The Environmental Impacts of Subsidized Crop Insurance

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THE ENVIRONMENTAL IMPACTS OF SUBSIDIZED CROP INSURANCE

by

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A partial equilibrium model of stochastic crop production is used to analyze the environmental impacts of popular subsidized crop insurance programs. Land use is unchanged only when an actuarially fair, perfectly separating insurance contract is offered. For the more typical pooling equilibrium contracts, however, land with a minimum quality that is strictly lower than the minimum quality without insurance will be added to production. In such cases, the environment will be adversely effected. If economically marginal land is also environmentally marginal, pooling crop insurance policies disproportionately contribute to the degradation of the environment. Popular subsidies merely exacerbate the problem.

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The Environmental Impacts of Subsidized Crop Insurance

1. Introduction

Subsidized crop insurance as a federal farm policy tool has been increasing in scope and scale for the past decade. An important economic question is the impact of crop insurance in general, and subsidized crop insurance in particular, on the level of environmental degradation due to expansion of the extensive margin in agricultural production. This study seeks to address this issue by constructing a partial equilibrium model of stochastic crop production. Land use is unchanged only when an actuarially fair, perfectly separating insurance contract is offered. For the more typical pooling equilibrium contracts, however, land with a minimum quality that is strictly lower than the minimum quality without insurance will be added to production. In such cases, the environment will be adversely effected. If economically marginal land is also environmentally marginal, pooling crop insurance policies disproportionately contribute to the degradation of the environment.[1] Popular subsidies merely exacerbate the problem.

This paper builds on an existing literature, yet fills a critical void. A large body of economic research exists on the impacts of crop insurance on variable input use and the intensive margin. Notable theoretical studies include Nelson and Loehman (1987), Chambers (1989) and Quiggin (1993). Notable empirical studies include Horowitz and Lichtenberg (1994), Smith and Goodwin (1996) and Babcock and Hennessy (1996). Less has been written on the impacts of crop insurance on acreage and land quality decisions, i.e. the impacts of these policies on the extensive margin. As will be demonstrated, this is surprising given that such decisions have profound implications for the nation's water quality. Only recently has a simulation and empirical literature arisen. Gardner and Kramer (1986), Goodwin, Smith and Hammond (1999), Keeton, Skees and Long (1999), and Young, Schnepf, Skees and Lin (1999) all conclude that subsidized crop insurance results in the additional employment of marginal acreage.[2] To the authors' knowledge, however, a formal economic theory that underpins this research does not yet exist. This study attempts to fill this void.

Section 2 of this paper motivates the analysis and provides a brief overview of the institutional

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[1] "Disproportionate" environmental degradation refers to the pollution damage attributable to an acre added in response to a crop insurance program, relative to the pollution damage attributable to an acre farmed in the absence of the program.

[2] Similarly, Williams (1988), Turvey (1992), and Wu (1999) have examined the impact of crop insurance on the choice of crop type. Soule, Nimon, and Mullarkey (2000) provide an excellent overview of this and other extensive margin related studies.

context. Section 3 develops a partial equilibrium model to analyze our key economic question. The model is stylized, of course, but represents the critical elements of a realistic agricultural production environment. A novel approach to indexing land quality is included. Section 4 develops and examines a rational expectations market equilibrium for risk neutral agents, which serves as a base case for analytical comparisons. Section 5 then explores the unsubsidized equilibria that result from the presence of perfectly separating or pooled crop insurance contracts. Section 6 develops model extensions, including premium subsidies. Finally, section 7 presents interpretations and conclusions.

This paper studies the effects of a Federally subsidized crop insurance program on land use and the environment. The model is stylized, but critical features of realistic production conditions and crop insurance programs are included. We do not study the design and implementation of optimal insurance contracts and their implementation. This general area is well developed in the literature, including the seminal works of Akerlof (1970) and Rothschild and Stiglitz (1976). We also abstract from traditional the notion of moral hazard and the associated effects on the intensive margin. These simplifications permit us to isolate and focus on the primary economic forces of subsidized crop insurance on the extensive margin of agricultural production.

Similar reasons motivate us to model producers as risk-neutral agents. This permits us to emphasize the first-order incentives on the extensive margin effects and associated environmental consequences. The assumption of risk aversion is popular in the economics of uncertainty. Given that risk effects are primarily driven by variance and other higher moments, their impacts would need to be large to dominate the first order incentive effects of the risk neutral case. It has been argued that risk neutrality is the proper framework for the current problem. Wright and Hewitt (1994) argue that crop and tillage diversification, off-farm income, and smoothing income and consumption over time mitigate the risk faced by agricultural producers. The empirical analysis of Just, Calvin, and Quiggin (1999) supports this assertion, where it is found that producers' risk management incentives are small relative to the incentives created by premium subsidies.

