Structural Estimation of Rank-Order Tournament Games with Private Information

Tomislav Vukina and Xiaoyong Zheng

In this article we propose and solve a game-theoretic model of a rank-order tournament with private information. Using the contract settlement data from a poultry company, we estimate a fully structural model of a symmetric Nash equilibrium of this game. We show that growers' equilibrium effort depends on four factors: the spread in piece rates between the performance brackets, the number of players in each tournament, the number of performance brackets used, and the density of growers' private shocks. We use estimates to simulate how changes in the tournament characteristics affecting equilibrium effort impact the growers' and the integrator's welfare.

Key words: private information, production contracts, rank-order tournaments, structural estimation

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In most sporting events, prizes are awarded not on basis of absolute performance but based on relative performance, or tournaments. Besides sporting events, tournaments are also frequently used in labor contracts. The name "tournament" typically suggests a rank-order (ordinal) scheme such as is considered by Lazear and Rosen (1981), whereas a broader definition applies to any compensation scheme based on relative performance (e.g., Nalebuff and Stiglitz 1983; Tsoulouhas and Vukina 1999). Despite the sizeable theoretical literature on tournaments, empirical work related to these models remains rather limited. Most of the theoretical literature on tournaments (see McLaughlin 1988 for a survey) has been concerned primarily with the comparison of tournaments against various independent reward structures under various assumptions about risk preferences, the number of participants and prizes, specifications of production shocks, and the asymmetry of information. Previous empirical work has largely focused on testing the predictions of the theoretical models. This includes articles on executive compensation (e.g., Main, O'Reilly and Wade 1993; Ericksson 1999; Gibbons and Murphy 1990), professional sports (e.g., Ehrenberg and Bognanno 1990; Bronars and Oettinger 2001) and broiler production contracts (Knoeber and Thurman 1994; Levy and Vukina 2004; Leegomonchai and Vukina 2005).

Empirical articles on tournaments are all done with data sets from industries where performance measures for individual tournament contestants are available. In principle, this data feature enables researchers to measure the effects of changes in the incentive structure on the individual performances of tournament participants, even if the data set per se contains no incentive regime changes. This can be accomplished by using a structural econometrics approach where researchers estimate only the model primitives, such as densities of random shocks or parameters of the agents' utility or cost functions, which cannot be influenced by the quantitative or qualitative changes in the incentive structure. Somehow, this type of work has not been done for tournament-style labor contracts, but has been done in the context of individualized labor contracts. A good example is an article by Paarsch and Shearer (2000) who estimated a structural model with moral hazard in the context of tree-planting labor contracts and found that incentives caused a 22.6% increase in productivity, only a part of which represented valuable output because workers responded to incentives by reducing the quality of their work.

This article focuses on rank-order tournaments used to settle broiler production tournaments. The modern broiler industry in the United States represents a completely vertically integrated chain involving the production

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of hatching eggs, hatcheries, production of broilers, as well as slaughtering and further processing. The production of broilers is almost entirely organized via production contracts between firms, called integrators, and independent producers, most of them being small family farmers. At some point in the evolution of the contract design, the industry started using feed conversion or production cost tournaments. Some of those early tournaments were based on ordinal rankings of growers, whereas most modern contracts seem to be predominantly settled using cardinal tournaments where an individual grower's bonus or penalty depends on the distance between her performance and the group average performance.

In this article we propose a new game-theoretic model of a rank-order tournament with private information and characterize its equilibrium. Our model modifies the original Lazear and Rosen (1981) and Green and Stockey (1983) rank-order tournament models to capture the most important features of production contracts observed in the broiler industry. Using the data set of Knoeber and Thurman (1994), we estimate a fully structural model of a symmetric Nash equilibrium of this game. We show that growers' equilibrium effort depends on four factors: the spread in piece rates between the performance brackets, the number of players in each tournament, the number of performance brackets used, and the density of growers' private information. We use estimates of productivity shocks density to simulate how changes in the tournament characteristics that affect equilibrium effort impact total welfare and the distribution of welfare between the growers and the integrator. Considering the typical industry performance measures (cost of production, feed conversion) all obtained results look very reasonable.

