Designing Contracts to Reduce Agricultural Non-point Source Pollution*

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The restructuring of agriculture offers opportunities to reduce nonpoint source pollution via new contract designs. A seed corn contract is used as an early exploration of applying a principal-agent model. We illustrate contract designs which have potential to reduce nitrate leaching. Future research areas are explored as well.

Keywords: *production contracts, nonpoint source pollution, principal-agent theory, seed corn, nitrate leaching*

1. Introduction

Agricultural non-point source pollution (NPSP) is now widely recognized

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as a serious water quality problem in the United States. Pesticides and nitrates are two examples of nonpoint source pollutants that have been found in both ground and surface water (Hallberg 1989; U.S. Environmental Protection Agency 1990; Kellogg et al. 1992). Other examples are livestock wastes and soil erosion (National Research Council 1993). Agricultural nonpoint source pollution is characterized as "non-exclusive goods" and "non-rival goods". NPSP is an unintended side effect of agricultural production; it is produced by many small polluters without a distinctive discharge site, and the concentration of pollutants is affected by random factors, such as weather.

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 Pigouvian taxes, effluent 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; and Taylor et al. 1992). However, most NPSP control polices are difficult to enforce due to asymmetric information between regulators and polluters (Segerson, 1988; Tomasi, Segerson, and Braden, 1994). It is generally difficult to infer from observation of ambient pollution levels the contribution originating from any individual source (Russell and Shogren, 1993; Tomasi et al., 1994). Due to these asymmetric information problems, the standard environmental policies have been criticized as having high transaction costs (Xepapadeas, 1991, 1992).

An alternative approach to resolving the externality problem was initially proposed by Coase (1960).[1] Applied to NPSP, the Coasian approach suggests that when the sources and consequences of pollution are clear, property rights are established, and transactions costs are low, contracts can be developed between "actors" so that "externalities are internalized". In the ongoing debate over policy vehicles to reduce nonpoint source pollution, contracts have been ignored, perhaps because these assumptions appeared to be violated. As the political and agribusiness environment evolves, however, the situation is changing.

The restructuring of U.S. agriculture toward vertically integrated, contract production provides an opportunity to reduce NPSP. Production under contractual arrangements takes place in many US industries, including poultry, hogs, vegetables and specialty grains (Drabenstott, 1994). For many years, these agricultural production contracts have provided contractors, indirectly, significant incentives to use inputs intensively in order to achieve high output goals, or intensify livestock numbers per hectare. The heavy use of some inputs, such as fertilizers and pesticides, can cause NPSP, degrading environmental quality. For instance, seed corn production has been accused of causing nitrate contamination in the groundwater due to heavy fertilization and contracts encourage heavy fertilization by rewarding high yield (Peterson and Corak, 1994).

The link between U.S. agricultural processors and producers is becoming tighter with the spread of agricultural "industrialization" (Drabenstott, 1994). 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 transaction cost of contractual incentives to reduce polluting activities. The reduced transaction cost creates opportunities to build upon the existing trend in voluntary pollution reduction in the private sector (National Research Council, 1993). It is easy to imagine, therefore, that contracts could be re-constructed to serve a mechanism that allows buyers (e.g., processors) to influence the sellers (e.g., producers) in their environmental stewardship. This research will explore possible ways to design contracts that can induce producers to "voluntarily" reduce NPSP.

The objective of this paper is to examine how a contract might be designed to reduce agricultural nonpoint source groundwater 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 alternative contract designs that can lead to reduced leaching while maintaining acceptable contract terms for both parties.

2. 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 the principal and the 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) can be adapted 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 Ω be the set of actions (elements of Ω 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 ω), and the state of nature jointly determine a verifiable outcome $y = y(\omega, \epsilon)$ as well as the monetary payoff $\pi = \pi(\omega, \epsilon)$ to the processor; y can be interpreted as the yield of seed corn production and π as the revenue of the seed corn processor. Let the utility functions of the processor $(v(.))$ and the grower-contractor $(u(.))$ both be increasing in monetary payoff. Let $s(y)$ be the payment received from the processor (the principal) and c(ω) be the cost of the grower-contractor's action. The total utility of the representative grower-contractor (agent) can be written as $u(s(y) - c(\omega))$. 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 the yield, y, by the choice of action, ω, the agent effectively chooses a distribution over y, which can be derived from the production distribution, g, via the production technology $y(.)$.