2. Motivation and Institutional Background

The environmental implications of any large-scale agricultural policy are indeed important. The U.S. Environmental Protection Agency classifies about 35 percent of domestic river and stream miles and 45 percent of domestic lake acreage as 'impaired'. 'Impaired' waterways are not clean enough to support safe recreational activities or do not provide for the protection and propagation of aquatic life. In addition, wetlands are being lost at a rate of nearly 100,000 acres annually. Agriculture is cited as the leading source of current water pollution problems, contributing to approximately 60 percent of river impairment and 30 percent of lake impairment. It is also cited as the leading source of wetlands destruction. (CITE NWQI)

Agricultural and environmental interactions are also quite diverse. In order of major domestic waterway impairment, farming contributes to sedimentation and siltation, pathogen discharges, nutrient based pollutants, oxygen depletion and organic enrichment, ph and temperature modification, and toxic discharges. First, natural erosion and soil depletion is accelerated by agricultural processes. Second, fertilizers and livestock wastes contribute to pathogens, nutrient-based pollutants, and organic enrichment. Third, toxic chemicals are common in pesticides, herbicides and insecticides. And finally, conversion of land for agricultural uses is the leading cause of the past and present decline in domestic wetland acreage. The above issues contribute to aquatic ecosystem damage, adverse recreational conditions, and increased costs of drinking water treatment. Toxics may also contribute to developmental defects in offspring, immune system disorders, and several types of cancer.

Land conversion, tilling and plowing, and grazing all contribute to the underlying problems. Specifically, these activities often produce vegetation-free tracts of land that are particularly susceptible to rapid wind and water erosion. Additionally, plowing and leveling lead to flatter fields that are less run-off resistant. Therefore, agricultural activities contribute to sedimentation and siltation, total suspended solids (TSS), and turbidity problems. Such problems damage aquatic ecosystems, adversely impact recreation, and increase the costs of drinking water treatment.

Second, fertilizers and livestock wastes contribute to pathogens, nutrient-based pollutants, and organic enrichment. Pathogens include bacteria, like *E. coli*, and fecal coliform. At high levels, these organisms produce unsafe recreational conditions, preclude the human consumption of fish and shellfish, and can dramatically increase the cost of drinking water treatment. Waterborne nitrates, nitrites, and phosphorous also pose significant health hazards to humans, mammals and aquatic life. Organic enrichment and biochemical oxygen demand (BOD) significantly disrupt entire aquatic ecosystems. For example, large fish-kills, foul odors, and algal blooms are common after large spills of livestock waste. Consider the following: BOD levels in industrial point source discharges are typically regulated to less than 30 milligrams per liter, while raw manure contains a biochemical oxygen demand of several thousand milligrams per liter. (CITE ISU)

Additionally, conversion of land for agricultural uses is the leading cause of the past and present decline in domestic wetland acreage. Less than half of the United States' original wetlands remain, although the rate of decline has significantly decreased in recent years. (CITE NWQI) Wetlands provide flood protection and pollution filtration, and represent critical habitat for numerous species of flora and fauna.

Finally, toxic chemicals are common in pesticides, herbicides and insecticides. Domestically, over 20,000 agricultural chemicals are registered or licensed for use in controlling pests or insects on over 1 million farms. Common applications include conventional pesticides, antimicrobials, and biochemical pesticides. The scientific consensus on the human and aquatic ecosystem effects of pesticide toxins are developmental defects in offspring, immune system disorders, and several types of cancer. Agricultural chemicals also leak into groundwater, increasing drinking water and health care costs into the future.

Clearly, agriculture must play a key role in current environmental policy. However, the vast majority of agricultural facilities and their corresponding discharges are not directly regulated. Large animal feeding operations are the only agricultural facilities treated as pollution point sources, and they are regulated under the National Pollution Discharge Elimination System (NPDES). Also, pesticides and similar agricultural chemicals require registration and licensing, but their direct application is not monitored. Regardless, recall that pesticide issues are among the least important nationally for the current health and environmental consequences of agricultural production, most likely because they receive extensive resources and much public attention.

The vast majority of agricultural pollutants are classified as attributable to non-point sources. While the Environmental Protection Agency recognizes the need to oversee discharges from such sources, it has yet to completely do so. The best avenue the agency currently has is the Total Maximum Daily Load (TMDL) program. Initially authorized under section 303(d) of the 1972 Clean Water Act (CWA), TMDL's are total maximum sums of single pollutants' amounts in a specific impaired waterway. The maximums are based upon pollutant levels that will restore the navigable body to conditions that permit safe recreational activities and allow for the protection and propagation of aquatic life. Allocations of the total allowable maximums must also be broadly attributable to the pollutant's sources. After substantial litigation in recent decades, TMDL's are now required for all impaired bodies of water in which specific pollutants can be identified.

