Economic Design for the Supply Side of Agricultural Insurance Markets

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We examine the industry structure of the crop insurance program through the lens of industrial organization theory and develop an analytical framework to evaluate alternative economic design considerations and policy proposals.

Key words: agricultural (crop and livestock) insurance, oligopoly, oligopsony, double auction

JEL codes: D81, D82, G22, G28, L13, Q12, Q18

1. Introduction

Amid increased budget pressures, the current industry structure of the U.S. Federal Crop Insurance program has been criticized in that it might be encouraging excessive rents on the side of agents. As an alternative, competitive bidding by companies for the right to delivery of crop insurance program has been offered up for consideration (Smith, Glauber and Dismukes, 2014; Babcock, 2015).

The examples of auctioning off the natural monopoly position can be seen in utilities (gas and power plants) where the entire market is served by one company makes economic sense due to the increasing returns to scale—unit cost declines with output—(Train, 1992). If, on the contrary, the additional premium and acres only come in with skills and effort expanded on the side of agents, then marginal cost can be increasing in output, and the crop insurance delivery and provision can have decreasing returns to scale, that is, unit cost increases in output beyond a

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certain level. Because the cost structure (minimum efficient scale) relative to the aggregate insurance demand is not determined, a given number of companies cannot be asserted as optimal.

The winner has to bid downwards towards the opportunity cost of their capital and other factors of production. Nevertheless, the resulting rate of return may not be sustainable, and there may be some unintended consequences. The incumbent may gain informational and institutional advantages over potential entrants over time. For instance, one company instead of remaining seventeen would have better bargaining position in negotiating agent commissions as well as negotiating with the government. Furthermore, if a company is selected, others may not be readily available to bid next time around, say in five years. In the longer run, this would mean less innovation and limited breadth of coverage (Mahul and Stutley, 2010). Agents and loss adjusters would have only one alternative to work for, which in turn may be detrimental for farmers' satisfaction with the program.

In order to evaluate alternative design considerations, this paper examines the industry structure of the crop insurance program through the lens of industrial organization theory and intends to develop an analytical framework.

2. Modeling

For the appropriate decision model for the insurer's problem, we adapt an insurer's problem that was initially developed in the context of flood insurance (Kleindorfer and Klein, 2003) to the U.S. agricultural insurance markets. The model is consistent with the view of insurance firm in Stone (1973) and Borch (1990, p. 112). In the model, the insurer facing fixed and convex variable marketing and acquisition costs—where agents' efforts are subsumed as inputs in the cost function— is choosing exposure level in markets and reinsurance capital to maximize the expected profit and remain solvent. We expand on this model by adding some institutional

elements pertaining to the U.S. agricultural insurance markets—stemming from the Standard Reinsurance Agreement (SRA) between the government and companies.

Denote the expected profit for the insurer for a typical year with $V = V(x, K; r, A)$, where x is insurer's exposure (the book of business), K is the reinsurance capital, r is the payment to capital providers (reinsurance premium), A is the sum of the assets of the insurer supporting the business. We assume both r and A are exogenously given. For simplicity, we set $A = 0$ and no longer refer to it in the objective function. Now, the components of the insurer's expected profit can be written as

$$V(x, K; r) = \left(1 - (\alpha - \gamma)\right) R(x) - \left(1 - (\alpha + \theta)\right) \overline{L}^* - C(x) - rK - F \,, \qquad (1)$$

where x is the amount of exposure in a given market; $R(x)$ is the annual revenue (premium volume); $\overline{L}^*$ is the expected amount of losses (indemnities) from all markets, truncated at some stop-loss point; $C(x)$ is the variable marketing, sales and distribution (annual) expenses; and F is the sum of fixed costs associated with entering a particular market.