Broiler Industry

The broiler industry represents an entirely vertically integrated chain, including all stages from breeding flocks, hatcheries and grow-out to feed mills, transportation divisions, and processing plants. The production of live birds is organized almost entirely through contracts with independent growers. Modern poultry production contracts are agreements between an integrator company and farmers (growers) that bind farmers to tend for the company's birds until they reach market weight in exchange for monetary compensation. Poultry contracts have two main components: the division of responsibility for providing inputs and the method used to determine grower compensation. Growers provide land and housing facilities, utilities (electricity and water), and labor. Operating expenses such as repairs and maintenance, clean up cost, manure, and mortality disposal are also the responsibility of the grower. An integrator provides animals to be grown to processing weight, feed, medications, and the services of field personnel and makes decisions about the frequency of flock rotations on any given farm. Most integrators nowadays require that houses be built according to strict specifications regarding construction and equipment.

Extensive but incomplete empirical evidence suggests that most broiler contracts are nowadays settled using a two-part cardinal tournament scheme consisting of a fixed base payment per pound of live meat produced and a variable bonus payment based on the grower's relative performance. However, some of the earlier broiler contracts used rank-order tournaments to compensate their growers. In our data set, growers that competed in the same tournament were ranked by performance from the smallest settlement cost (best performance) to the largest settlement cost, and this ranking was then divided into quartiles. The settlement cost was determined as the sum of two production input costs, that is, the number of chicks placed multiplied by 12 cents and the total feed intake (in kilocalories) multiplied by 6 cents, divided by the total live weight (in pounds) of birds produced. Growers received an incremental per pound compensation of 0.3 cents per pound of live weight as they moved to the next higher (lower cost per unit of output) quartile.

The data set includes production information for seventy-five contract growers that produced broilers from November 30, 1981 until December 17, 1985. For the period between November 1981 and June 1984 the minimum pay for growers ranked in the bottom quartile was 2.6 cents per pound, with the exception of late 1981 and early 1982 when the base payment was temporarily lowered and ranged from 1.98 cents to 2.45 cents per pound. The incremental pay for performance in higher quartiles remained 0.3 cents over the entire period through June 1984, when the contract form switched from the rank-order tournament to a cardinal tournament. Due to the infeasibility of figuring out which growers belong to which cardinal tournaments, this part of the data set (June 1984–December 1985) was not usable for the purposes of our article. The problem of exactly determining which growers belong to which tournament was present in the rank-order tournament part of the data set as well. However, this difficulty is considerably mitigated by the fact that the scheme uses quartiles; so it is only natural to believe that the number of participants has to be a multiple of four. Since, according to Knoeber and Thurman (1994), the tournaments were formed by putting together growers whose flocks were harvested within approximately ten-day periods, the obvious number of participants in each tournament turned out to be eight.[1]

In total, we have ninety-three tournaments and 744 observations. The variable *settlement* denotes the monetary value of inputs used (in cents) to grow a chick with the target weight. On average, the per chick settlement costs for the growers in the data is 20.94 cents, with a standard deviation of 0.71 and a range from 17.19 cents to 25.42 cents.[2] The variation in settlement costs is mainly caused by weather, fluctuations in quality of inputs supplied by the integrator (chicks and feed), and growers' idiosyncrasies.

Rank-Order Tournament with Private Information

We model the integrator–grower relationship in the principal–agent framework. The effort exerted by the grower is not perfectly observable by the integrator, who therefore faces a moral hazard problem in the delegation of production tasks. The incentives to the agents to behave according to the principal's objective are provided through a payment scheme based on a rank-order tournament. The contestants in the tournament are competing to produce certain target weight chickens at the smallest possible cost to the principal. For simplicity we assume that each grower i ($i = 1, 2, \ldots, N$) is given one baby broiler chick that she is supposed to tend until the chick reaches the weight of M pounds.[3] Upon reaching the target weight, the mature broiler is harvested and transported to the processing plant. The processed broilers are sold and after paying the growers for their services and covering the costs of feed and chicks, the integrator becomes the residual claimant on the realized profits.

