INTEGRATOR CONTRACTS WITH MANY AGENTS AND BANKRUPTCY

THEOFANIS TSOULOUHAS AND TOMISLAV VUKINA

This article analyzes optimal livestock production contracts between an integrator company and many independent growers in three similar industries: broiler, turkey, and swine. The analysis provides an explanation for the simultaneous existence of distinct incentive schemes in these industries by examining the effects of bankruptcy. The key factors are shown to be the output price volatility and the firm size. With large companies dominating the broiler industry, a small price volatility facilitates the use of two-part piece rate tournaments. By contrast, given the prevalence of smaller companies in the swine industry, a larger price volatility generates a bankruptcy risk which renders the use of tournaments infeasible. Given the combination of medium-size companies in the turkey industry, an intermediate price volatility produces a mixed result where tournaments and fixed performance standards exist simultaneously.

Key words: bankruptcy, contracts, moral hazard, multiple agents, tournaments.

Contracts are becoming an ever more important mechanism for organizing agricultural production. Aside from cropshare contracts which have been extensively analyzed (e.g., Eswaran and Kotwal, Allen and Lueck), the literature on other contractual arrangements in agriculture is rather limited. One type of contractual arrangement that is frequently observed is an integrator contract, that is, a contract between an integrator company and independent farmers (growers). Integrator contracts dominate meat production in sectors such as broilers, turkeys, and, to a certain extent, hogs. Similar contracts also play a significant role in the production of fruits and vegetables, notably, apples, tomatoes, potatoes for chips, and pickles. This article focuses on the broiler, turkey, and swine industries. The broiler and turkey industries are overwhelmingly organized via contracts with independent growers. Following in similar footsteps is the hog industry. For instance, in North Carolina, the nation's fastest growing swine producing state, over 80% of the hogs are already produced under contractual arrangements between integrators and growers (Hurt and Zering).

An interesting feature of the existing contractual arrangements is the simultaneous presence of distinct remuneration schemes in these similarly organized industries, or even within the same industry. Particularly puzzling is the complete adoption of two-part piece-rate tournaments in broiler production, the prevalence of fixed performance standards in swine production, and the simultaneous existence of tournaments and fixed performance standards in turkey production. In a two-part piece-rate tournament scheme, the grower receives a bonus if his performance is better than the group average and a penalty if his performance is below the group average. In a fixed performance standard scheme, bonuses depend upon the performance of a grower compared to a predetermined technological standard. This article provides a framework for solving this apparent puzzle by bringing bankruptcy considerations explicitly into the analysis. The results are supported by evidence on output price volatility and firm size in the three industries. Given the prevalence of small companies in the swine industry, a large price volatility generates a significant bankruptcy risk which renders the use of tournaments infeasible. By contrast, with large companies dominating the broiler industry, a smaller price uncertainty facilitates the use of

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tournaments. Given the combination of medium-size companies in the turkey industry, an intermediate price volatility allows the simultaneous existence of tournaments and fixed performance standards.

Assuming a risk-neutral integrator, one of the main purposes that contracts serve is to provide insurance to risk-averse growers. However, insurance provision can be hindered by grower opportunism and the inability of the integrator to fully monitor the growers' actions. It has been well established in the literature that agent opportunism limits a firm's ability to provide insurance.[1] In the case of livestock production contracts, however, grower provision of relationship-specific capital virtually eliminates opportunism. The remaining factor of concern is the integrator's inability to observe the growers' efforts. Because of this inability, the integrator can never provide full insurance to the growers, meaning that payment schemes cannot be independent of realized outcomes. Via payment schemes that depend on observed outcomes, contracts provide incentives to growers to exert unobservable effort. Yet, in the presence of production uncertainties that are common to all growers, the integrator may be able to offer some insurance if the outcomes obtained by the growers convey information about common uncertainties. Examples of common production uncertainties include the effects of weather, untried feed mixes and newly introduced genetic stock. In the presence of such uncertainties, relative performance evaluation via tournaments provides a mechanism to partially insure the growers by filtering away common production uncertainty.[2] Contests among growers have no intrinsic value in improving grower performance. They are valuable only when peer performance offers information about common production uncertainty, provided that the number of agents is sufficiently large (Holmström 1982).

The explanation for the utilization of tournaments in the broiler industry focused on common uncertainties. Knoeber argued that tournaments reduce the overall cost of contracting. They remove the common production uncertainty from the grower's responsibility, and adapt to technical change without the need for more complicated contracts or renegotiation. Grower provision of relationship-specific capital, in the form of housing facilities, reduces opportunism, provides incentives to perform, and encourages the self-selection of high-ability growers. Knoeber and Thurman (1995) decomposed the total risk in the broiler industry into components of price, common production, and idiosyncratic production risks. They found that price risk accounts for 84% of total risk, common and idiosyncratic production risks account for 3% each, and the remaining percentage was attributed to the joint contributions of the three components.

In light of these results, explaining the utilization of tournaments in integrator contracts solely by the filtering of common production shocks does not seem complete. A significant price uncertainty may hinder the firm's ability to filter away common uncertainty from the responsibility of growers. In particular, the possibility of bankruptcy due to price volatility presents an important factor determining the firm's leeway in designing contracts. The institution of limited liability effectively makes an otherwise risk-neutral integrator a risk-lover willing to commit to contract terms that he will never have to live up to. Realizing this, rational growers will never agree to a contract that does not provide for payments that can be recovered from the firm's revenue and its liquidation value. This requirement can be interpreted as a safeguard against the firm promising high payments in unfavorable states of nature and then pleading bankruptcy due to the inability to deliver these payments. The analysis shows that this requirement would not be satisfied if the firm used a two-part piece-rate tournament; by contrast, it can always be satisfied if the firm uses a fixed performance standard. If all growers obtained an unfavorable outcome, then their average outcome would also be unfavorable. Therefore, comparing an individual grower's performance with the group average would prevent a sufficient reduction in payments to growers in unfavorable states that would satisfy the bankruptcy constraint.

The article is organized as follows. First, the stylized facts about the nature of integrator contracts are presented. Next, the model is introduced, followed by a discussion of the benchmark contracts when there is no common production uncertainty. The core case when there is common uncertainty is then analyzed, and it is shown that whereas a two-part piece-rate tournament can be optimal

[1] For instance, see Harris and Holmström, Meyer, and Tsoulouhas (1996).