In line with the U.S. crop insurance experience, the government supports this industry in various ways. First, it provides reinsurance in the form of a stop-loss, for which the threshold is denoted with L^* and taken as the two times the maximum possible loss in a given year under the SRA. Denoting the expected loss with $\overline{L}$, we write $L^* = \eta \overline{L}$ where $\eta > 1$, that is, L^* is some multiple of the expected loss. Second, the government shares in gains and losses. In line with Duncan and Myers (2000), the insurer gives up a proportion of premium, denoted with $0 \le \alpha < 1$, while the government pays a proportion of losses in return, denoted with $\alpha + \theta$, where $0 \le \theta \le (1 - \alpha)$. Note that whenever $\theta > 0$ holds, it suggests an implicit subsidy as the government pays higher proportion of losses than the proportion of premium it receives. Finally,

the government pays a portion of premium volume, denoted with $0 \le \gamma < 1$, as reimbursement for the delivery of the program on behalf of farmers.[1] All the parameters of government's reinsurance are exogenously determined. [2]

Denoting the cumulative distribution function (CDF) of the company's total loss with $F(L;x)$, one can obtain the probability that losses exceeding L^* and denote that with $\delta > 0$, that is, $\Pr\left(\tilde{L}(x) > L^*\right) = \left(1 - F(L^*;x)\right) \le \delta$. (Note that in the preceding equation and throughout the text, the superscript "~" indicates a random variable.) Moreover, one can express $\overline{L}^*$ as

$$\overline{L}^* = (1-\delta)E\left[\tilde{L}(x)\Big|_{\tilde{L}(x)<L^*}\right] + \delta L^*, \tag{2}$$

where $E\left[\tilde{L}(x)\Big|_{\tilde{L}(x)<L^*}\right]$ is the expected value conditional on $\tilde{L}(x)$ is less than L^*.

The SRA require companies to hold enough "net surplus" to cover a loss at the magnitude of L^* subject to the gain-loss provisions of the SRA considered earlier. The company can meet the requirement with its underlying reserves and asset and reinsurance capital:

$$\left(1-(\alpha+\theta)\right)L^* = S(x,\delta) = \left(1-(\alpha-\gamma)\right)R(x) - C(x) - F + (1-r)K. \tag{3}$$

Based on foregoing, the insurer's problem can be re-expressed as

$$\underset{(x,K)}{Max}\ V(x,K;r)$$

$$\textit{subject to}\ \left(\left(1-(\alpha-\gamma)\right)R(x) - C(x) - F + (1-r)K\right) \ge S(x,\delta). \tag{4}$$

The Lagrangian (denoted with Λ) for the preceding problem is

[1] Risk premium subsidies are implicitly accounted at the moment.
[2] In light of Bulut (2016), some strategic interaction between the government and companies is conceivable.

$$\underset{(x,K)}{Max}\ \Lambda = V(x,K;r)$$
$$+\lambda\Big(\big((1-r)K-F\big)-\Big(S(x,\delta)-\big(\big(1-(\alpha-\gamma)\big)R(x)-C(x)\big)\Big)\Big),$$

where λ is the Lagrange multiplier. Substituting $V(x,K;r)$ with the expression in equation (1), the first-order-conditions (F.O.C.s) for the preceding problem (at the interior solution) are

$$\frac{\partial\Lambda}{\partial x}=\big(1-(\alpha-\gamma)\big)\frac{\partial R}{\partial x}-\frac{\partial C}{\partial x}-\big(1-(\alpha+\theta)\big)\frac{\partial\overline{L}^*}{\partial x}+\lambda\left(-\frac{\partial S}{\partial x}+\big(1-(\alpha-\gamma)\big)\frac{\partial R}{\partial x}-\frac{\partial C}{\partial x}\right)=0\,. \qquad (5)$$

$$\frac{\partial\Lambda}{\partial K}=-r+\lambda(1-r)-\underbrace{\frac{\partial\overline{L}^*}{\partial K}}_{=0}=0\,. \qquad (6)$$

$$\frac{\partial\Lambda}{\partial\lambda}=(1-r)K-F-\Big(S(x,\delta)-\big(1-(\alpha-\gamma)\big)R(x)+C(x)\Big)=0\,. \qquad (7)$$