Unfortunately, however, current TMDL's have no binding regulatory structure to ensure enforcement and compliance for non-point sources. In fact, non-point control programs are still entirely voluntary. States may use CWA section 106 water program grants or section 319 pollution control grants to enact regulatory programs for non-point sources, but they are not required to do so. In July 2000, a federal advisory committee published revisions to regulations that would require specific implementation plans for TMDL's. These implementation procedures would require states to provide lists of actions and schedules to meet quality standards, and would establish a goal of meeting those standards within 10 years. It is these explicit lists of actions that would address compliance and enforcement issues. The proposed legislative revisions, however, were immediately prohibited by Congress. Funding was explicitly cut for the program until October of 2001, and future funding seems doubtful unless mandated by the courts.

The upshot of the previous discussion is clear. The EPA considers agriculture to be the primary source of most current water pollution problems in the United States, and its discharges are not directly regulated. Therefore, any large-scale agricultural policy must have direct and important consequences for the environment. In particular, programs that contribute to farmland acreage expansion are potentially detrimental to the quality of the nation's waterways. Further, if this expansion occurs on marginal agricultural acreage that has a minimum quality strictly lower than land employed in the absence of the policy, then the environmental consequences are likely to be even more severe. In particular, economically marginal land is typically considered to environmentally marginal. For example, poorer quality soils often allow for more rapid erosion and runoff, disproportionately contributing to siltation, nutrient, pathogen, and toxic chemical pollution. Additionally, economically marginal land simply requires greater fertilizer, pesticide and insecticide applications than its more productive counterparts.

And subsidized crop insurance is indeed a large-scale agricultural program. Two pieces of legislation in the mid-1990's pushed risk management tools to the forefront of those policies designed to protect American farmers. The 1994 Federal Crop Insurance Act authorized increased funding for insurance products, and mandated that the Federal Crop Insurance Corporation (FCIC) devote increasing resources to the development of broad and innovative pilot programs. Other provisions of the act included subsidies for producer premiums, federal reinsurance, and federal funds for covering the administrative expenses of insurance providers. The Federal Agricultural Improvement Act of 1996 further strengthened crop insurance's role by eliminating the deficiency payment and supply management programs that had been the backbone of farm support since 1973. These programs were replaced with direct temporary payments to producers and permanent increased funding and availability of insurance programs.

Coverage is now available in every state and insurance is offered for every major agricultural commodity produced domestically, including wheat, corn, cotton, forage production, sorghum, soybeans, peanuts, barley, sunflower, rice, tobacco and rangeland. As of 1999, 196 million acres of domestic agricultural land were insured by the FCIC, covering over $30 billion in liabilities. Significantly, crop insurance is still growing. While the 2002 federal budget appropriations include a 10.2 percent reduction in general agricultural funding, the Agricultural Risk Protection Act of 2000 (ARPA) has authorized $8.2 billion over the next five years to improve crop insurance coverage and to offer more programs. The USDA's Risk Management Agency states that its goals are to insure 85% of all planted acreage in the United States by 2005, assuming $42 billion in liabilities. (CITE RMA)

To achieve these goals, ARPA mandates higher producer premiums for all coverage levels and programs. For a given insurance policy, premiums depend upon the coverage level chosen. For 85 to 100 percent of liability coverage, premium subsidies are 38 percent. They are 48 and 55 percent for 80 and 75 percent coverage, respectively. And all coverage levels between 65 and 75 percent are subsidized 59 percent. It should be noted that even if premiums are initially actuarilly fair, subsidies exceed implicit insurance deductibles by more a large margin. Additionally, ARPA allocates $175 million for the development of new pilot programs that target crop and livestock producers that are currently 'underserved' by risk management programs. Subsidized crop insurance is also likely to continue expanding, since it is the only form of agricultural support currently 'green-boxed' under the major international trade agreements.

3. A Simple Model of Agricultural Production

This section develops a partial equilibrium model to analyze our key economic question, "What is the impact of subsidized crop insurance on the extensive margin of agricultural production?" The subsequent answers can then be utilized to examine the implications for the environment. The model presented is stylized, yet captures the essence of the economic forces at work in federal crop insurance.

Such a model requires several ingredients. The supply curve is positively sloped in the "short-run," while constant returns to variable inputs are exhibited in the "long-run." Empirical evidence suggests that this is the appropriate specification. See, for example, Madden and Partenheimer (1972), Miller, Rodewald and McElroy (1981), and Smith, Knutson and Richardson (1986). Variable inputs are committed to production prior to the realization of a random event that influences the actual yield. This is, of course, reflective of true agricultural processes. For example, a given plot of land is worked, seeded, and fertilized prior to the realization of weather outcomes. Additionally, the random events enter the model within the well-known Just and Pope (1979) production function framework. In particular, the model allows for the effects of an input to independently influence output mean and variance.

