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DESIGNING CONTRACTS TO REDUCE AGRICULTURAL NON-POINT SOURCE POLLUTION[1]

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DESIGNING CONTRACTS TO REDUCE AGRICULTURAL NON-POINT SOURCE POLLUTION

U.S. agricultural non-point source pollution is now reasonably well documented; pesticides (Hallberg 1989; U.S. Environmental Protection Agency 1990) and nitrates (Kellogg et al. 1992) have been found in both ground and surface water. Other water pollution problems stem from livestock wastes and soil erosion (National Research Council 1993).

Applied economic research to date has focused mainly on public policy remedies to the problem. This approach stems from a welfare economics perspective that identifies water pollution as the product of an externality which results when the private cost of a given action is less than the social cost. Standard remedies that have received recent empirical examination include input taxes and bans, effluent taxes and standards, tradeable pollution permits, and subsidies for pollution-reducing practices (Crutchfield et al. 1992; Hrubovcak et al. 1990; Johnson et al. 1991; Ribaudo and Bouzaher 1994; Swinton and Clark 1994; Taylor et al. 1992).

An alternative approach to resolving the externality problem was initially proposed by Coase (1960)[1]. The Coasian approach demonstrated that when the sources and consequences of pollution are clear and transactions costs are low, contracts can be developed between "actors" so that these "externalities are internalized". In the recent debate over means to reduce nonpoint source pollution, contracts have been ignored as a potential vehicle to reduce pollution perhaps because these assumptions appeared to be violated.

As the political and agribusiness environment evolves, however, the situation is changing. Although the sources of actual nonpoint source pollution problems are not verifiably clear, the *appearance* of being a potential pollution source is clear. And many agricultural firms have developed

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[1] The Coasian property rights approach has been elaborated and expanded by many authors (see for example Dahlman, 1979); however the basic concept of defining property rights so as to reduce social costs of pollution remains.

the expectation that such an *appearance* may lead eventually either to government regulation of their industry, with attendant costs and reduction of flexibility, or to liability for damages. The concern over potential liability may be propelled by knowledge of point source liability legislation. For example, the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 ("Superfund Act") has tied cleanup costs to any firm associated with the polluter that remained in business and might be able to pay.

The transactions cost of linking nonpoint source pollution to processor firms appears to be excessively high in industries where commodity-style production is the rule, where homogeneous products cannot easily be traced from the processor to the producer, and where contractual arrangements are few. However, in growing sectors of U.S. agriculture, the link between processors and producers is becoming tighter with the spread of agricultural "industrialization" (Drabenstott, 1994) and related contractual arrangements. This change has two important effects. First, it links the processor (and its reputation) to producer activities. Second, the prior existence of contracts to regulate product quality dramatically reduces the transactions cost of contractual incentives to reduce polluting activities. The reduced transaction costs create opportunities to build upon the existing trend in voluntary pollution reduction in the private sector (National Research Council, 1993).

The objective of this paper is to examine how a contract might be designed to reduce agricultural nonpoint source water pollution. We first develop a theoretical model of principal and agent in the context of agricultural nonpoint source pollution reduction. That model is applied to the problem of redesigning a seed corn production contract so that it will encourage fertilization practices that reduce nitrate leaching from the status quo. We conclude with a broader discussion of issues relating alternative contract designs that can lead to reduced leaching while maintaining acceptable contract terms for both parties.

Contract design and the principal-agent model

Contract design is a subfield of information economics that is usually treated in the context of principal-agent problems. A central issue is that of information asymmetries between principal and agent which make it impossible or costly for the principal to observe actions taken by the agent. Such situations present the potential for moral hazard--instances in which the agent can influence his or her welfare through actions that the principal cannot observe but which may be contrary to the principal's welfare. Thus, if the principal wants the agent to take an action favorable to the principal but costly for the agent, an incentive must be designed to induce the agent to do so (Baron, 1987; Demski and Sappington, 1984; Hirshleifer and Riley, 1992; Kreps, 1990; Varian, 1992).