Assume that the derived density function is $f(y; \omega)$. 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 (ω) that maximizes the processor's objective function, $v(\pi - s(y))$, over all states of nature,

$$\underset{s}{Max} \quad \int v(\pi - s(y)) f(y;\omega) dy$$

$$subject\ to \quad \int u(s(y) - c(\omega)) f(y;\omega) dy \geq u^0 \qquad (1)$$

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

where $\omega'(\omega' \epsilon\ \Omega)$ is an agent's alternative action.

This model illustrates the two key constraints that represent the nature 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 (ω) over alternative feasible actions (ω').

3. Optimal Grower–Contractor Behavior under Actual Seed Corn Contracts

Actual contracts between seed corn companies and contractor-growers[2] can be examined in this principal-agent context. We will examine a case study of the seed corn contract used in southwestern Michigan, where seed corn is widely grown on sandy, irrigated soil, and where significant nitrate levels have been found in groundwater. Seed corn production is a exceptionally important because maize is one of the major crops in the world. Hybrid seed is commercialized because it cannot be reproduced by the farmers. In order to maintain genetic purity and stable supply, seed corn processing firms almost always contract with growers to multiply hybrid seed.

In a typical seed corn production contract, the processing firm offers price premiums to encourage contractual growers to achieve high yields. One way to accomplish this goal is to fertilize heavily with nitrogen, a practice which can lead to excessive nitrate leaching. Consider the following generic contract payment formula (Shaw et al., 1989), the one most commonly used in U.S. seed corn production:

$$s(y) = \{[\alpha(y - y^0) + Q]\beta P\}A \tag{3}$$

where s denotes total payment from the seed processor to contractor-growers; y, grower yield of seed corn per acre; y^0, 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; 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 the price of seed corn is normalized to 1, the payment to the seed corn grower per acre in terms of seed corn yield equivalent becomes:

$$s(y) = [\alpha(y - y^0) + Q]\beta P' \tag{4}$$

where P' is the price ratio of commercial corn to seed corn. The fixed portion, $Q\beta P'$, 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, $[\alpha(y-y^0)]\beta P'$, is the premium to insure 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.

Before proceeding, note that the seed corn grower payment in equation (4) can be rewritten in a linear form as:

$$\begin{aligned} s(y) &= [(Q-\alpha y^0)\beta P'] + (\alpha\beta P')y \\ &= a + by \end{aligned} \tag{5}$$

This formulation of the payment can be separated into a fixed payment, $a=\beta P'(Q-\alpha y^0)$, and a variable payment, $by=\alpha\beta P'y$. This linear payment form this two advantages, Not only does it provide a convenient basis for analysis, but more importantly, a linear form has been shown to be optimal for the principal to induce desired agent actions (Diamond, 1995).

To illustrate the optimal contract design, two components need to be identified: the objective functions as well as the production technology for both the seed corn processing firm (principal) and the contractor-grower(agent). The seed corn processor is assumed to be risk-neutral.[3] If the processor does not consider the environmental impacts, he (or she) will choose a, a fixed payment, as well as b, a variable payment, to maximize expected profits within the contract,

$$\underset{a,b}{Max} \quad E[y-s(y)] = (1-b)y - a \tag{6}$$

Let grower-contractor yield of inbred seed corn (y) depend on nitrogen fertilizer (n), other inputs (z, such as labor and capital), and exogenous factors (such as soil nitrate levels and weather). For simplicity, z is assumed to be fixed at z^0, making n the only choice variable for the grower-contractor. The grower-contractor's production function is characterized by $y = ln(n) + \epsilon$, where $n \geq 1$,[4] and ϵ is a random term that is normally distributed with mean and variance $(0,\sigma^2)$. ϵ captures random yield disturbances due to weather, pest population, soil nitrate levels and machinery failure. Assume nitrogen fertilizer increases yield at a diminishing rate ($y_n > 0, y_{nn} < 0$, where y_n denotes $\partial y/\partial n$ and y_{nn} denotes $\partial^2 y/\partial n^2$).[5] The corresponding expenditure on inputs is represented in linear form as $c(n, z^0) = pn + z^0$, where p is the price of nitrogen. The use of nitrogen fertilizer generates a by-product — nitrate leaching, $L(n)$, where $L_n(or\ \partial y/\partial n) > 0$. Nitrate leaching is assumed to be external to the grower's objective function.