Land is a quasi-fixed input. Individual units of land are distinguished by a qualitative index. The farmer simply chooses an interval of quality on which to produce. The higher the quality of land, the greater the mean and the smaller the variance of production, *ceteris paribus.* A producer's quality interval choice implicitly defines simultaneous land qualities that are infra-marginal, marginal, and on the extensive margin. Note that a unit of higher quality land earns a greater internal rate of return than an equivalently sized parcel of lower quality land. Thus, the equilibrium market price of land increases with land quality, i.e. land quality differences are fully capitalized in long-run rental rates.

Let the qualitative index of land quality be represented by $\theta \in [0,1]$. With access to reasonably functioning credit markets, farmers should be able to finance production on any land with positive economic returns. Therefore, the producer may be assumed to have access to land of all qualities, but chooses to produce only on those lands with positive expected profits. Further, let the amount of planted acreage of a given level of quality be $k(\theta)$. Therefore, $\theta\ k(\theta)$ can be thought of as the 'effective' land of quality θ in use.[3]

Given land of some quality θ, a planned production is a function of the utilization of the quasi-fixed input, effective acreage, and a variable input, labor. All inputs are fully committed prior to the realization of the stochastic process that distinguishes planned from actual output. For simplicity, we will assume a Cobb-Douglas technology for planned production,[4]

$$\overline{q}(\theta) = \sqrt{\theta k(\theta)\ell(\theta)}\,. \tag{1}$$

Realized output is a function of planned production and a stochastic multiplicative disturbance, $\varepsilon(\theta)$,

$$q(\theta) = \overline{q}(\theta)[1 + \varepsilon(\theta)]\,, \tag{2}$$

where $\varepsilon(\theta)$ is normal with mean 0 and variance $\sigma^2(\theta)$, independently distributed across θ. Note that this production process is wholly consistent with the popular Just-Pope production framework. In particular, it is the unique specification consistent with such a production process that doesn't lead to relative input distortions. Moral hazard, while potentially important in the relationship between a farmer and an insurer, is not considered here in order to directly analyze the first-order incentive effects of crop insurance on land use choices and their subsequent environmental consequences.

Total production follows a Weiner process across land quality, so that actual production for land

[3] For example, if the amount of land of quality $\theta = 0.75$ is 1 acre, the resulting equivalent usage of the best land possible (i.e. the 'effective acreage') is 0.75 acres.

[4] The fundamental results of this paper can be generated with any technology that can be represented by a linear homogenous production function of n variable inputs and effective land as a quasi-fixed input.

of quality $\hat{\theta}$ and higher in production is,

$$Q(\hat{\theta}) = \int_{\hat{\theta}}^{1} [\overline{q}(\theta)d\theta + \overline{q}(\theta)\varepsilon(\theta)\sqrt{d\theta}] \,, \tag{3}$$

where $\hat{\theta} \in [0,1]$. The implications of this stochastic framework are once again consistent with real-world agricultural production processes. Specifically, on relatively homogeneous and small land areas, the central limit theorem implies the supply disturbances are normally distributed.

We assume that the variance of the best quality land is nonnegative and that variance decreases with land quality:

$$\sigma^2(1) \geq 0 \,; \tag{4}$$

$$\frac{d\sigma^2(\theta)}{d\theta} \leq 0 \,. \tag{5}$$

Note that "better" land results in production with a higher mean *and* a lower variance per unit of land (i.e., the variability of yield per acre decreases with quality). Also note, once again, the lack of moral hazard in our model: $\sigma(\theta)^2$ depends only on θ, and not on the level of input use.

An economically rational, risk neutral farmer makes decisions based upon expected values. Therefore, expected total supply, given utilization of all land of quality $\hat{\theta}$ and higher, is

$$\overline{Q}(\hat{\theta}) = \int_{\hat{\theta}}^{1} \overline{q}(\theta)d\theta \,. \tag{6}$$

Total cost, for each quality θ, is the sum of variable cost and the rent on the quasi-fixed input, effective land. Noting that

$$\overline{q}(\theta) = \sqrt{\theta k(\theta)\ell(\theta)} \;\Rightarrow\; \ell(\theta) = \overline{q}(\theta)^2 \,/\, \theta k(\theta) \,,$$

total cost for given θ can be represented by

$$TC(\theta) = \frac{w\overline{q}(\theta)^2}{\theta k(\theta)} + r(\theta)k(\theta) \,, \tag{7}$$

where w is the (deterministic) wage rate for the variable input labor and $r(\theta)$ is the internal rate of return on a unit of land with quality θ. Marginal cost, given θ, is the derivative of total cost with respect to planned supply,