[2] The theoretical justification is in Lazear and Rosen, Holmström (1982), Green and Stockey, and Nalebuff and Stiglitz.

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when the bankruptcy constraint is nonbinding, this is not true when the bankruptcy constraint is binding. Finally, some empirical evidence supporting our results is provided.

The Organization of Production Via Contracts

The specific information on contract design is based on reviewing poultry and swine contracts offered to growers in North Carolina. The information gathered is considered to be representative of the entire industry. North Carolina ranks first in turkey production, second in hog production, and fourth in broiler production nationally. The focus of our attention is the so-called finishing contract where animals of a certain age group, say one-day-old chicks, are brought to the farm and then grown (fattened) to market weight. We abstract from other types of production contracts that exist in the three industries, such as breeder and hatching egg contracts in the broiler industry, brooding contracts in the turkey industry, and feeder pig, nursery, and farrow-to-finish contracts in the swine industry. The reason for not analyzing these contracts is the fact that the earlier stages of production in the three industries differ significantly from each other.

A production (grow-out) contract is an agreement between an integrator company and a farmer (grower) that binds the farmer to specific production practices. Contracts vary from company to company, but all of them have two main components. One is the division of responsibility for providing inputs, and the other is the method used to determine growers' compensation. Both features have been subjected to modifications over time and are still undergoing changes. The grower provides land and housing facilities, utilities (electricity and water), and labor. Operating expenses such as repairs and maintenance, clean-up costs, and manure and mortality disposal are also the responsibility of the grower. The integrator company provides animals to be grown to processing weight, feed, medication, and services of field men. Typically, the company also owns and operates hatcheries, feed mills, and a processing plant, and provides transportation of feed and live animals. Items like fuel or litter can be the responsibility of either the integrator or the grower, or they can be shared. The decision about the volume of production, that is, the rotation of flocks (batches) on a given farm, is determined by the integrator, and so is the size (capacity) of the technological unit (finishing floor). Nowadays, most integrators would require that houses be built according to strict specifications regarding construction and equipment. New houses are typically well-insulated units, with highly automated feeders, drinkers, and heating and cooling devices.[3]

Most of the modern finishing contracts have a fairly similar structure, taking the form of a two-part piece-rate tournament or a fixed performance standard. A two-part piece-rate tournament consists of a fixed base payment per pound of live meat produced and a variable payment based on the grower's relative performance. The variable payment is determined by comparing the individual grower's performance with the group average. The performance is determined largely by the feed conversion ratio, which is a coefficient indicating pounds of feed used to produce a pound of live weight. Frequently, the performance is measured by the so-called settlement cost which is obtained by combining feed with other integrator's costs (chicks, medication, etc.) divided by the total pounds of live weight produced. There is little difference between the simple feed conversion ratio and the settlement cost because "prices" used to convert physical units into costs are not market prices but fixed weights associated with the number of chicks and the amount of feed used (for an example, see Knoeber, p. 275). For a feed conversion below average (i.e., above-average performance), the grower receives a positive amount over the base payment, and for a feed conversion above average (i.e., below-average performance) he receives a penalty. The calculation of the group average performance includes growers whose flocks were harvested at approximately the same time (within a week or up to the last six weeks at the maximum). The total payment to grower $i \in N = \{1, 2, \ldots, n\}$, denoted r^i, is the sum of the base and bonus payments per pound multiplied by the live weight of poultry or pork moved from the grower's farm:

$$(1) \qquad r^i = \left[b + \beta \left(\frac{1}{n} \sum_{j \in N} \frac{x^j}{y^j} - \frac{x^i}{y^i} \right) \right] y^i, \quad \forall\, i$$

[3] For more details about broiler contracts see Vukina and Foster.

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where x^i/y^i is the feed conversion ratio (x^i denotes feed used and y^i represents output), b denotes the base payment per live pound and β is a bonus factor measuring the intensity by which the tournament influences the total payment the grower receives (usually between 0.5 and 1.0). It can be easily seen that equation (1) can be rewritten as

$$(2) \quad r^i = \left[b + \beta \frac{(n-1)}{n}\left(\frac{1}{n-1}\sum_{j \in N, j} \frac{x^j}{y^j} - \frac{x^i}{y^i}\right)\right] y^i, \quad \forall\, i.$$

Note that, for a sufficiently large number of growers, $(n-1)/n$ converges to 1; therefore, the bonus payment depends on the difference between the group average feed conversion excluding grower i's, and i's individual feed conversion.

A second type of grower remuneration is based on a fixed performance standard. A critical difference between a tournament and a fixed standard lies in the computation of the benchmark against which the performance of an individual grower is compared. Whereas in the first case the benchmark is determined by a contest among the growers, in the second case it represents a predetermined technological constant. There are several different types of the fixed performance standard scheme. One of them is the following scheme:

$$(3) \quad r^i = \left[b + \beta\left(s - \frac{x^i}{y^i}\right)\right] y^i, \quad \forall\, i$$

where s represents a fixed feed conversion ratio. The feed conversion standard varies with the species and the weight of the animal. For example, it is 2.6 (i.e., 2.6 pounds of feed per pound of gain) for turkey toms, 2.3 for turkey hens, and 2.8 for hogs. Another version of the fixed performance standard is a discrete scheme where, for a given weight of the finished animal, the contract design specifies different bonus payments in different feed conversion intervals (brackets). Two more variations of the payment scheme include a version where a base payment is paid per pound of live weight and the bonus payment is paid per head of the delivered animal, and a version where there is no explicit base payment but the entire payment per pound of live weight delivered varies with the bracket in which the individual grower's feed conversion lies.

Two-part piece-rate tournaments are used by virtually all broiler companies and by a significant number of turkey companies, yet they are absent from the swine industry. Fixed performance standard schemes dominate hog finishing contracts. They are also observable in the turkey industry, but they are virtually nonexistent in the broiler industry. Note that rank-order tournaments, that is, payment schemes with prespecified prizes depending on the performance ranking of growers, are largely absent from all three industries, even though they have been used by some integrators in the past (see Knoeber and Thurman 1994). One possible explanation is that rank-order tournaments are informationally wasteful when grower performance can be measured cardinally rather than ordinally, which is the case in all three analyzed industries (see Lazear and Rosen, and Holmström 1982).