Upon re-arranging equation (5), and dividing the both sides of the equation with $(1+\lambda)$, one obtains $\left(\big(1-(\alpha-\gamma)\big)\frac{\partial R}{\partial x}-\frac{\partial C}{\partial x}\right)-\frac{\big(1-(\alpha+\theta)\big)}{(1+\lambda)}\frac{\partial\overline{L}^*}{\partial x}=\frac{\lambda}{(1+\lambda)}\frac{\partial S}{\partial x}$. Alternatively, one can write

$$\frac{\partial V}{\partial x}=\frac{\lambda}{(1+\lambda)}\left(\frac{\partial S}{\partial x}-\big(1-(\alpha+\theta)\big)\frac{\partial\overline{L}^*}{\partial x}\right). \qquad (8)$$

Regarding the choice of capital, we first note that because the stop loss point L^*—set by the government—depends only on exposure choice x from the definition of L^*. Then, $\frac{\partial\overline{L}^*}{\partial K}=0$ holds.[3] Plugging the preceding finding in equation (6) yields

[3] Note that Kleindorfer and Klein (2003) obtain $\partial\overline{L}^*/\partial K=(1-r)\delta>0$. That is because the solvency point is endogenous to capital in their modeling framework.

$$\lambda = \frac{r}{(1-r)}. \tag{9}$$

Using β as the short-hand notation for $\frac{\lambda}{(1+\lambda)}$ and plugging the expression for λ from equation (9), one can verify that $\beta = r$ holds.[4] Putting all the pieces together, equation (8) becomes

$$\left(\left(1-(\alpha-\gamma)\right)\frac{\partial R}{\partial x} - \frac{\partial C}{\partial x} - \left(1-(\alpha+\theta)\right)\frac{\partial \overline{L}^*}{\partial x}\right) = r\left(\frac{\partial S}{\partial x} - \left(1-(\alpha+\theta)\right)\frac{\partial \overline{L}^*}{\partial x}\right). \tag{10}$$

Now, the optimal level of exposure, $\hat{x}$, will be determined from equation (10). Upon evaluating equation (3) at $\hat{x}$, one can obtain the optimal level of capital, $\hat{K}$ from the same equation as:

$$\hat{K} = \max\left\{\frac{\left(\left(1-(\alpha+\theta)\right)L^* + C(\hat{x}) + F - \left(1-(\alpha-\gamma)\right)R(\hat{x})\right)}{1-r}, 0\right\}. \tag{11}$$

3. An Application and Preliminary Results

The following illustrates the workings of the model. Suppose that there is only one state in which insurers can operate. Denote the average premium rate per unit of exposure with $\pi > 0$, and the average indemnity per unit of exposure with $l > 0$. Assume that $(\pi - l) > 0$. Now, specify the functions $R(x)$, $\overline{L}^*$, $C(x)$ and $S(x,\delta)$ as follows.

We write the revenue in a straightforward manner:

$$R(x) = \pi x. \tag{12}$$

For the marketing costs, we assume that crop insurance industry is increasing marginal cost industry and write

[4] In Kleindorfer and Klein (2003), β initially depends both δ and r (see the previous footnote). For simplification purposes, they revert to the following limit result: $\beta(r,\delta) \to r$ as $\delta \to 0$. The latter corresponds to the case the solvency requirement becoming highly stringent.

$$C(x) = cx^{\rho}, \tag{13}$$

where $c > 0$ is the cost parameter that subsumes input prices and ρ is the scale parameter. Setting $\rho = 2$ would yield the cost function $C(x) = cx^2$ as in Kleindorfer and Klein (2003). To allow for the possibility that the scale economies can be large, as we have seen in the crop insurance industry, we consider this parameter to take values towards the lower end of the range $1 < \rho < 2$. Overall, the cost structure in equation (13) reflects the opportunity cost of agents' and adjusters' time, skills and efforts.