(8)
$$MC(\theta) = \frac{2w\overline{q}(\theta)}{\theta k(\theta)} \,.$$

4. Rational Expectations Market Equilibrium

The short-run, rational expectations equilibrium for risk neutral producers in a competitive market is defined by the equality of the expected marginal cost of planned output and the market price. Market demand is given by

(9)
$$p(\hat{\theta}) = \alpha - \beta Q(\hat{\theta}) \,.$$

The short-run market equilibrium can be represented by equating the right hand side of equation (8) with the expected value of the right-hand side of equation (9),

(10)
$$\frac{2w\overline{q}(\theta)}{\theta k(\theta)} = \alpha - \beta \overline{Q}(\hat{\theta}) \,,$$

from which it follows that

(11)
$$\overline{q}(\theta,\hat{\theta}) = \frac{\theta k(\theta)[\alpha - \beta \overline{Q}(\hat{\theta})]}{2w} \;\forall\; \theta \in [\hat{\theta},1] \,.$$

This expression then implies that total planned supply, over all values of θ for which land is employed in production of the crop, is implicitly defined by

(12)
$$\overline{Q}(\hat{\theta}) = \int_{\hat{\theta}}^{1} \overline{q}(\theta)d\theta = \frac{[\alpha - \beta Q(\hat{\theta})]}{2w} \int_{\hat{\theta}}^{1} \theta k(\theta)d\theta \,.$$

Let $K(\hat{\theta}) = \int_{\hat{\theta}}^{1} \theta k(\theta)d\theta$ denote *total effective land* in production. Substitution into equation (12) yields total planned quantity as

(13)
$$\overline{Q}(\hat{\theta}) = \frac{K(\hat{\theta})\alpha}{2w + K(\hat{\theta})\beta} \,.$$

This result, coupled with our residual demand equation (9), allows us to solve for the short-run equilibrium mean output price,

(14)
$$\overline{p}(\hat{\theta}) = \frac{2w\alpha}{2w + K(\hat{\theta})\beta} \,.$$

Finally, substitution into our equilibrium conditions (equation (11)) allows us to solve for planned production for each quality level,

$$\overline{q}(\theta;\hat{\theta}) = \frac{\theta k(\theta)\alpha}{2w + K(\hat{\theta})\beta}\,. \tag{15}$$

We complete the basic model setup with the variances and covariances for quantities and prices:

$$\mathrm{V}(q(\theta)) = \frac{\alpha^2\theta^2 k(\theta)^2\sigma(\theta)^2}{[2w + K(\hat{\theta})]^2}\,; \tag{16}$$

$$\mathrm{V}(Q(\hat{\theta})) = \frac{\alpha^2\int_{\hat{\theta}}^{1}\theta^2 k(\theta)^2\sigma(\theta)^2\,d\theta}{[2w + K(\hat{\theta})\beta]^2}\,; \tag{17}$$

$$\mathrm{V}(p(\hat{\theta})) = \frac{\alpha^2\beta^2\int_{\hat{\theta}}^{1}\theta^2 k(\theta)^2\sigma(\theta)^2\,d\theta}{[2w + K(\hat{\theta})\beta]^2}\,, \tag{18}$$

$$\mathrm{Cov}(Q(\hat{\theta}), p(\hat{\theta})) = -\frac{\alpha^2\beta\int_{\hat{\theta}}^{1}\theta^2 k(\theta)^2\sigma(\theta)^2\,d\theta}{[2w + K(\hat{\theta})\beta]^2}\,. \tag{19}$$

Note that the realized crop yield on a single land quality, θ, is uncorrelated with market price, due to the Brownian motion hypothesis across qualities. However, if each farmer owns some land of various qualities (with strictly positive Lebesgue measure on the unit interval), then the total farm output will be (negatively) correlated with the observed market price. These variance-covariance measures could be combined with information on the distribution of land quality ownership to derive the optimal inputs, output and insurance choices for risk averse farmers under various assumptions or conditions.