The Model

We model a contractual relationship between a single integrator (principal) and a number of growers (agents). Each grower raises animals for the integrator independently of other growers in exchange for a monetary compensation. Animals and feed are provided by the integrator. Labor and housing facilities are provided by the growers. The sequence of moves is shown in figure 1. First, a take-it-or-leave-it contract is simultaneously proposed by the integrator to each grower. Second, each grower decides whether to accept or reject the offer. If the grower rejects the offer, he receives his reservation payoff. If the offer is accepted, then, once the contract is signed, each grower exerts effort. Since the integrator cannot directly observe the effort level of each grower, there exists a "hidden action" moral hazard problem.[4] The integrator only observes each grower's realized feed and output levels; hence, contracts are contingent on these observable variables. The output price is uncertain at the beginning of the production cycle. This uncertainty is resolved after production is concluded, at which time the integrator decides whether to make payments to the growers or plead bankruptcy. The integrator is the residual claimant when the firm is solvent.

[4] Note that we do not consider moral hazard on the integrator's side. Tsoulouhas (1998), motivated by the analysis in Carmichael, has shown that such moral hazard is eliminated by tournaments or fixed performance standards when the number of agents grows large.

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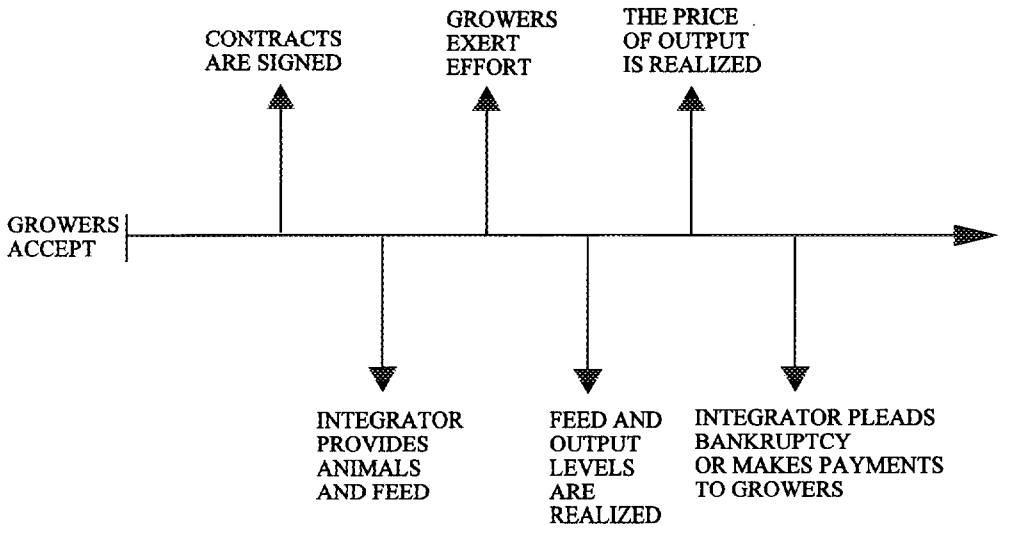

Figure 1. The sequence of moves

The production technology is determined by a standard nutrition practice where animals eat *ad libidum*. As a result of that, effort becomes the grower's only decision variable once he or she signs a contract. By exerting effort, growers stochastically influence feed utilization and output (see figure 2). By exerting more effort, growers can separately affect feed utilization by preventing spillage through frequent and careful maintenance of feeders, watering lines, and storage bins. They can also separately influence output (live weight) by exerting effort aimed at the prevention of excessive animal mortality. Finally, growers can jointly influence feed utilization and output by maintaining the optimal housing environment to achieve the maximum possible conversion of feed into weight gain (i.e., the lowest possible feed conversion ratio).

The exact modeling of the above stochastic production technology is quite complex. However, the analysis can be considerably simplified by following Knoeber and Thurman (1994). Assuming that flocks and the target market weight of animals placed are the same for all growers, the number of pounds produced is roughly the same as well. Effectively, what the maintained assumption does is to ignore the potential impact of effort on the prevention of animal mortality. The growers' performances differ depending only on feed, where the amount of feed used stochastically depends on the exerted effort.[5]

Feed realization x^i for grower i's activity is in the interval $[x_L, x_H]$. The output target for each grower is set to $\bar{y}$. Effort e^i exerted by grower i takes one of two values $\{e_L, e_H\}$ denoting low and high effort. Feed realization by grower i is stochastically related to his or her effort e^i as described by the conditional distribution function $H^i(x^i \mid e^i)$, with density $h^i(x^i \mid e^i)$ such that $h^i(x^i \mid e^i) > 0$ for all e^i in $\{e_L, e_H\}$ and all x^i in $[x_L, x_H]$. For the activity of each grower, we assume that the distribution of utilized feed when he exerts low effort first-order stochastically dominates the distribution when he exerts high effort; that is, $H^i(x^i \mid e_L) \leq H^i(x^i \mid e_H)$, for every x^i in $[x_L, x_H]$, with strict inequality on some open set which is a subset of $[x_L, x_H]$. This condition says that the probability that

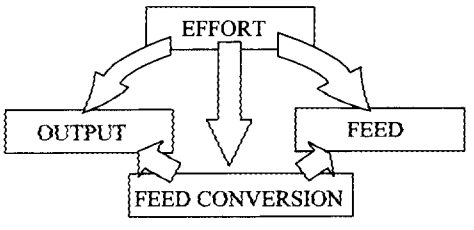

Figure 2. The stochastic effects of effort

[5] We would like to thank a referee for pointing out the importance of randomness in output in the presence of moral hazard. A note which expands the model to the case when both feed and output are stochastic is available from the authors upon request. The note shows that the main results are preserved in the more complex framework.

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the feed used by a grower exceeds any given level decreases with his or her effort. It implies that a grower's expected feed use is smaller when the high effort is chosen than when the low effort is chosen:

$$(4)\qquad \int_{x_L}^{x_H} x^i h^i(x^i \mid e_H)\, dx^i < \int_{x_L}^{x_H} x^i h^i(x^i \mid e_L)\, dx^i.$$

The output market is assumed to be competitive. The price of output, p, is stochastic as described by the distribution function $G(p)$, with density $g(p)$ such that $g(p) > 0$ for all possible prices $[p_B, p_G]$. The distribution is known to all parties at the time of contracting, and the realized price is directly observed by all parties. For simplicity, the price of feed is deterministic and normalized to one.[6] The integrator is risk neutral with respect to profit. For simplicity, each grower has the same von Neumann-Morgenstern utility function of the form $U(r^i) - c(e^i)$, where r^i is the grower's remuneration and $c(\cdot)$ is his or her disutility of effort. Thus, growers differ only in the distributions of feed. Function $U(\cdot)$ is twice continuously differentiable, with $U'(\cdot) > 0$ and $U''(\cdot) < 0$ (i.e., growers are risk averse). Because the high effort (which minimizes expected feed utilization) is more costly to the grower than the low effort [i.e., $c(e_H) > c(e_L) > 0$], there is potential tension between the interests of the integrator and those of the grower.