To formulate the conditional expectation given in equation (2), we begin by formulating the unconditional moments

$$\bar{L}(x) = E\left[\tilde{L}(x)\right] = lx. \tag{14}$$

Denote the unconditional variance (risk) in the portfolio with $\sigma^2_{\tilde{L}(x)}$. Now, in line with Kleindorfer and Klein (2003), we assume that the coefficient of variation of losses is constant for simplification purposes and denote that with ω. Then, the variance of the portfolio is $\sigma^2_{\tilde{L}(x)} = \omega^2 l^2 x^2$, which in turn implies that the standard deviation of the portfolio is

$$\sigma_{\tilde{L}(x)} = \omega l x. \tag{15}$$

Assume that the loss distribution is normal. Given the exposure levels, the critical level of loss can be reexpressed as

$$L^* = \eta \bar{L}(x), \tag{16}$$

where $\eta > 1$ and determined in the SRA. Transforming L^* into the standard normal variable yields $L^* = \bar{L} + \sigma_{\tilde{L}(x)} z^*$, where z^* corresponds to the critical value of the standard normal

distribution beyond which the probability mass is δ. Note that z^* is decreasing in δ. Solving for z^* yields

$$z^* = \frac{\bar{L}(\eta - 1)}{\sigma_{\tilde{L}(x)}} = \frac{(\eta - 1)}{\omega}. \tag{17}$$

Notice that the preceding expression is independent of exposure level x. Denote the standard normal random variable with $\tilde{z}$. Now, because the event $\tilde{L} \le L^*$ occurring is tantamount to the event $\tilde{z} \le z^*$ occurring, one can reexpress the truncated mean in equation (2) as $E\left[\tilde{L}(x)\big|_{\tilde{L}(x)<L^*}\right] = \bar{L} + \sigma_{\tilde{L}(x)} E\left[\tilde{z}\big|_{\tilde{z}\le z^*}\right]$. The latter truncated mean can be obtained, by applying the formulas in Cameron and Trivedi (p. 540), as $E\left[\tilde{z}\big|_{\tilde{z}\le z^*}\right] = \frac{-\phi(z^*)}{(1-\delta)}$, where $\phi(z^*)$ is the probability density function for the standard normal distribution evaluated at z^*, that is,

$$\phi(z^*) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{(\eta-1)}{\omega}\right)^2}. \tag{18}$$

Using the preceding expression and equation (15), one can obtain $E\left[\tilde{L}(x)\big|_{\tilde{L}(x)<L^*}\right] = \bar{L}(x)\left(1 - \omega\frac{\phi(z^*)}{(1-\delta)}\right)$. Further substituting the preceding expression in equation (2), one can write

$$\bar{L}^* = lx\left(1 + (\eta - 1)\delta - \omega\phi(z^*)\right). \tag{19}$$

Note that for higher values of $\eta > 1$, both δ and ϕ would approach zero; as a result $\bar{L}^*$ would approach the unconditional mean, $\bar{L}$.

The following derivatives will prove to be useful:

$$\frac{dR}{dx} = \pi. \tag{20}$$

$$\frac{d\overline{L}}{dx} = l\,. \tag{21}$$

$$\frac{\partial S}{\partial x} = \frac{dL^*}{dx}\left(1-(\alpha+\theta)\right) = \eta l\left(1-(\alpha+\theta)\right). \tag{22}$$

$$\frac{d\overline{L}^*}{dx} = l\left(1+(\eta-1)\delta-\omega\phi(z^*)\right). \tag{23}$$

$$\frac{dC}{dx} = MC(x_j) = c\rho x^{(\rho-1)}\,. \tag{24}$$

Plugging the preceding equations in equation (10) yields

$$\widehat{x} = \left(\frac{\pi\left(1-(\alpha-\gamma)\right)-l\left(1-(\alpha+\theta)\right)\left(r\eta+(1-r)\left(1+(\eta-1)\delta-\omega\phi(z^*)\right)\right)}{c\rho}\right)^{\frac{1}{(\rho-1)}}. \tag{25}$$

From the formulation of $\widehat{x}$, some comparative static results can be discerned in a straightforward manner.