Finally, assume the grower-agent's risk preferences are characterized by a mean-variance utility function with constant absolute risk aversion[6] (Young, 1979; Freund, 1955), where the risk aversion coefficient is denoted by γ. The grower-agent's expected utility per acre from growing seed corn becomes:

$$Eu(w) = Eu(s(y) - c(n, z^0)) = [(Q - \alpha y^0)\beta P'] + \alpha\beta P' ln(n) - pn - z^0 - (\gamma/2)(\alpha\beta P')^2\sigma^2$$
$$= a + b\ ln(n) - (\gamma/2)b^2\sigma^2 - pn - z^0 \quad (7)$$

This contract must ensure that farmers can earn with seed corn production an amount that at least equals with their reservation utility level, u^0. Therefore the participation constraint would be:

$$Eu(w) = a + b\ ln(n) - (\gamma/2)b^2\sigma^2 - pn - z^0 \geq u^0 \quad (8)$$

In this case, the nitrogen fertilizer is the only control variable for the contractor-grower. For a grower who takes the contract, the incentive compatibility constraint can be characterized by the first order condition that maximizes the contractor-grower's expected utility with respect to nitrogen use, n^*. It yields the result: $b/n^* = p$ (i.e., $\alpha\beta P'/n^* = p$) or $n^* = b/p$. As the variable payment b increases, or the price of nitrogen p decreases, the application of nitrogen fertilizer will increase.

The processor's related objective can be expressed as:

$$\underset{a,b}{Max} \quad E[y - s(y)] = (1-b)ln(n) - a \tag{9}$$

Without environmental consideration, an optimal contract will be

$$\begin{aligned} &\underset{a,b}{Max} && (1-b)ln(n) - a \\ &subject\ to && a + b\ ln(n) - \frac{\gamma}{2}b^2\sigma^2 - pn - z^0 \geq u^0 \\ & && b/n = p \end{aligned} \tag{10}$$

The corresponding interior solution will be

$$\begin{aligned} b^* &= \frac{-1 + \sqrt{(1 + 4\gamma\sigma^2)}}{2\gamma\sigma^2} \\ n^* &= \frac{-1 + \sqrt{(1 + 4\gamma\sigma^2)}}{2\gamma\sigma^2 P} \\ a^* &= u^0 - b\ ln(n) + pn + \frac{\gamma}{2}b^2\sigma^2 \\ & \frac{\partial b}{\partial \gamma}, \frac{\partial b}{\partial \sigma^2}, \frac{\partial n}{\partial \gamma}, \frac{\partial n}{\partial \sigma^2} < 0 \end{aligned} \tag{11}$$

To design an optimal contract that reduces incentives to "overuse" nitrogen fertilizer, the processing firm needs to incorporate the amount of nitrate leaching generated from seed corn production into its objective function. The following hypothetical examples illustrate three ways to design "green" contracts.

4. Contract Design for Reducing Nitrate Leaching

The risk of future government regulation or legal liability for environmental damage are two reasons for a seed corn processor to seek to avoid environmental problems, such as nitrate leaching by grower-contractors. Recall that in the absence of environmental concern, the processor offers a linear incentive payment scheme, $s(y) = a + by$, designed to optimize grower yield (y) when the processor cannot observe all inputs applied to achieve that yield.

A seed corn processor can choose from several potential approaches to induce grower-contractors to reduce nitrate leaching. These approaches include (1) constraining the contractor-grower, (2) specifying financial "punishment" within contracts, and (3) adjustment the variable payment to reduce nitrate leaching. Reducing nitrate leaching by reducing nitrogen fertilizer use, however, may reduce seed corn yield. Therefore, an optimal contract must incorporate the trade-off between yield 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 (or a fee) directly on the grower-contractor or else by adjusting the variable payment in order to incorporate the processor's objective.