The grower performance in the tournament critically depends on the quantity of feed, measured in calories, she utilized to grow the chick to the target weight. We assume that observable and verifiable feed utilization depends on the unobservable grower effort $e_i > 0$ as

$$(1) \qquad w = \underline{w} + \frac{\bar{w} - \underline{w}}{1 + \theta_i \eta e_i}$$

where θ_i represents the private productivity shock that grower i observes prior to exerting effort (e.g., after observing the chick quality) and η represents the common productivity shock that materializes slowly during the production process (e.g., temperature and humidity common to all growers in the same tournament). Each grower's private productivity shock is assumed to be drawn from a distribution $G(\cdot)$ with support $[\underline{\theta}, \bar{\theta}]$, where $\bar{\theta}$ can either be a finite number or infinity, and $\underline{\theta} \geq 0$. $G(\cdot)$ is twice continuously differentiable and has a density $g(\cdot)$ that is strictly positive on the support. When choosing how much effort to exert, each grower knows her own private productivity shock, but she does not know the private productivity shocks of other growers in the same tournament. Each grower only knows that all the private productivity shocks are independently drawn from $G(\cdot)$, which is common knowledge to all growers. Furthermore, the common productivity shock η is assumed to be drawn from a distribution $F(\cdot)$ with support $[\underline{\eta}, \bar{\eta}]$, where $\bar{\eta}$ can either be a finite number or infinity, and $\underline{\eta} \geq 0. F(\cdot)$ is twice continuously differentiable and has a density $F(\cdot)$ that is strictly positive on the support. Each grower only learns η after the grow-out process is complete but it is common knowledge that the common shock is drawn from $F(\cdot)$. As a result, all growers are *ex ante* identical and the game is symmetric.[4]

This specification implies that if the grower exerts 0 effort, then the feed intake will be $\bar{w}$ calories, which represents the upper bound determined by the prevailing technology (nutrition, genetics, and housing design). By exerting

[1] Having twelve growers in each tournament would extend the difference between the harvest dates for the first flock and the 12th flock in the same tournament to fifteen to twenty days. Given that tournaments' main purpose is to filter away the common production shock, the time period in which contestants compete has to be sufficiently short such that all of them are exposed to similar random influences.

[2] Notice, that prices entering the settlement cost formula is not market prices but rather fixed weights. Therefore they are the same for all growers and all tournaments and hence this comparison of grower performance is fair since the payment scheme insulates them from market price volatilities.

[3] Assuming constant returns to scale production technology and the absence of mortality, this assumption is entirely innocuous.

[4] However, *ex post*, growers represent a heterogeneous group, since their equilibrium efforts which are the function of received shocks could be different.

effort, the grower can decrease feed consumption, which also depends on the total productivity shock $\theta_i\eta$. The higher the shock, the more efficient becomes her effort. In the limit, when the grower exerts large effort and her productivity shock is very high, she can reduce the feed intake to $\underline{w}$ calories, the lower bound determined by the current technology.[5]

Ultimately, the grower i's rank in any given tournament will be determined by the *settlement cost*

$$(2) \qquad f_i = \frac{J + K\left(\underline{w} + \frac{\bar{w} - \underline{w}}{1 + \theta_i \eta e_i}\right)}{M}$$

which measures a dollar value of inputs a grower has used per pound of live chicken weight produced. Each baby chick is valued at J cents and each calorie of feed is valued at K cents. The grower payment is determined as

$$(3) \qquad \begin{aligned} R_i &= A_1 M \text{ if } f_i \text{ (the performance measure) is in the lowest quartile} \\ &= A_2 M \text{ if } f_i \text{ is in the second lowest quartile} \\ &= A_3 M \text{ if } f_i \text{ is in the third lowest quartile} \\ &= A_4 M \text{ if } f_i \text{ is in the highest quartile} \end{aligned}$$

where A_1 is the per pound piece rate if the grower's performance is in the lowest quartile (the best performance category), and similarly for A_2, A_3, and A_4. Also, $A_1 > A_2 > A_3 > A_4$.[6]