Lemma 1: *The following holds:*

(i) *As the cost of delivery increases, the optimal exposure decreases, that is,* $\frac{\partial \widehat{x}}{\partial c} < 0$.

(ii) *As the insurer gets more efficient, that is, the scale parameter declines to one, the optimal exposure increases, that is,* $\frac{\partial \widehat{x}}{\partial \rho} < 0$.

(iii) *As the government's reinsurance subsidy increases, the optimal exposure increases, that is,* $\frac{\partial \widehat{x}}{\partial \theta} > 0$.

(iv) *As the compensation rate for delivery costs increases, the optimal exposure increases, that is,* $\frac{\partial \hat{x}}{\partial \gamma} > 0$.

Using the formulation of $\hat{x}$, the amount of capital necessary is obtained from equation (11) as

$$\hat{K} = \frac{F}{(1-r)} + \hat{x}\frac{1}{(1-r)}\left(\left(1-(\alpha+\theta)\right)\eta l - (1-(\alpha-\gamma))\pi\right) + \hat{x}^{\rho}\frac{c}{(1-r)}. \tag{26}$$

That holds whenever the right hand side of the preceding equation is positive—otherwise no capital would be necessary; hence, $\hat{K} = 0$ would hold.

Plugging $\hat{x}$ and $\hat{K}$ back in equation (1), one observes that the insurer should obtain enough profit to meet the fixed cost of entering that particular market.

4. Conclusion and Future Directions

We have proposed a modeling of insurance supply that has roots in Kleindorfer and Klein (2003). The resulting model can be used to study the impact of various factors (including the SRA related factors) on the supply of agricultural (crop) insurance and the insurers' portfolio allocation decisions in various markets. The initial comparative static results suggest that the model has some promise to be useful. We plan to expand on this modeling in several steps.

First, we intend to allow for competition through companies' entry decisions. Figure 1 shows the number of companies operating in states as a function of premium volume, where the former is increasing non-proportionally in the latter. A similar pattern can be obtained in a simple theoretical model for markets where there is free entry with exogenous entry costs, identical firms compete in choosing output-*a la* Cournot and the price is determined at the game-theoretic equilibrium (Cabral, 2000; p. 244). (The equilibrium under heterogeneous entry

costs also exists but may not be unique.) As such, this framework is natural starting point in modeling the competition among companies.

Second, we intend to allow endogeneity in agent compensation by viewing the stage where multiple companies interact with multiple agents from a “double auction” perspective. It is known that, in industry with homogeneous good, when buyers and sellers are allowed to interact using their demand and supply functions respectively as strategic instruments, buyers tend to under represent their reservation price, while sellers tend to exaggerate their costs. This inefficiency tends to decline with the number of actors in either side of the market (Bulut and Koray, 2008; Rustichini, Satterthwaite and Williams, 1994.). The existing variation in the number of agents and companies across states should be helpful in empirically testing this hypothesis.

Finally, the modeling approach appears to be fairly flexible to incorporate other aspects of the program: *(i)* the premium rates are set by the Risk Management Agency (RMA) to be actuarially fair, and delivery expenses cannot be passed on to customers as expense load as in regular insurance business; *(ii)* Companies are incentivized to provide service, technology solutions, claims handling, and be cost efficient; *(iii)* There are sunk costs—companies, as well as agents, have been investing in crop insurance program both in the form of human capital, information technology, and infrastructure—hence, costless exit may not hold; *(iv)* If a particular input gets relatively expensive, in the longer run, companies will try to find substitutes for it—perhaps, they invest more in technology and seek more innovations; *(v)* Excessive rents, if any, on the agents’ side of the market would attract entry, and the rents would normalize over time; and *(vi)* If agents are better informed than the RMA in assessing the riskiness of policies, then they can be expected to extract some rents.

This research intends to contribute to an informed public debate on alternative economic design considerations. Particularly, it can motivate empirical studies under the terms of the most recent contract between the government and companies (2011 Standard Reinsurance Agreement, SRA).