Depending on the relation between the growers' feed distributions, we examine two cases. In the benchmark case, the distributions are independent, meaning that there is no underlying common production uncertainty and all production uncertainty is idiosyncratic. In the main case, the distributions are dependent, meaning that there is common production uncertainty.

The Contracts When the Distributions Are Independent

To obtain a benchmark, this section analyzes the contracts without common production uncertainty. If the distributions of the growers' feed utilizations were independent and known to the integrator, a contract offer to grower i would specify a customized payment r^i depending on his or her own feed utilization, $r^i(x^i)$. It is useful to view the payment to a grower as a specification of contingent utility. Let $u^i(x^i) \equiv U[r^i(x^i)]$ denote utility payments, and let the inverse $U^{-1}[u^i(x^i)] = r^i(x^i)$ denote equivalent income. Since U is increasing and strictly concave, U^{-1} is increasing and strictly convex.

If the growers' efforts were freely observable by the risk-neutral integrator, the integrator would be able to offer full insurance to the growers, in the sense that their compensations would be independent of feed.[7] Because efforts are unobservable, if compensations were independent of feed, growers would shirk. Thus, if the integrator wants the growers to exert effort, he must offer them sufficient incentives via compensation schedules that depend on feed, thereby imposing risk on the growers. Following the Grossman and Hart procedure, a scheme $\{u^i(x^i;\, e^i)\}_{i\in N}$ is said to implement effort levels $\{e^i\}_{i\in N}$ if, given the scheme, effort e^i provides grower i with at least his or her reservation utility and maximizes his or her expected utility. An incentive-efficient scheme for effort levels $\{e^i\}_{i\in N}$ is a scheme that implements $\{e^i\}_{i\in N}$ at minimum cost to the integrator. To derive the optimal contracts, first we derive the incentive-efficient scheme for each possible array of effort levels. Then we determine the effort levels that are optimal for the integrator. The incentive-efficient scheme $\{u^i(x^i;\, e^i)\}_{i\in N}$ for effort levels $\{e^i\}_{i\in N}$, is the solution to the program:

$$(\text{P.1})\qquad \min_{u^i(x^i;e^i),i\in N} \sum_i \int_{x_L}^{x_H} U^{-1}[u^i(x^i;\, e^i)] h^i(x^i \mid e^i)\, dx^i$$

subject to

$$(5)\qquad \int_{x_L}^{x_H} u^i(x^i;\, e^i) h^i(x^i \mid e^i)\, dx^i - c(e^i) \geq 0, \quad \forall\, i$$

[6] Note that this assumption is not overly restrictive because the feed components used in all industries are the same, only the feed mixes differ, hence, any input price volatility is similar across all industries.

[7] The optimum utility payment would satisfy $u^i(x^i) = c(e^i)$, $\forall x^i \in [x_L, x_H]$, $\forall i$, which would yield an optimum payment $r^i(x^i) = U^{-1}[c(e^i)]$, hence, payments would be independent of feed.

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$$(6)\quad \int_{x_L}^{x_H} u^i(x^i;\, e^i)h^i(x^i|e^i)\,dx^i - c(e^i) \geq \int_{x_L}^{x_H} u^i(x^i;\, e^i)h^i(x^i|\tilde{e}^i)\,dx^i - c(\tilde{e}^i), \quad e^i \neq \tilde{e}^i, \quad \forall\, i.$$

The incentive-efficient scheme has the following standard properties. The individual rationality constraints (5) bind; the growers receive no rents, but they still accept the contracts. Constraints (6) guarantee that it is incentive compatible for each grower i not to deviate away from e^i when the integrator has offered $u^i(x^i; e^i)$. These constraints are binding for $e^i = e_H$, and are nonbinding for $e^i = e_L$. Therefore, the first best scheme is implementable for $e^i = e_L$ but not for $e^i = e_H$. The incentive-efficient scheme for $e^i = e_H$ is second best. In determining $u^i(x^i; e_H)$, both the individual rationality and the incentive constraints are binding.

The integrator's expected profit from implementing effort levels $\{e^i\}_{i\in N}$, by offering the incentive-efficient scheme $\{u^i(x^i; e^i)\}_{i\in N}$, is

$$(7)\quad E\Pi(e^1, e^2, \ldots, e^n) = n\bar{y}\int_{p_B}^{p_G} g(p)\,dp - \sum_i \int_{x_L}^{x_H} [x^i + U^{-1}[u^i(x^i; e^i)]]\, h^i(x^i|e^i)\,dx^i.$$

We assume that the integrator prefers implementing the high effort, that is,

$$(8)\quad E\Pi(e^1 = e^2 = \cdots = e^n = e_H) > E\Pi(e^1 = e^2 = \cdots = e^n = e_L).$$

Thus, the second-best allocation is the action e_H for the growers and the incentive-efficient scheme $\{u^i(x^i; e^i)\}_{i\in N}$. Given program (P.1), this incentive efficient scheme satisfies

$$(9)\quad (U^{-1})'[u^i(x^i; e_H)] = \lambda^i + \mu^i\left[1 - \frac{h^i(x^i|e_L)}{h^i(x^i|e_H)}\right], \quad \forall\, x^i \in [x_L, x_H], \quad \forall\, i$$

where $\lambda^i > 0$ is the multiplier for grower i's individual rationality constraint, and $\mu^i > 0$ is the multiplier for grower i's incentive compatibility constraint. Note that, under the scheme in equation (9), and assuming that the integrator knows the feed distributions, he or she offers customized contracts.