The above results are now used to develop an expression for the profit of risk-neutral producers in a long run, rational expectations equilibrium. Expected total revenue is the product of expected output price (14) and expected production (15). Similarly, expected total costs are obtained by substituting our expressions for the expected equilibrium price and quantity into our cost relationship (7). Therefore, expected profit for land of quality θ is given by

$$E[\pi(\theta)] = \frac{w\alpha^2\theta k(\theta)}{[2w + K(\hat{\theta})\beta]^2} - r(\theta)k(\theta)\,. \tag{20}$$

Let r_0 denote the exogenous (i.e., market determined) risk free rate of return on alternative capital investments. The marginal land quality in the crop market, $\hat{\theta}$, is defined by the condition

$r(\hat{\theta}) = r_0$, where

(21) $$r(\theta) = w\alpha^2\theta \big/ [2w + K(\hat{\theta})\beta]^2 \ ,$$

is the internal rate of return for land with quality θ. Noting that

(22) $$\frac{dr(\hat{\theta})}{d\hat{\theta}} = \frac{w\alpha^2}{[2w + K(\hat{\theta})\beta]^2} + \frac{2w\alpha^2\beta\hat{\theta}k(\hat{\theta})}{[2w + K(\hat{\theta})\beta]^3} > 0 \ ,$$

it follows that all land of quality $\hat{\theta}$ and higher will be fully utilized in the production of the crop in the long-run equilibrium, while all lower quality land will be left idle.

3. An Actuarially Fair, Perfectly Separating Crop Insurance Equilibrium

Consider a multiple peril crop insurance scheme where a farmer receives an indemnity if yields fall below some threshold value. This threshold is determined by the product of the *coverage level* ρ and a predetermined production level representing the actual yield history of each plot covered. Assume that this yield history equals historical planned production, which in turn equals the current period's planned production. If paid, the value of the indemnity equals a guaranteed price times the difference between realized yields and the contract's threshold level. Therefore, the gross indemnity for land of quality θ, can be represented by

(23) $$i(\theta) = p_g[\max\{\rho\overline{q}(\theta) - q(\theta), 0\}] \, ,$$

where p_g represents the insurance contract's guaranteed price. Alternatively, expression (23) can be rewritten as:

(24) $$i(\theta) = p_g\overline{q}(\theta)\max\{\rho - 1 - \varepsilon(\theta), 0\} \, .$$

Begin by considering a perfectly separated equilibrium insurance program in which, for each land quality θ, the insured pays a premium that equals the expected value of the indemnity. Let τ(θ) represent the fair premium E[i(θ)], so that

(25) $$\tau(\theta) = p_g\overline{q}(\theta)E[\rho - 1 - \varepsilon(\theta) \mid \varepsilon(\theta) < \rho - 1] \, ,$$

Recall that the expected value of a mean zero, normally distributed random variable given some truncation at ε* is σλ(ε*/σ), where λ is the standard inverse Mills ratio. The actuarially fair premium, given land quality θ, can then be expressed as

$$\tau(\theta) = p_g \overline{q}(\theta)\left[\rho - 1 + \sigma(\theta) \cdot \frac{\phi((\rho-1)/\sigma(\theta))}{\Phi((\rho-1)/\sigma(\theta))}\right]. \tag{26}$$

For any given coverage level, ρ, the fair premium over the entire market for the crop is therefore

$$\mathrm{T}(\hat{\theta}) = p_g \int_{\hat{\theta}}^{1} \left\{ \overline{q}(\theta)\left[\rho - 1 + \sigma(\theta) \frac{\phi((\rho-1)/\sigma(\theta))}{\Phi((\rho-1)/\sigma(\theta))}\right]\right\} d\theta\,, \tag{27}$$

which in turn equals the total expected indemnity payments for this crop. Thus, with a perfectly separating, actuarially fair insurance policy, expected profits remain unchanged when crop insurance is introduced. The premium required is identically equal to the expectation of indemnities, and therefore expected net payments from an insurance contract are zero. In addition, land and other input use decisions remain the same with or without crop insurance. Finally, if farmers are risk neutral, then each one is indifferent between the insurance and no insurance choice, and observed insurance purchases could be anything from no land to all land in production. However, if farmers are risk averse, then we would expect to see all farmers purchasing actuarially fair insurance in a perfectly separating equilibrium.

4. An Actuarially Fair Pooling Equilibrium

We now turn to the impact of crop insurance on land input decisions wherein the owners of land of all qualities pay the same premium rate for a given coverage level. Consider, as a starting point, a "long-run" equilibrium in which entry and exit have driven economic profits for land of marginal quality $\hat{\theta}$ to zero. In the current context, adverse selection arises when the insurer is unable to offer premiums that are actuarially fair for each land quality and therefore offers a common premium schedule, based only on the coverage level and the overall average expected indemnity payment, to all farmers.

Note that a rational farmer will only insure a given divisible parcel of land if the insurance offered for that parcel has a non-negative expected pay-off. Since inferior land has a higher variability of yields relative to higher quality land, the expected indemnity, net of premium, will be positive for parcels at the very low end of the quality spectrum and negative for land at the high end. The benefit of passing off inferior land is then exacerbated by the fact that the poorer land has a lower mean output than the land from which the payment threshold is derived.