The principal-agent framework of Hart and Holmstrom (1987) is introduced and is subsequently adapted below to examine the relationship between a seed corn processor (the principal) and a grower-contractor (the agent). The use of a single representative agent presupposes that agents have identical technology and attitudes toward risk. In the framework below, let **A** be the set of actions (elements of **A** can be a vector, such as levels of nitrogen fertilizer, labor, and capital inputs) available to the agent. ϵ is assumed to be a state of nature drawn from a probability distribution **g**. The action taken by the grower-contractor (denoted by **a**), and the state of nature jointly determine a verifiable outcome $\mathbf{y}=\mathbf{y}(\mathbf{a},\epsilon)$ as well as the monetary payoff $\pi=\pi(\mathbf{a},\epsilon)$ to the processor; **y** can be interpreted as the yield of seed corn production and π as the revenue of the seed corn processor. It is assumed that the utility functions of both the processor and the grower-contractor increase in monetary payoff. Let **s(y)** be the payment received from the processor (the principal) and **c(a)** be the cost of the grower-contractor's action. The total utility of the representative grower-contractor (agent) can be written as **u(s(y)-c(a))**. That is, the monetary payoff to the grower-contractor is a function of the payment received and the cost of complying with the contract. Hart and Holmstrom suggested that if π is a function of **y**, by the choice of **a**, the agent effectively chooses a distribution over **y**, which can be derived from **g** via the technology **y(.)**.

Assume that the derived density function is **f(y;a)**. This parameterized distribution formulation is proposed by Mirrlees(1974, cited by Hart and Holmstrom) and further explored by Holmstrom (1979). From this setting, the processor's problem is to determine the incentive scheme of payments **(s(.))** to induce the grower-contractor to take the action **(a)** that maximizes the processor's objective function, **v(π-s(y))**, over all states of nature,

$$\max_{s} \int v(\pi - s(y)) f(y;a) dy$$

$$\text{subject to} \quad \int u(s(y)-c(a)) f(y;a) dy \geq u^{o} \qquad (1)$$

$$\int u(s(y)-c(a)) f(y;a) dy \geq \int u(s(y)-c(a')) f(y;a') dy \qquad (2)$$

where **a'** (**a'** ∈ **A**) is an agent's alternative action.

This model illustrates the two key components of the principal's problem. The **participation constraint** in equation (1) insures that the agent elects to engage in the principal's enterprise, because participation yields utility at least equal to what the agent might obtain from some alternative feasible enterprise. The **incentive compatibility constraint** in equation (2) insures that the optimizing agent will choose those actions preferred by the principal **(a)** over alternative feasible actions **(a')**.

Optimal grower-contractor behavior under current seed corn contracts

Existing contracts between seed corn companies and contractor-growers[2] can be examined in the principal-agent context. Consider the following generic contract for production of hybrid corn seed:

$$\begin{aligned} s(y) &= \{[\alpha(y-y^{o})+Q]\beta P\}A \\ &= [(Q-\alpha y^{o})\beta PA]+(\alpha\beta PA)y \end{aligned} \qquad (3)$$

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[2] Commercial hybrid seed corn is raised by crossing two parent genetic lines called inbred varieties. The process entails planting one row of male inbred for every three rows of female. Male rows are removed after tasseling and fertilization of the female rows. Contractor-growers are typically compensated for the reduced yields due to the lower yield capacity of the inbreds and the loss of the male rows.

where s denotes total payment from the seed processor to contractor-growers; **y**, grower yield of seed corn per acre; $\mathbf{y^o}$, regional yield per acre; **Q**, base crop yield, which is based on the average yield of commercial corn in this region; **A**, grower acres of seed corn, **P**, the price of commercial corn per bushel; α, a coefficient that transforms seed corn yield to commercial corn equivalents; β, a price premium adjustment coefficient. Because the inbred lines have lower yields than commercial hybrids, the value of α is always greater than one. The transaction costs associated with contract production are compensated through a price premium adjustment coefficient, β, which also is greater than one.

If price **P** is normalized to 1, the payment per acre in terms of commercial corn yield equivalent becomes:

$$s(y) = [\alpha(y-y^o)+Q]\beta = a + by \tag{4}$$

This formulation of the payment can be separated into a fixed payment, $a=\beta(Q-\alpha y^o)$, and a variable payment, $by=\alpha\beta y$. The fixed portion, **Q**, can be interpreted as a participation constraint which insures that the seed grower is compensated for the opportunity cost of not raising the commercial hybrid corn (and presumably any other crops to which hybrid corn might be preferred).