Condition (9) implies

$$(10)\quad U'[r^i(x^i; e_H)] = \frac{1}{\lambda^i + \mu^i[1 - LR^i(x^i)]}, \quad \forall\, x^i \in [x_L, x_H], \quad \forall\, i$$

where the likelihood ratio

$$(11)\quad LR^i(x^i) \equiv \frac{h^i(x^i|e_L)}{h^i(x^i|e_H)}$$

is assumed to be nondecreasing in feed via the standard monotone likelihood ratio assumption (abbreviated MLR). MLR states that as x^i increases, the likelihood of a feed realization x^i when the grower exerts a low effort relative to the likelihood when he exerts a high effort cannot decrease. MLR implies that a smaller feed level allows the integrator to statistically infer "favorable news"; that is, a smaller feed level is indicative of greater effort exerted by the grower.[8] Given that $U(\cdot)$ is concave, it follows that $r^i(x^i; e_H)$ is nonincreasing in x^i. Under the MLR assumption, the payment decreases with the realized feed level so that the grower is provided with correct incentives to exert effort. Note that the scheme flattens at very low feed levels, because these levels are quite unlikely to occur with low effort; hence, the likelihood ratio gets close to zero and the payment becomes almost independent of feed. The degree of concavity of the scheme depends on the form of the utility function $U(r^i)$ and the forms of the feed distributions $h^i(x^i|e_L)$ and $h^i(x^i|e_H)$. For example, if $U(r^i) = \ln r^i$, then condition (10) implies $r^i(x^i; e_H) = \lambda^i + \mu^i[1 - LR^i(x^i)]$. If, in addition, the feed distributions are chi-square, then the payment scheme looks like the scheme in figure 3. If the feed distributions are normal, then the scheme is less concave; in fact, it is linearized at all feed levels except at the very low feed levels.

[8] MLR can be satisfied by distributions such as the normal, the chi-square, the exponential, the Poisson, and other distributions (see Milgrom). As an example, consider two chi-square distributions $h^i(x^i|e_L)$ and $h^i(x^i|e_H)$, where the former has more degrees of freedom than the latter, or two normal distributions $h^i(x^i|e_L)$ and $h^i(x^i|e_H)$ where the former has a higher mean than the latter.

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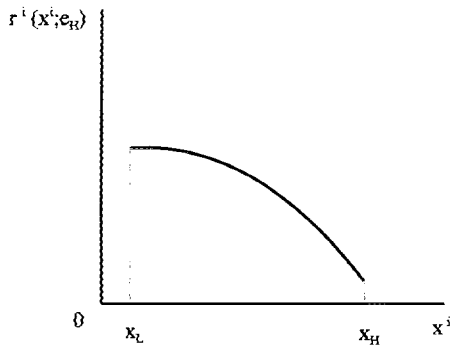

Figure 3. The optimum scheme with independent distributions

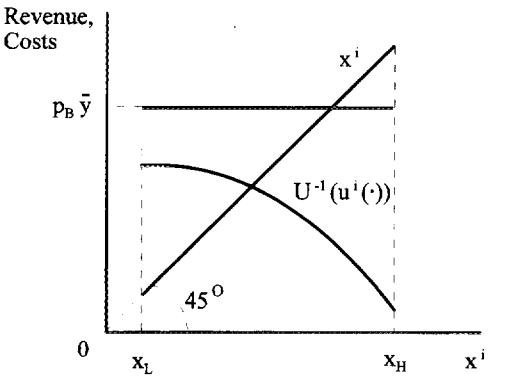

Figure 4. Revenue and costs in the absence of the bankruptcy constraint

We now allow for the possibility of bankruptcy. Assume that the integrator is subject to limited liability. Thus, the integrator is liable only up to the liquidation value of his firm if insolvency occurs. Following Sappington, Farmer, and Kahn and Scheinkman we refer to limited liability as a situation of bounded state-dependent payments via a bankruptcy constraint. In every possible output price, and in every possible realization of feed levels, costs cannot exceed gross revenues from production plus the liquidation value of the firm. Thus, the following limited liability or bankruptcy constraint is included in program (P.1):

$$(12)\quad np\bar{y} - \sum_i [x^i + U^{-1}(u^i(x^i; e_H))] + A \geq 0, \qquad \forall\, x^i \in [x_L, x_H], \qquad \forall\, p \in [p_B, p_G]$$

where $A > 0$ is the liquidation value of the firm. Limited liability effectively makes an otherwise risk-neutral integrator a risk-lover willing to commit to contract terms in the neighborhood of the liability limit that he or she will never have to live up to. The growers, realizing this, would never agree to a contract that would permit the firm to enter bankruptcy in unfavorable states.[9] Note that if constraint (12) is satisfied at the lowest possible price $p = p_B$, then it is automatically satisfied at any $p \in (p_B, p_G]$. Therefore, it reduces to

$$(13)\quad np_B\bar{y} - \sum_i [x^i + U^{-1}(u^i(x^i; e_H))] + A \geq 0, \qquad \forall\, x^i \in [x_L, x_H].$$

Whether the bankruptcy constraint is binding or not depends on the value of p_B, on the liquidation value of the firm, and on the realization $(x^1, x^2, \ldots, x^n)$ of the feed levels. Figure 4 depicts revenue and costs associated with the activity of a grower in the absence of the bankruptcy constraint [i.e., when the incentive scheme is determined by condition (10)]. The increase in feed realization, as the figure indicates, can make the bankruptcy constraint binding or nonbinding depending on the decrease in the compensation cost $r^i(x^i; e_H) = U^{-1}(u^i(x^i; e_H))$. For the purposes of our analysis, it is useful to distinguish between three main cases, because the analysis of all possible cases would add unnecessary complexity without offering any new insights.

In the first case, the lowest possible price, p_B, is sufficiently large, and/or the liquidation value of the firm is sufficiently large, so that the bankruptcy constraint (13) is nonbinding at any feed levels $(x^1, x^2, \ldots, x^n)$, with x^i in $[x_L, x_H]$. In this case, the incentive efficient scheme $r^i(x^i; e_H)$ satisfies condition (10) above. In the second case, p_B is sufficiently small, and/or the liquidation value of the firm is sufficiently small, so that the bankruptcy constraint is binding regardless of the realized feed levels. The optimum payment to each grower for any realization of feed must be smaller that the one characterized by the incentive efficient scheme which satisfies condition (10). However, since this scheme leaves no rents to the grower [i.e., since the individ-

[9] We are thankful to a referee for this interpretation. Also see Kahn and Scheinkman. Greenwald and Stiglitz offer an additional justification for including a bankruptcy constraint, by arguing that a firm's managers can be averse to bankruptcy, since bankruptcy can lead to turnover with significant costs to the managers. Gilson found that turnover following default has been as high as 52%, compared to 18% for unsuccessful firms that do not default.