Because of the increased profitability of low quality land, due to the positive expected net indemnity payments, adverse selection results in some lands having higher economic values in the presence of crop insurance than they would in its absence. Some of this acreage will be of quality $\theta < \hat{\theta}$ due to the continuity of the profit function and the expected indemnity payment

$p_g\overline{q}(\theta)\left[\rho - 1 + \sigma(\theta)\,\phi((1-\rho)/\sigma(\theta))\big/\Phi((1-\rho)/\sigma(\theta))\right]$. A subset of the previously unemployed lands would therefore enter into production. Thus, the introduction of crop insurance in pooling equilibrium results in the employment of land with a minimum quality that is lower than the minimum quality without insurance or in a perfectly separated equilibrium.

Consider the case where the insurance policy is a new offering, and the insurer sets a single premium rate that is actuarially fair for the market as a whole as it exists prior to the insurance offering, but not necessarily so for an arbitrarily chosen quality level θ. Therefore, the insurance contract resembles that of the previous section, but with an identical premium for all θ. From the definition for the expected indemnity payment for land of quality θ, the expected value of total indemnities is equal to

(28) $$I(\hat{\theta}) = p_g \int_{\hat{\theta}}^{1} \overline{q}(\theta)\left[\rho - 1 + \sigma(\theta)\frac{\phi((1-\rho)/\sigma(\theta))}{\Phi((1-\rho)/\sigma(\theta))}\right]d\theta\,.$$

The actuarially fair pooling equilibrium insurance premium is then equal to

(29) $$\overline{\tau}(\hat{\theta}) \equiv I(\hat{\theta})\Big/\int_{\hat{\theta}}^{1}\overline{q}(\theta)d\theta\,.$$

It can be shown that Mill's ratio, $\phi((1-\rho)/\sigma(\theta))\big/\Phi((1-\rho)/\sigma(\theta))$, is a positive valued, decreasing function of the limit point, (1-ρ)/σ(θ). The standard error, σ(θ), is decreasing in θ, so that the term $\left[\rho - 1 + \sigma(\theta)\,\phi((1-\rho)/\sigma(\theta))\big/\Phi((1-\rho)/\sigma(\theta))\right]$, which determines the relative magnitude of the expected indemnity payment for land of quality θ, is decreasing in θ. By the second mean value theorem,[5] therefore, there is a quality level, say $\overline{\theta}$, for which the initial pooling equilibrium insurance contract is a fair bet. For land qualities lower than this level, the contract is profitable, while for higher land qualities it is unprofitable. Hence, the highest quality land will not be insured, while some land with quality levels in the neighborhood of $\hat{\theta}$, but strictly less than this value, will become profitable with the crop insurance program. These lands will initially come into production, purely because of the introduction of crop insurance and the inherent subsidy on low quality land that results from a pooling equilibrium.

Intuitively, a farmer will choose not to insure any land of quality θ $> \overline{\theta}$, because the expected indemnities on such acreage are below the premiums charged. On the other hand, there are incen-

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[5] The second mean value theorem states that if f and g are continuous functions on the closed and bounded interval $[a,b]$, then there is a point $c \in [a,b]$ such that $\int_a^b f(x)g(x)dx = f(c)\int_a^b g(x)dx$. For the present case, define $f(\theta) = [\rho - 1 + \sigma(\theta)\,\phi((1-\rho)/\sigma(\theta))\big/\Phi((1-\rho)/\sigma(\theta))]$ and $g(\theta) = \overline{q}(\theta)$.

tives to purchase contracts for land of quality $\theta < \overline{\theta}$. Such acreage has expected indemnities that are greater than the premiums required. Therefore, the economic returns on lands of quality $\theta < \overline{\theta}$ are unequivocally higher. This in turn implies that the minimum (or marginal) land quality must decrease. A pooling equilibrium in crop insurance implies land that would not otherwise be employed now becomes utilized.

As other studies have noted, primarily beginning with the seminal work of Rothchild and Stiglitz (1976), the long-run actuarially fair pooling rate will necessarily rise to account for the fact that the very best risks are not purchasing insurance, while some of the worst risks are. This will tend to reduce the short-run adverse selection entry of marginal farmland at the low end of the quality spectrum. Moreover, an increase in the insurance premium will also lower the upper bound $\overline{\theta}$ for the break-even land quality, exacerbating the adverse selection problem at the high end of the quality spectrum. In the limit, with risk neutral farmers and an actuarially fair pooling premium, the equilibrium dissolves in the long-run to a single quality type, which necessarily lies at the low end of the quality spectrum of land in production. Moreover, the owners of that specific quality of land will be indifferent between the insurance and no insurance choice, so that the long-run pooling equilibrium is essentially equivalent to no insurance in this case. However, if farmers are risk averse, then there will be a counterbalance to the dissolution of the pooling equilibrium, with a positive interval of land at the low end of the quality spectrum being insured in both the short and the long-run.