The payment above average regional yield $\mathbf{y^o}$ is the premium to insures that the grower will strive to obtain the maximum yields desired by seed corn processors (Peterson and Corak, 1994). Note that the incentive payment is determined by the grower-contractor's yields *relative to the regional mean yield of those growers raising the same inbred line*. This relationship has important consequences for optimal input demand of fertilizer, as will be shown below.

In order to illustrate the optimal contract design, two components needs to be further identified: the technology for seed corn production and objective functions for both principal and agent. Let grower-contractor yield of inbred seed corn (**y**) depend on nitrogen fertilizer (**n**), other inputs (**z**, such as labor and capital), and weather that is stochastic. For simplicity, **z** is assumed to be fixed at $\mathbf{z^o}$ making **n** the only choice variable for the grower-contractor. The grower-contractor's production function is characterized by $\mathbf{y = ln(n) + \epsilon}$, where $\mathbf{n \geq 1}$ (notice that the ambient mineral nitrogen is assumed to be zero), and $\mathbf{\epsilon \sim N(0,\sigma^2)}$. Nitrogen fertilizer increases yield at a diminishing rate $(\mathbf{y_n > 0,\ y_{nn} < 0})$[3]. The corresponding expenditure on inputs is represented in linear form as $\mathbf{c(n,z^o) = pn + z^o}$, where **p** denotes the price of nitrogen.

Finally, assume the grower-agent's risk preferences are characterized by a mean-variance utility function with constant absolute risk aversion (Freund, 1956), where the risk aversion coefficient is denoted γ. The expected utility function per acre from growing seed becomes:

$$\mathbf{Eu(s(y)-c(n,z^o)) = [(Q-\alpha y^o)\beta] + \alpha\beta ln(n) - pn - z^o - (\gamma/2)(\alpha\beta)^2\sigma^2}$$

$$\mathbf{= a + bln(n) - (\gamma/2)b^2\sigma^2 - pn - z^o} \qquad (5)$$

This contract must ensure that farmers can earn at least equal to reservation utility level. Therefore the participation constraint would be

$$\mathbf{Eu(w) = a + bln(n) - (\gamma/2)b^2\sigma^2 - pn - z^o \geq u^o} \qquad (6)$$

In this case, the nitrogen fertilizer is the only control variable for the agent. For a grower who takes the contract, the incentive compatibility constraint can be characterized by the first order condition that maximizes the agent's expected utility with respect to nitrogen use, **n**. It yields the result: $\mathbf{b/n = p}$ or $\mathbf{n = b/p}$. As the variable payment (**b**) increases, or the price (**p**) of nitrogen fertilizer decreases, the application of nitrogen fertilizer will increase. However, evidence indicates that there is an excessive nitrate concentration in the groundwater of some seed corn production regions (Peterson and Corak, 1994). This result implies that if the procession firm cares about its indirect influence on environmental quality, then this contract design puts too much weight on the variable payment. Hence, under current seed corn contracts, there is an incentive to use more nitrogen than with commercial hybrid production.

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[3] This assumption mirrors reality only for certain circumstances. Evidence exists for instances where yield may plateau or actually decline with supplemental nitrogen (Peterson and Corak, 1994). Plant response depends heavily on existing soil nitrate levels, climate, and biological activity.

If the processing firm cares about nitrate leaching, the objective of reducing nitrate leaching should be incorporated into the payment scheme as well.

In the case that the processor does not consider the environmental impact, assume that he (or she) is risk-neutral. The processor will incorporate within the contract **a**, a fixed payment, as well as **b**, a variable payment, to maximize expected profits (in terms of seed corn yield),

$$\mathbf{E(\pi) = E[y - s(y)] = (1\text{-}b)\ln(n) - a} \qquad (7)$$

Without environmental consideration, an optimal contract will

$$\begin{aligned} &\underset{a,b}{Max}\ (1-b)\ \ln(n)-a \\ &subject\ to \\ &\quad a+b\ \ln(n)-\frac{\gamma}{2}b^2\sigma^2-pn-z^o\ \geq\ u^0 \\ &\quad b/n=p \end{aligned} \qquad (8)$$