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ual rationality constraint (5) is binding], the decrease in payments, which is necessary to satisfy the bankruptcy constraint, violates the individual rationality constraint. The grower would reject such an offer; hence, the integrator does not make a contract offer. Clearly, this case is an extreme case. In the third case, p_B is sufficiently small, and/or the liquidation value of the firm is sufficiently small, but the bankruptcy region is entered only in unfavorable high-feed states. In this case, the bankruptcy constraint is nonbinding at low feed levels, but it is binding at high feed levels, because the reduction in compensation cost is outweighed by the increase in feed realization. This third case is analyzed below.

It can easily be shown that when the bankruptcy constraint is binding at high feed levels, then the incentive compatibility constraint can be binding or nonbinding depending on the distribution of feed and on the range of feed levels for which the bankruptcy constraint is nonbinding. However, the interesting case is the case when the incentive compatibility constraint is binding. In this case, the incentive efficient scheme satisfies equation (10) at low feed levels where the bankruptcy constraint is nonbinding, and

$$U'[r^i(x^i; e_H)] = \frac{1 + \dfrac{\tau}{h^i(x^i|e_H)}}{\lambda^i + \mu^i[1 - LR^i(x^i)]}, \quad \forall\, i \tag{14}$$

at high feed levels where the bankruptcy constraint is binding. Note that $\tau > 0$ is the multiplier associated with the bankruptcy constraint. Then, if $h^i(x^i|e_H)$ is decreasing at high feed levels, and given the MLR assumption, $r^i(x^i; e_H)$ will be decreasing in feed since the effect of the bankruptcy constraint will be reinforcing that of the incentive compatibility constraint. The optimum scheme is shown in figure 5. The bankruptcy and incentive constraints restrict the payments the integrator can make in unfavorable high-feed states. However, the payments in favorable low-feed states must be large enough in order for the grower to participate and exert effort.

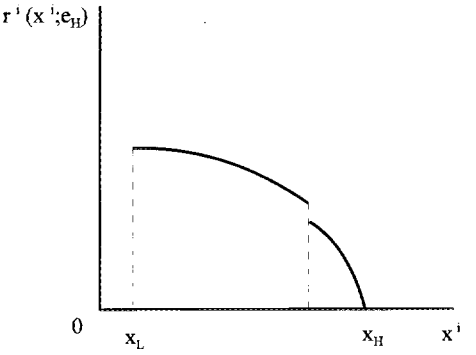

Figure 5. The optimum scheme with the bankruptcy constraint

The Contracts When the Distributions Are Dependent

We now analyze the main case of the article, when the distributions of feed levels for the growers are dependent due to common production uncertainty. In this case, a contract offer to grower i specifies a payment r^i which depends on the feed level obtained by i, x^i, and the feed levels obtained by the rest of the growers, $x^{-i} \equiv (x^1, x^2, \ldots, x^{i-1}, x^{i+1}, \ldots, x^n)$. This is so because the feed levels obtained by the rest of the growers convey information about common production uncertainty and, as a result, the effort choice of any given grower. Formally, x^i is not a sufficient statistic for x^{-i} with respect to e^i. Knowledge of the feed levels obtained by the rest of the growers filters common uncertainty and can provide an informative signal about the effort of grower i.[10] Let remunerations be denoted by $r^i(x; e_H)$ where $x \equiv (x^i, x^{-i})$, effort levels by all growers except i be denoted by $e^{-i} \equiv (e^1, e^2, \ldots, e^{i-1}, e^{i+1}, \ldots, e^n)$, and effort levels by all growers be denoted by $e \equiv (e^i, e^{-i})$. The joint density function of x given e is denoted by $\chi(x|e)$, and the marginal density by $h^i(x^i|e)$. From conditional probability, we can write

$$\chi(x|e) = h^i(x^i|e)h^{-i}(x^{-i}|x^i, e). \tag{15}$$

If the bankruptcy constraint is nonbinding because p_B is sufficiently large and/or the liquidation value of the firm is sufficiently large, by analogy to condition (10) and given condition (15), the optimum compensation rule for grower i satisfies

[10] See deGroot and Holmström (1982) for sufficient statistics, and Holmström (1979) for the link between sufficient statistics and informativeness of signals.

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$$(16)\quad U'[r^i(x; e_H)] = \frac{1}{\lambda^i + \mu^i\left[1 - \dfrac{h^i(x^i|e^i = e_L, e^{-i} = e_H)h^i(x^{-i}|x^i, e^i = e_L, e^{-i} = e_H)}{h^i(x^i|e = e_H)h^{-i}(x^{-i}|x^i, e = e_H)}\right]},$$
$$\forall\ x, \quad \forall\ i.$$

If the bankruptcy constraint is binding in the unfavorable high-feed states, and assuming that the incentive constraint is binding as well, by analogy to condition (14) the optimum rule satisfies

$$(17)\quad U'[r^i(x; e_H)] = \frac{1 + \dfrac{\tau}{h^i(x^i|e = e_H)h^{-i}(x^{-i}|x^i, e = e_H)}}{\lambda^i + \mu^i\left[1 - \dfrac{h^i(x^i|e^i = e_L, e^{-i} = e_H)h^{-i}(x^{-i}|x^i, e^i = e_L, e^{-i} = e_H)}{h^i(x^i|e = e_H)h^{-i}(x^{-i}|x^i, e = e_H)}\right]},$$
$$\forall\ x, \quad \forall\ i$$

in the high-feed states, and equation (16) in the low-feed states.

The optimal rules in equations (16) and (17) are customized to fit individual grower characteristics (i.e., feed distributions), assuming that the integrator knows these characteristics. However, the actual rules that we observe in the three analyzed industries are not customized, and they are primarily simple linear rules. A natural explanation for the existence of uncustomized simple linear rules is that the integrator does not know the precise grower characteristics and he has to gather information about them. However, gathering precise information about individual grower characteristics is prohibitively costly. In this case, the integrator can either offer a menu of contracts and let the growers select from the menu, or treat the growers as a homogeneous group. For a menu of contracts to be optimal, the integrator must screen the grower types by designing the offers in the menu in such a way that no certain type of grower benefits by selecting the offer that is meant for some other type. To ensure that this is the case requires complicated sorting conditions. Thus, given the wide variety of possible distributions of outcome, the integrator is likely to treat the growers as homogeneous. Further, given that the focus of this article is the moral hazard and not the adverse selection problem, the assumption in the remaining analysis is that growers are homogeneous. The adverse selection problem is the focus of future work.