4.1 Constraining the Grower–Contractor

First consider the case in which nitrate leaching has a non-random relationship with nitrogen fertilizer, and the amount of nitrogen application can be observed or measured with certainty. Since nitrate leaching is a function of nitrogen use, assume that n^0 is directly related to a regulatory maximum contaminant level for nitrate leaching (i.e., $L^0 = L(n^0)$), such as the 10 ppm nitrate-nitrogen in drinking water standard of the U.S. Public Health Service under the Safe Drinking Water Act (Fan et al., 1987). The contract can specify a constraint on the permissible level of nitrogen fertilizer (n^0). The consequence of failing to comply is loss of the seed corn contract. The grower-contractor's optimization problem becomes:

$$\underset{n}{Max} \quad Eu(y) = a + b\ ln(n) - (\gamma/2)b^2\sigma^2 - pn - z^0$$
$$Subject\ to\ \ n \leq n^0 \tag{12}$$

Optimization yields the following decision rule:

$$b/n^* = p + \mu \tag{13}$$

where μ, the Lagrangian multiplier on the constraint, represents the shadow price of the additional constraint on nitrogen use. It takes the value zero if the constraint is not binding, i.e., when the amount of nitrogen used by the contractor-grower falls below the threshold level n^0. When the constraint is binding, the shadow price, μ, is a positive value and thus increases the opportunity cost for nitrogen input. As a result, the use of nitrogen fertilizer will decrease to the permissible level n^0 in order to grow seed corn. Otherwise, the grower-contractor will lose the seed corn contract. 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. This conclusion assumes that the amount of nitrogen applied is known by the seed corn processor.

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 small. 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 fixed part (a) of the incentive payment, $s(y) = a + by$, must be enhanced.

4.2 Specifying Financial "Punishment" within Contracts

One alternative to a rigid restriction is a financial penalty associated with exceeding a specified threshold level of fertilizer application, n^0, or nitrate leaching, L^0. If nitrogen fertilization is observable and directly related to the permissible nitrate leaching level, L^0, the processor can impose a fee, r, on the contractor-grower's nitrogen use n which exceeds the threshold level n^0. The maximization for the optimization for the contractor-grower becomes

$$\underset{n}{Max} \quad Eu(y) = a + b\ ln(n) - (\gamma/2)b^2\sigma^2 - pn - z^0 - r(n - n^0) \tag{14}$$

The grower's optimization yields the following decision rules:

$$\begin{aligned} b/n &= p + r \quad && \text{if} \quad n > n^0 \\ b/n &= p \quad && \text{if} \quad n \leq n^0 \end{aligned} \tag{15}$$

This result shows that imposing a financial punishment increases the opportunity cost of nitrogen use when it is greater than n^0. When the financial punishment r increases, the amount of nitrogen use will decrease, given diminishing marginal returns to nitrogen use. The amount of financial fee,

r, can be determined according to the processor's preference for reducing nitrate leaching. This contract design will not affect those growers who use nitrogen fertilizer below n^0. Because the processor's objective is to comply with the permissible nitrate leaching level L^0, the processor obtains no extra benefit when leaching falls below this threshold. Therefore, there is no need to subsidize the grower for fertilizing below n^0.

The chief disadvantage of using the fertilizer constraint or charge approaches is the high monitoring cost. It may be hard to enforce compliance where the actions of the grower-contractor cannot always be observed. For this reason, we examine a third contract mechanism that can be used to reduce nitrate leaching.

4.3 Adjusting the Variable Payment to Reduce Nitrate Leaching

An alternative to imposing a nitrogen fertilizer constraint or fee directly on the grower-contractor is to design an incentive payment that incorporates the processor's nitrate leaching reduction objective. Such specification works when the amount of nitrate leaching, L, or nitrogen use, n, is difficult to observe yet both L and n are directly related to the processor's objective. Due to perceived risk of future regulation, the processor may expect that some variant of a Pigouvian fee (or liability) may be imposed on the amount of nitrate leaching exceeding the safe drinking water standard due to seed corn production. One form in which environmental concern could enter the processor's objective function is as a per-unit leaching penalty, $t \in [0,1]$, on nitrate leaching when leaching $(L(n))$ exceeds some threshold (L^0).[7] Such a "penalty" could be interpreted as a weighting determined by the processor firm of the risk of future regulation or a tarnishing of his "green" image that might result from groundwater contamination tied to the company's activities.