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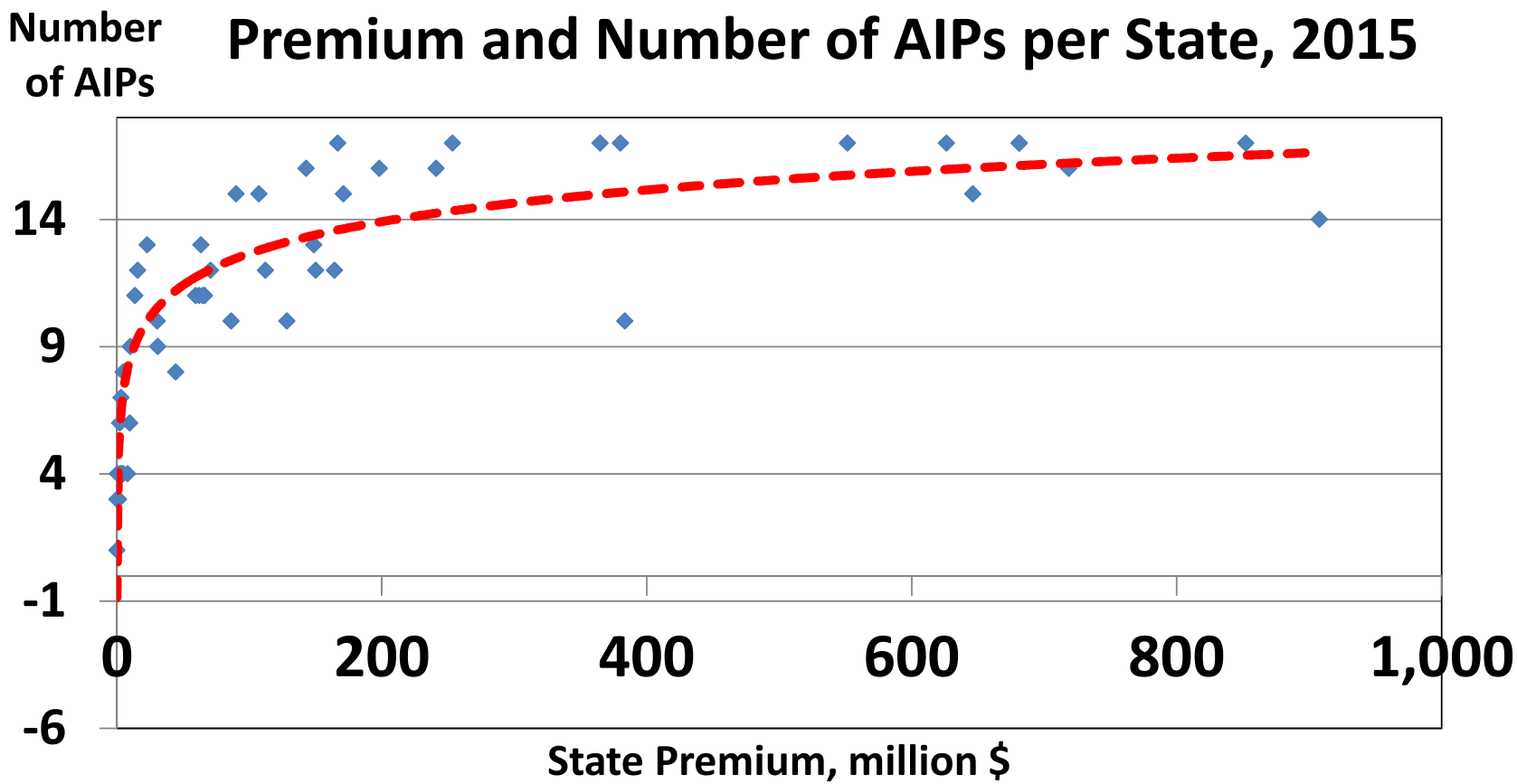

Figure 1. Premium and number of approved insurance providers (AIPs) per state, 2015.