With this discussion in mind, consider the optimum compensation schemes in equations (16) and (17) for a grower. These complicated schemes can be considerably simplified by taking a first-order Taylor approximation. In particular, given an array of feed levels by the rest of the growers, replace the right-hand side of equation (16) or equation (17) with $\Phi^i(x^i; x^{-i})$ to obtain

$$(18)\quad r^i(x^i; x^{-i}, e_H) = (U')^{-1}[\Phi^i(x^i; x^{-i})].$$

To demonstrate the relevance of a first-order Taylor series approximation assume that the grower is of average ability and his marginal density $h^i(x^i|e)$ is normal. Then the likelihood ratio is almost linear at all feed levels except at the very low feed levels, so that the second derivative of the likelihood ratio is almost zero almost everywhere.[11] Holmström and Milgrom, however, have argued that schemes that adjust compensation to account for rare events (i.e., very low feed states) may not provide correct incentives in ordinary, high-probability circumstances, therefore, the focus should be on the feed levels where the likelihood ratio is almost linear. But if the likelihood ratio is linear, the second- and higher-order terms in the Taylor approximation are very small and can be disregarded. Thus, consider a first-order Taylor expansion of the scheme in equation (18) at $x^i = x_o$:

$$(19)\quad r^i(x^i; x^{-i}, e_H) \approx (U')^{-1}[\Phi^i(x_o; x^{-i})] + [(U')^{-1}]'[\Phi^i(x_o; x^{-i})] \times \Phi^{i\prime}(x_o; x^{-i})(x_o - x^i).$$

[11] To see this, consider two normal distributions $h^i(x^i|e_L)$ and $h^i(x^i|e_H)$ where the former has a higher mean than the latter.

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When no customized schemes are offered, condition (19) represents a linear scheme of the form $r^i(x^i; x^{-i}, e_H) = b + \beta(x_o - x^i)$, for every i, with b, $\beta > 0$. But which x_o should the integrator use when making an offer to an agent? In the presence of common uncertainty and provided that the number of agents is large, a natural candidate is the average outcome obtained by all agents other than i, $\bar{x}^{-i}$. Holmström (1982) has shown that $\bar{x}^{-i}$ can capture all the relevant information that is conveyed by the performance of all agents other than i about common uncertainty, when the number of agents grows large, because all such uncertainty can be discerned in the limit. In such a case, equation (19) represents a linear, two-part piece rate, tournament $r^i(x^i; x^{-i}, e_H) = b + \beta(\bar{x}^{-i} - x^i)$, where a grower is paid a base payment plus a bonus or penalty depending on his performance relative to the group average. The integrator offers a simple uncustomized linear scheme to all growers, which filters away common uncertainty from their responsibility.

Observe that a simple linear tournament increases the expected payments to a grower compared to the payments he would earn had the integrator known the grower's precise characteristics. Otherwise, a linear tournament would have been the optimum scheme even if the integrator were fully informed about grower characteristics. The fact that expected payments increase with a tournament is not an issue when the bankruptcy constraint is nonbinding, because this is the best the integrator can do when it is prohibitively costly to obtain full information about the grower types. Yet when the bankruptcy constraint is binding in unfavorable states, this can be a serious problem. To see this, consider the payment that the tournament would imply in the most unfavorable of the circumstances, if the highest feed level x_H were realized by all growers. This payment would be $r^i(\cdot) = b + \beta(x_H - x_H) = b$, where b should be sufficiently large to ensure the *ex ante* participation of growers. This payment to the grower would violate the bankruptcy constraint that requires a minimal payment in highly unfavorable states. One possible solution to this problem is to take the Taylor expansion at some value $x_o = s$ that the integrator determines, instead of taking the expansion at $x_o = \bar{x}^{-i}$. This gives rise to a fixed performance standard scheme $r^i(\cdot) = b + \beta(s - x^i)$ that can satisfy the bankruptcy constraint. For instance, if s is set equal to a value around the average outcome in the range of possible outcomes [i.e., $(x_L + x_H)/2$], then a grower will receive less than b in the unfavorable case where he obtains x_H. If s is set equal to $x_H - (b/\beta)$, then, a grower will receive a zero payment when he or she obtains x_H. With a fixed performance standard, unlike with a tournament, the grower's payment is not fully immune from common uncertainty because s is predetermined. Finally, note that while the fixed performance standard must yield payments that are sufficiently low in unfavorable states to satisfy the bankruptcy constraint, the payments in favorable states where the constraint is nonbinding must be sufficiently high so that growers will participate *ex ante* and exert effort. Given that the optimum scheme is composed of equation (16) in favorable states and equation (17) in unfavorable states, the Taylor expansion to obtain a fixed performance standard scheme should depend on the range of states over which bankruptcy is binding, relative to the range over which it is not. If the range of unfavorable states is relatively larger, then the Taylor expansion should be obtained from the scheme in equation (17), while if the range of favorable states is relatively larger, then the expansion should be obtained from the scheme in equation (16). In either case, however, the parameters in the scheme must be adjusted to eliminate the possibility of bankruptcy while ensuring grower participation and provision of correct incentives.

Empirical Evidence

This section provides empirical evidence to support the theoretical predictions of the model for the broiler, turkey, and swine industries. Three pieces of evidence are especially important: the data on firm size, the data about the design of the compensation schemes, and the data on the price volatility of output. Assuming that common production uncertainty exists, two testable hypotheses can be formulated:

(*i*) If price volatility of output is relatively small, and the integrator firm has a sufficiently large liquidation value so that the bankruptcy constraint is nonbinding, then a two-part piece-rate tournament is approximately optimal.

(*ii*) If price volatility of output is relatively large, and the integrator firm has a sufficiently small liquidation value so that the bankruptcy constraint is binding in unfa-

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vorable states, then a fixed performance standard scheme is approximately optimal.

Let us start with the firm size. A 1996 survey of broiler companies conducted by the Broiler Industry (Thornton) lists forty-eight companies, which account for virtually the entire U.S. broiler output. The top fifteen companies jointly control 77% of the total industry production. There are eight companies whose estimated annual sales in 1996 were larger then half a billion dollars. The largest broiler company is Tyson, controlling close to 22% of the entire market with estimated annual sales of about 4 billion dollars.