For illustration purposes, nitrate leaching is assumed to occur without time lags and to be linear in nitrogen fertilizer use, i.e., $L(n) = c + dn + \eta$, where c could be determined by the ambient mineral nitrogen level, and η is a random term with zero mean, affected by weather or soil nitrate levels. The processor's problem becomes:

$$\begin{aligned} &\underset{a,b}{Max} && (1-b)ln(n) - a - t(c+dn-L^0) \\ &subject\ to && a + b\ ln(n) - \frac{\gamma}{2}b^2\sigma^2 - pn - z^0 \geq u^0 \\ & && b/n = p \end{aligned} \tag{16}$$

If nitrate leaching exceeds the threshold level, L^0, such that the penalty takes effect, the optimal variable payment that solves the processor's problem is

$$\begin{aligned} b^* &= \frac{-\left(1+\frac{td}{P}\right) + \sqrt{\left(1+\frac{td}{P}\right)^2 + 4\gamma\sigma^2}}{2\gamma\sigma^2} \\ n^* &= \frac{-\left(1+\frac{td}{P}\right) + \sqrt{\left(1+\frac{td}{P}\right)^2 + 4\gamma\sigma^2}}{2\gamma\sigma^2 P} \end{aligned} \tag{17}$$

If expected nitrate leaching is smaller than the threshold level, L^0, the optimal variable payment is the same as the case without environmental constraint (equation 9 and 10) since the term $t(c+dn-L^0)$ is zero. Equation 17 suggests several interesting results for design of an optimal variable payment (b). As expected, the variable payment, b, declines with increases in the leaching "penalty", t, when expected nitrate leaching exceeds the threshold level. 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 will bear all costs of reducing leaching. The reduced incentive payment (b) would force the fixed payment (a) to increase by a corresponding amount in order to satisfy the participation constraint in equation (1). Since the 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. However, the reduction of nitrate leaching will improve the processor's reputation for environmental stewardship and also avoid future liability. The grower-contractor, on the other hand, will be no worse off than before.

5. Conclusions

The restructuring of U.S. agriculture toward more contractual arrangements between processor and producer implies new opportunities for the creative design of contracts to reduce NPSP. 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.

The preliminary discussion above illustrates three kinds of potential contract designs that would incorporate environmental concerns into agricultural production contracts. It remains to develop empirical estimates of feasible contract parameters, such as the fees, incentive payments, and constraints proposed here. Two further areas deserve research, both theoretical and empirical. First, risk plays a key role through the risk preferences of contract parties as well as through the technical links among input use, output (yield) risk and environmental risk. Second, the dynamics of the biophysical production and environmental processes deserve scrutiny along with the responses of principal and agent to changing incentives over time. This last is enriched by changing exogenous supply-demand conditions and the principal's option of not renewing contracts and switching agents.

Looking beyond grain crops, a much broader set of contract design issues emerges, even when the focus remains narrowed only 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. Broadening the context to confined livestock operations, the pollution problem involves the environmentally safe disposal of animal waste and dead animals. The redesign of livestock contracts so that they are acceptable to all parties may be more feasible where waste products can be economically transformed into marketable products, such as animal manure or poultry litter pretreated for use as a crop fertilizer.

In conclusion, there exist a plethora of new research possibilities for the design of production contracts that reduce environmental contamination. Our theoretical exploration of potential contract designs to reduce nitrate leaching from seed corn production is just a beginning.

Footnotes

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.
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.

3. The seed corn processor examined in our model is a large firm. A large firm often has insurance against losses, and has the ability to spread out risks through equity as well as other investment, therefore it reasonable to assume risk-neutral behavior (Diamond, 1995).
4. A natural logarithmic functional form is assumed for illustrative purposes as well as for computational convenience. The assumption $n \geq 1$ ensures positive yield. The ambient mineral nitrogen is zero in this case.
5. This assumption mirrors reality for many but not all circumstances. Evidence also exists for instances where yields plateau or actually decline with supplemental nitrogen (Peterson and Corak, 1994). Actual plant response depends heavily on existing soil nitrate levels, climate, and biological activity.
6. A mean-variance framework is consistent with the expected utility function, because the linear form of incentive payment in our case satisfies the location and scale condition (Meyer, 1986).
7. 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.

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用契約的設計減少農業非點源污染

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因應農業結構的變遷，農產契約的更新設計得以用來減少農業生產過程所產生的非點源污染。本文以玉米種籽的生產契約及氮肥使用為例，分析如何利用雇傭模型以訂定最適的農業契約，並探討如何透過多種契約的設計以降低非點源污染。

關鍵詞：農產契約、非點源污染、雇傭理論、玉米種籽、氮肥滲透