Finally, consider a pooling equilibrium crop insurance program where the insurance premium is subsidized by the federal government. The change in profits induced by crop insurance is then indemnities paid less the product of (1-s) and the premiums paid,

$$\Delta\pi(\theta) = i(\theta) - (1-s)\tau(\theta)\,, \tag{30}$$

where s indicates the subsidy level, i is the indemnity paid on land of quality θ, and $\tau(\theta)$ is the insurance premium. Indemnities less premiums net of subsidies increase and the economic value of land increases, resulting in additional marginal land becoming profitable and entering into production. Adverse selection for low quality land worsens. On the other hand, however, subsidies mitigate the problem associated with the adverse selection at the high end of the quality spectrum in the pooling equilibrium. More high quality/low risk land becomes enrolled in the program as expected indemnities become greater than premiums net of subsidies. If the subsidy is set high enough (including, if necessary, negative premiums paid by farmers), then land of the best quality will be brought into the federal crop insurance program.

5. Conclusions

The passage of the Freedom to Farm Act of 1996 signaled a new regime in U.S. farm policy. Without the luxury of price supports, producers have had to consider alternative risk management tools to cope with increased revenue volatility. Federally subsidized crop insurance is one such alternative and has moved to the forefront of many policy discussions. A concern expressed by some policy analysts and researchers is that crop insurance may indirectly degrade the environment through the expansion of the extensive margin in agricultural production. In this paper, we developed a formal economic theory to analyze this issue.

Using a stylized model, we find that the introduction of crop insurance typically results in the expansion of the extensive margin. If a perfectly separating, actuarilly fair equilibrium exists, crop insurance does not effect land utilization or any other operational choices. However, in the more practically feasible pooling equilibrium, additional acres are cultivated in the short-run. In particular, crop insurance results in the employment of land with a minimum quality that is strictly lower than the minimum quality without insurance. Subsidies merely exacerbate this problem.

In the long-run, adverse selection shrinks the pooling equilibrium. If farmers are strictly risk neutral, the equilibrium dissolves into one in which the lowest end of the quality spectrum is the only acreage insured. Risk aversion implies an equilibrium with a positive interval of land at the low end of the quality spectrum being insured. A long-run pooling equilibrium unequivocally results in the expansion of the extensive margin at the low end of the quality spectrum, regardless of risk preferences. Subsidies mitigate the adverse selection issue for lands of higher qualities and therefore increase participation, but once again exacerbate the expansion of the extensive margin at the low end of the quality spectrum. We conclude that under reasonable conditions, subsidized crop insurance creates incentives to utilize greater quantities of marginal quality land. If, as the empirical studies reviewed by Soule, Nimon and Mullarkey (2000) suggest, economically marginal land is also environmentally marginal, crop insurance contributes to the degradation of the environment.

We find that without any crop insurance program, all land of a critical quality and higher will be in production. The addition of a crop insurance program that is characterized by a *perfectly separating equilibrium* and an actuarially fair premium for each quality does not change input use or land allocation. However, with risk neutral farmers and actuarially fair premiums, all farmers are indifferent between the purchase and not purchase decision. Conversely, if farmers are risk averse, then all will purchase actuarially fair crop insurance. Subsidized crop insurance based on a perfectly separating equilibrium creates an incentive for the extensive margin to expand, with the expansion taking place at the lower end of the quality spectrum, i.e., there is adverse selection. All land in production without crop insurance remains in production with subsidized crop insurance. It is profitable to purchase subsidized crop insurance for all qualities of land in production with the introduction of this type of insurance.

An actuarially fair *pooling equilibrium*, in which total premiums across all land in production equals expected total indemnity payments, creates an incentive for the extensive margin to expand at the lower end of the quality spectrum, again leading to adverse selection. In the short-run, owners of the highest quality land will not insure their crops, while owners of the lowest quality land will purchase insurance, exacerbating the adverse selection problem. Over the long-run, for risk neutral farmers the pooling equilibrium premium rate increases until a limiting solution is obtained in which the owners of only one land quality type are indifferent between insuring and not insuring that single quality of land. For all practical purposes, this essentially dissolves the pooling equilibrium. However, for risk averse farmers there will be a nondegenerate pooling equilibrium in the long-run, displaying some degree of adverse selection. Subsidizing the insurance premiums in a pooling equilibrium leads to two opposing effects. The disincentive for higher quality landowners to purchase insurance that partially subsidizes lower quality land is mitigated with subsidies on the insurance premiums. However, the incentive to expand the extensive margin at the low end of the quality spectrum is exacerbated.

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