A 1996 survey of leading turkey companies conducted by *Turkey World* (Heffernan) shows that twenty-seven companies processed 6.9 billion pounds of live turkeys in 1996. Comparing the estimated annual sales between the turkey and broiler industries reveals that the leading turkey companies are smaller than their counterparts in the broiler industry. The largest turkey company (Butterball) controls only about 13% of the market and, with its annual sales of $600 million, would fit between seventh and eighth place on the broiler industry list.

In its exclusive report on the pork powerhouses, *Successful Farming* (Freese) presented a list of the top forty-three swine operations owning more than 10,000 sows each. With their 1.74 million sows producing over 30 million pigs, these firms capture one-third of the U.S. hog market. Comparing the sizes of firms in the three industries, measured by the estimated annual sales, indicates that hog companies are smaller then their turkey and, notably, broiler counterparts. The top fifteen hog companies jointly control only about 25% of the total market. The largest hog producer in the United States is Murphy Family Farms, controlling only about 5% of the U.S. market. Between second and eighth place is a group of firms with estimated annual sales in the $200–$250 million range. Compared to the size of broiler firms, these hog producers would not enter the top fifteen broiler list.[12]

To find out what type of remuneration schemes the companies use, an industry survey was conducted. Using the names and addresses of companies from the above-mentioned trade magazine lists, we surveyed forty-eight broiler companies, twenty-seven turkey companies, and forty-three swine companies, for a total of 118 firms. The response rate was reasonably high and we were able to assemble a data set with forty-six observations. The data set contains nineteen broiler companies, ten turkey companies and seventeen swine companies. Seventeen broiler companies, six turkey companies, and only two swine companies use tournaments as the way of settling contracts with their growers. The remaining two broiler companies use fixed performance standards. Two turkey companies use fixed performance standards, one uses the bracketed scheme, and one company does not contract production with independent growers but grows turkeys on company-owned farms instead. The swine industry presents the most diverse group. Except for two firms that use tournaments, most companies, nine of them, use fixed performance standards, one uses a fixed payment per pound, one uses the bracketed scheme, one pays a fixed rent per square foot of the house, and three companies are growing pigs on company-owned farms.[13]

Finally, to measure the output price volatility, we constructed a time series of monthly observations for the period from January 1978 to December 1996 of the wholesale prices for broilers, turkey hens, and hogs from the USDA data set. The price series starts with 1978, which marks the beginning of contract production in the North Carolina hog industry. The coefficients of variation are 11.8, 12.7, and 15.6, respectively, indicating the highest price volatility in hogs and the smallest in broilers.

The focus of the empirical analysis is testing whether our model correctly predicts the occurrence of tournaments in livestock production contracts as a scheme for settling these contracts. In particular, we are interested in testing whether the contributions of the relevant explanatory variables, notably the firm size and the volatility of output price, exert an influence on the probability of observing tournaments that is conformable with the predictions of the theoretical model. To test this, several binary choice models were estimated. Lacking the data on the firms's liquidation values, the size of the company was approximated by either its estimated annual sales or

[12] In all three industries, annual sales were estimated by multiplying their annual production by an average annual wholesale price. The annual production in the swine industry was estimated by assuming eighteen pigs per sow per year and an average weight of 250 pounds per pig.

[13] The survey instrument and the entire data set is available from the authors upon request.

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Table 1. Binary Choice Model Estimation Results for the Prediction of Tournaments

Variable Name	Coefficient	T-ratio	Weighted Aggregate Elasticity
Probit: Model 1			
Price volatility	−83.749	−4.0921	−3.7472
Market share	0.35129	2.1865	0.2099
Constant	10.376	3.9513	3.5938
Likelihood ratio test	31.574	with 2 d.f.	
Probit: Model 2			
Price volatility	−80.879	−3.6849	−3.5180
Annual sales	0.005462	2.3399	0.26288
Constant	9.8204	3.4334	3.2531
Likelihood ratio test	33.2427	with 2 d.f.	
Logit: Model 1			
Price volatility	−143.79	−3.6550	−3.5893
Market share	0.62813	2.1065	0.2168
Constant	17.703	3.5820	3.4343
Likelihood ratio test	31.4507	with 2 d.f.	
Logit: Model 2			
Price volatility	−141.52	−3.3360	−3.4656
Annual sales	0.009792	2.1687	0.27024
Constant	17.097	3.1534	3.1951
Likelihood ratio test	33.262	with 2 d.f.	

its market share. Both probit and logit model results are presented in table 1.

The results are fairly similar across models. All estimated coefficients are significant and have the expected signs. The impact of output price volatility is negative; that is, an increase in the volatility of output price reduces the probability of observing tournaments. The impact of either market share or annual sales is positive, meaning that an increase in the company size increases the probability of observing tournaments. The relative magnitudes of the weighted aggregate elasticities indicate that the output price volatility is a relatively more important factor in selecting tournaments as a means of settling contracts than the firm size. For example, in the logit model 2, an increase in the price volatility of output by 1% reduces the probability of observing the tournament by 3.5%, whereas an increase in annual sales by 1% increases the probability of observing tournaments by 0.27%. Overall, the results support the hypotheses derived in the theoretical part of the article.

Conclusions

The article analyzes the optimal form of contracts between a risk-neutral integrator and many risk-averse growers, when bankruptcy due to price volatility is possible. Contracts specify a division of responsibility for providing inputs and remuneration schemes. Since the feed is provided by the integrator, but feed utilization depends on the effort exerted by the growers, optimal remuneration schemes must provide incentives for growers to exert effort. The integrator's inability to freely monitor the growers' efforts hinders his or her ability to provide insurance. However, some form of insurance could be provided against production uncertainties that are shared by all growers if the integrator could extract information about them. This information extraction could be implemented by a tournament linking the performance of any grower directly to the performance of the rest of the growers.

The analysis shows that if bankruptcy is not an issue, a two-part piece-rate tournament can approximate the optimum. By contrast, in the presence of large output price volatility, a two-part piece-rate tournament could lead to bankruptcy in unfavorable states of nature. In the latter case integrators can resort to fixed performance standards. The empirical results provide supporting evidence. Tests of the contributions of output price volatility and firm

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size on the probability of observing tournaments conformed with the predictions of the theoretical model. The smaller the output price volatility and the larger the firm, the more likely it is that livestock companies will select tournaments as a means of settling contracts with their growers. By incorporating the implications of bankruptcy, this article provides a solution to the puzzle of the simultaneous presence of distinct contract forms in similarly organized industries.

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