The corresponding inner solution will be

$$\begin{aligned} b &= \frac{-1+\sqrt{(1+4\gamma\sigma^2)}}{2\gamma\sigma^2} \\ n &= \frac{-1+\sqrt{(1+4\gamma\sigma^2)}}{2\gamma\sigma^2 p} \\ a &= u^o-b\ \ln(n)+pn+\frac{\gamma}{2}\ b^2\ \sigma^2 \\ &\frac{\partial b}{\partial\gamma},\ \frac{\partial b}{\partial\sigma^2},\ \frac{\partial n}{\partial\gamma},\ \frac{\partial n}{\partial\sigma^2}<0 \end{aligned} \qquad (9)$$

Contract design for reducing nitrate leaching:

1. Constraining the grower-contractor

The potential for future government regulation or for judicial liability can make avoidance of environmental problems (such as nitrate leaching by grower-contractors) a legitimate concern for the seed corn processor. Recall that in the absence of environmental concern, the processor offers a linear incentive payment scheme, s(y), designed to optimize grower yield (y) when the processor cannot observe all inputs applied to achieve that yield:

$$s(y) = a + by.$$

A seed corn processor has several potential approaches to induce grower-contractors to reduce nitrate leaching. These approaches include providing fertilizer use information to grower-contractors, reducing the variable payment (b), imposing an additional penalty fee on nitrogen use after a certain level, and restricting the application of nitrogen fertilizer. However, reducing nitrate leaching by reducing nitrogen fertilizer use will likely reduce yields. Therefore, an optimal contract must incorporate the trade-off between seed corn yields and nitrate leaching.

In the following context, we consider that if the processor views reduction of nitrate leaching as an objective, such reduction can be attained either by imposing a constraint directly on the grower-contractor or else by adjusting the variable payment in order to incorporate the processor's objective. We first consider the case in which nitrate leaching has a non-random relationship with nitrogen fertilization, and can be observed or measured with certainty. The processor can thus impose on the grower-contractor a constraint on the permissible level of nitrogen fertilizer (n^o), where the consequence of failing to comply is loss of the seed corn contract. The grower-contractor's optimization problem becomes:

$$\text{Max } Eu(y) = a + b\ln(n) - (\gamma/2)b^2\sigma^2 - pn - z^o$$

$$\text{Subject to } n \leq n^o \tag{10}$$

Optimization yields the following decision rule:

$$r/n = p_n + \mu \tag{11}$$

where μ (the Lagrangian multiplier on the constraint) takes the value zero, if the constraint is not binding, or else represents the shadow price of the fertilizer use constraint, if the constraint is binding. A positive value of μ means that the use of nitrogen fertilizer will decrease. Depending on the value of the seed corn contract to the grower-contractor, this constraint could be a strong incentive to comply with the nitrogen fertilizer standard.

From a contract-design standpoint, then, much depends on the value of the contract. For a grower-contractor who values the seed corn contract only slightly more than an alternative enterprise, the value of the contract will be close to nil and therefore the incentive to comply with the fertilizer constraint will be very small. However, to the extent that such marginal grower-contractors fail to comply and lose their contracts, the processor will violate the participation constraint in equation (1), so the incentive payment, $\mathbf{s(y)=a+by}$, must be enhanced, as in the incentive payment scheme above. The fertilizer constraint approach also suffers from higher monitoring cost, as it may be hard to enforce compliance where the actions of the grower-contractor cannot always be observed.

2. Adjusting the variable payment to reduce nitrate leaching

The alternative to imposing a nitrogen fertilizer constraint directly on the grower-contractor is to design an incentive payment that incorporates the processor's nitrate leaching objective when only ambient nitrate leaching can be observed. This ambient level is assumed to be affected by stochastic weather. One form in which environmental concern could enter the processor's objective function is as a per-unit leaching penalty, $\mathbf{t} \in \mathbf{[0,1]}$, on nitrate leaching when leaching ($\mathbf{L(n)}$) exceeds some threshold ($\mathbf{L^o}$)[4]. Nitrate leaching is assumed to be linear to nitrogen fertilizer, i.e., $\mathbf{L(n)=c+dn+\eta}$, where $\eta \sim \mathbf{N(0,\nu^2)}$, where $\mathbf{c}$ could be determined by the ambient mineral nitrogen level. Such a "penalty" could

