\le 0\end{aligned}$$

Appendix-3

For a specific farmer, we could construct the Lagrangian as

$$\begin{aligned}\mathrm{L} &= (1-\mu)u\big(w-(1-p)vm\big) \\ &\quad +\mu u\left[\varepsilon w-(1-p)vm+m\right] \\ &\quad -\lambda_1\big(m-\gamma\cdot l(w)\big)-\lambda_2\left(M-\int_{\hat{w}}^{w_1} m(x)\cdot g(x)\,dx\right) \\ &\quad -\lambda_3\left(n-\int_{\hat{w}}^{w_1} g(x)\,dx\right)-\lambda_4\left(M_2-\int_{\hat{w}}^{w_1} m(x)^2\cdot g(x)\,dx\right) \\ &\quad -\lambda_5\begin{bmatrix}V^0(\hat{w})-(1-\mu)u\big(\hat{w}-(1-p)v\hat{m}\big) \\ -\mu u\big(\varepsilon\hat{w}-(1-p)v\hat{m}+\hat{w}\big)\end{bmatrix} \\ &\quad -\lambda_6\begin{bmatrix}V^0(w)-(1-\mu)u\big(w-(1-p)vm\big) \\ -\mu u\big(\varepsilon w-(1-p)vm+m\big)\end{bmatrix}\end{aligned}$$

in which $\lambda_4, \lambda_5, \lambda_6 \ge 0$.

According to the envelope theorem, the relationship between maximum expected utility and subsidy rate is given as

$$\begin{aligned}\left.\frac{dV}{dp}\right|_{p\in[0,1)} &= \left.\frac{\partial \mathrm{L}}{\partial p}\right|_{p\in[0,1)} \\ &= (1+\lambda_6)\begin{bmatrix}(1-\mu)u'\big(w-(1-p)vm\big)vm \\ +\mu u'\big(\varepsilon w-(1-p)vm+m\big)vm\end{bmatrix} \\ &\quad +\lambda_5\begin{bmatrix}(1-\mu)u'\big(\hat{w}-(1-p)v\hat{m}\big)v\hat{m} \\ +\mu u'\big(\hat{w}-(1-p)v\hat{m}\big)v\hat{m}\end{bmatrix} \\ &\ge 0\end{aligned}$$

農作物保険プログラムに対する政府の補助金政策：
予期しい帰結と予期しない帰結

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要　旨

政府が農業部門において保険を浸透させるために，農業従事者の保険料支払いに比例する補助金を与えることはよく知られている。本論文では高い取引費用が農業部門における保険の購入可能性に及ぼす影響をモデル化する。保険会社が自身のポートフォリオリスクを明確に知っている限り，リスクが独立かどうかに関係なく政府の介入が農業従事者の効用を向上させうることを示す。しかしリスクに関する情報が不完備で，カタストロフリスクが空間的相関を持つと，保険会社は保険商品に対して正確に価格付けすることが困難となる。結果として，保険会社がより高いリスクに曝され，支払いが困難になる可能性が高まる。

キーワード:農作物保険，比例補助金，カタストロフリスク，不完備情報