Finally, we assume that growers are risk-neutral and that their cost of effort function is given by $C(e_i) = e_i$. Consequently, grower i's preferences over revenue R_i and effort are given by the profit function

$$(4) \qquad \pi_i = R_i - C(e_i).$$

Characterization of the Equilibrium

Given the performance measure $f_i = [J + K(\underline{w} + \frac{\bar{w} - \underline{w}}{1 + \theta_i \eta e_i})]/M$, grower i's performance measure f_i being in the lowest quartile is equivalent to the product of her effort level e_i and her private shock, $h_i = \theta_i e_i$, being in the highest quartile. Therefore, the payment schedule can be rewritten as

$$(5) \qquad \begin{aligned} R_i &= A_1 M \text{ if } h_i \text{ is in the highest quartile} \\ &= A_2 M \text{ if } h_i \text{ is in the second highest quartile} \\ &= A_3 M \text{ if } h_i \text{ is in the third highest quartile} \\ &= A_4 M \text{ if } h_i \text{ is in the lowest quartile.} \end{aligned}$$

Since the growers in the above game are *ex ante* homogenous, a symmetric equilibrium is a natural outcome. The optimal strategy $e_i^* = s(\theta_i)$ is based on each grower's maximizing her *ex ante* expected utility with respect to e_i given all other growers adopt the same strategy $e_j^* = s(\theta_j)$ for $j \neq i$. As a result, given θ_i, choosing an optimal effort strategy $e_i^* = s(\theta_i)$ is equivalent to choosing an optimal strategy $h_i^* = p(\theta_i) = \theta_i s(\theta_i) = \theta_i e_i^*$. With this setup, the objective function of grower i can be expressed as a function of the new choice variable h_i,

$$(6) \qquad \begin{aligned} E\pi_i &= \left(A_1 M - \frac{h_i}{\theta_i}\right) \Pr(h_i \text{ is in the highest quartile}) \\ &\quad + \left(A_2 M - \frac{h_i}{\theta_i}\right) \Pr(h_i \text{ is in the second highest quartile}) \\ &\quad + \left(A_3 M - \frac{h_i}{\theta_i}\right) \Pr(h_i \text{ is in the third highest quartile}) \\ &\quad + \left(A_4 M - \frac{h_i}{\theta_i}\right) \begin{bmatrix} 1 - \Pr(h_i \text{ is in the highest quartile}) \\ - \Pr(h_i \text{ is in the second highest quartile}) \\ - \Pr(h_i \text{ is in the third highest quartile}) \end{bmatrix} \\ &= (A_1 - A_4) M \Pr(h_i \text{ is in the highest quartile}) \\ &\quad + (A_2 - A_4) M \Pr(h_i \text{ is in the second highest quartile}) \\ &\quad + (A_3 - A_4) M \Pr(h_i \text{ is in the third highest quartile}) \\ &\quad + A_4 M - \frac{h_i}{\theta_i} \end{aligned}$$

[5] Notice that animal husbandry is characterized by animals eating *ad libidum* (at will), that is, the feed is always there for them to eat. So, even if the grower does absolutely nothing, the birds will still eat and grow, although the total feed utilization will be higher relative to the situation where the grower did everything possible to create the chicken house environment conducive to efficient metabolism.

[6] Notice that the payment scheme in this contract is different from Lazear and Rosen (1981) and Green and Stocky (1983). In their models, A_1 represents the total payment for the best category, whereas here A_1 is just the piece rate.

where we used the relationship $e_i = \frac{h_i}{\theta_i}$. Now we can state the following result.