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[4] Other means of embodying concern about future regulation are also possible. For example, the processor might target some efficiency standard for the proportion of fertilizer nitrogen taken up by the plant.

be interpreted as a weighting put by the processor firm of the risk of future regulation resulting from perceived groundwater contamination that is tied to the company's activities. If nitrate leaching is linear with respect to nitrogen fertilizer use, then the processor's problem becomes:

$$\begin{aligned}
&\underset{a,b}{Max}\ (1-b)\ln(n)-a-t(c+dn-L^{0})\\
&subject\ to \qquad\qquad\qquad\qquad\qquad\qquad (12)\\
&\quad a+b\ \ln(n)-\frac{\gamma}{2}b^{2}\sigma^{2}-pn-z^{o}\ \geq\ u^{0}\\
&\quad b/n=p
\end{aligned}$$

If nitrate leaching exceeds the threshold level, **L°**, such that the unit leaching penalty takes effect, the optimal variable payment that solves the processor's problem is

$$\begin{aligned}
b &= \frac{-(1+\frac{td}{p})+\sqrt{(1+\frac{td}{p})^{2}+4\gamma\sigma^{2})}}{2\gamma\sigma^{2}}\\
n &= \frac{-(1+\frac{tc}{p})+\sqrt{(1+\frac{tc}{p})^{2}+4\gamma\sigma^{2})}}{2\gamma\sigma^{2}p}
\end{aligned} \qquad (13)$$

Equation 13 suggests several interesting results for design of an optimal variable payment (**r**). As expected, variable payment, **b**, declines with increases in the leaching "penalty", **t**. Variable payment, **b,** also decreases with increases in the grower-contractor's level of risk aversion (γ) and in the level of yield risk (σ^2).

While this contract design avoids the moral hazard (enforceability) problem inherent in the nitrogen constraint contract, the processor bears all costs of leaching reduction. The reduced incentive payment (b) would force the fixed payment (a) to increase by a corresponding amount in order to respect the participation constraint in equation (1). Since expected seed corn yield would decline, the processor would be worse off by the value of the yield decline plus the change in the fixed payment minus the weighted value of the variable payment. Because the participation constraint is always binding, the grower-contractor will be no worse off than before.

Conclusion

The preliminary discussion above illustrates two kinds of potential contract designs that would incorporate environmental concerns into agricultural production contracts. Much refinement remains and much research is needed even in the narrow area of seed corn contracts discussed here. Two deserving topics are alternative specifications of risk preferences and the links among nitrogen fertilizer use, yield risk, and environmental risk. Research into the production technology for seed corn may also lead to identifying a "middle ground" for nitrogen application that allows nitrate leaching to be reduced without corresponding loss of seed corn yield. Such research should look into effective means of predicting nitrogen deficiency (such as plant tissue, and soil nitrogen tests, Babcock and Blackmer, 1992, and Follett et al., 1991). Increased knowledge about alternative production technology may open new opportunities for contract design (e.g., contracts based on efficient input use or substitution of information for physical input use).

Looking beyond seed corn contracts, a much broader set of contract design issues emerges, even when the focus remains narrowed to managing nitrate leaching. For example, reducing nitrogen use in horticultural crops may lead to product quality reduction, with concomitant reduction in price received. This result implies that product price itself becomes an indirect function of nitrogen fertilizer use. The same quality effects would be relevant to contract design incorporating pesticide use in fruit and vegetable production.

Broadening the context even farther, many contractual arrangements can also be found in livestock production, particularly in the poultry and the hog sectors. With confined livestock operations, the pollution problem involves the environmentally safe disposal of animal waste and dead animals. Here too there is potential for the redesign of contracts to address these potential environmental problems. However, the redesign of livestock contracts so that they are acceptable for all parties is more feasible where waste products can be economically transformed into marketable products, such animal manure or poultry litter pretreated for use as a crop fertilizer.

The restructuring of agriculture toward more contractual arrangements between processor and producer implies fresh opportunities for the creative design of contracts. New contract designs may offer incentives not only for the pursuit of traditional profit and product quality goals, but also for the pursuit of environmental goals. Information economics and the principal-agent framework provide an excellent starting point for analysis of alternative contract designs.

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