PROPOSITION 1. *Any symmetric pure-strategy Bayesian Nash equilibrium $h_i^* = p(\theta_i)$ $(i = 1, 2, \ldots, N)$ of this rank-order tournament game is strictly increasing.*

Proof. Since $h = p(\theta) = \theta s(\theta)$ is a function of θ, and since θ is a random variable, h is also a random variable with its own distribution. Here, we do not impose any condition on the relationship between θ and $e = s(\theta)$, that is, $e = s(\theta)$ can either be a nonmonotone or a monotone function of θ. Now, let h_1 denote the highest-order statistic of h outside the highest quartile with distribution $G_1^h(\cdot)$, h_2 the highest-order statistic of h outside the top two quartiles with distribution $G_2^h(\cdot)$, and h_3 the highest-order statistic of h in the lowest quartile (outside the top three quartiles) with distribution $G_3^h(\cdot)$. With this notation, grower ith expected profit (6) can be rewritten

$$(7)\quad \begin{aligned} E\pi_i &= (A_1 - A_4)M \Pr(h_1 \le h_i) \\ &\quad + (A_2 - A_4)M \Pr(h_2 \le h_i) \\ &\quad + (A_3 - A_4)M \Pr(h_3 \le h_i) \\ &\quad + A_4 M - \tfrac{h_i}{\theta_i} \\ &= (A_1 - A_4)MG_1^h(h_i) \\ &\quad + (A_2 - A_4)MG_2^h(h_i) \\ &\quad + (A_3 - A_4)MG_3^h(h_i) + A_4 M - \tfrac{h_i}{\theta_i}. \end{aligned}$$

By definition, in equilibrium, given that other players play the strategy $h_j = p(\theta_j)$ $\forall j \ne i$, a grower with shock θ_i prefers $h_i = p(\theta_i)$ to $h_i' = p(\theta_i')$ where θ_i' is any shock such that $\theta_i' < \theta_i$. At the same time, a grower with shock θ_i' prefers $h_i' = p(\theta_i')$ to $h_i = p(\theta_i)$. Thus, we have,

(8)

$$\begin{aligned} &(A_1 - A_4)MG_1^h(h_i) + (A_2 - A_4)MG_2^h(h_i) \\ &\quad + (A_3 - A_4)MG_3^h(h_i) + A_4 M - \frac{h_i}{\theta_i} \\ &\ge (A_1 - A_4)MG_1^h(h_i') + (A_2 - A_4)MG_2^h(h_i') \\ &\quad + (A_3 - A_4)MG_3^h(h_i') + A_4 M - \frac{h_i'}{\theta_i} \end{aligned}$$

and

(9)

$$\begin{aligned} &(A_1 - A_4)MG_1^h(h_i') + (A_2 - A_4)MG_2^h(h_i') \\ &\quad + (A_3 - A_4)MG_3^h(h_i') + A_4 M - \frac{h_i'}{\theta_i'} \\ &\ge (A_1 - A_4)MG_1^h(h_i) + (A_2 - A_4)MG_2^h(h_i) \\ &\quad + (A_3 - A_4)MG_3^h(h_i) + A_4 M - \frac{h_i}{\theta_i'}. \end{aligned}$$

Subtracting: $LHS(8) - RHS(9)$ and $RHS(8) - LHS(9)$ yields,

$$(10)\quad \frac{h_i}{\theta_i'} - \frac{h_i}{\theta_i} \ge \frac{h_i'}{\theta_i'} - \frac{h_i'}{\theta_i}.$$

Rearranging gives

$$(11)\quad (h_i - h_i')\Big(\frac{1}{\theta_i'} - \frac{1}{\theta_i}\Big) \ge 0.$$

Since $\theta_i - \theta_i' > 0$, we must have $h_i \ge h_i'$.

To complete the proof, we still need to show that in equilibrium, $h_i \ne h_i'$. This can be done by showing that the opposite, i.e., $h_i = h_i'$, cannot be an equilibrium. If $h_i = h_i'$ then it would imply that $h_i = p(\theta_i) = z \ge 0$ is constant for any $\theta_i' < \theta_i$. In particular, it would imply that $p(\theta_i) = p(\underline{\theta})$ where $\underline{\theta}$ is the lower support of the density of θ. Since the game is symmetric and all the growers play the same strategy $p(\cdot)$, this further implies that this equilibrium has the feature that $h_i = z$ for all growers, no matter what kind of shocks they receive. In such a situation, a grower with private shock θ_i will always gain by playing $h_i = z + \varepsilon$ (where ε is a small positive number) instead of $h_i = z$. Because all other growers play the equilibrium strategy $h_j = z\, \forall j \ne i$, the grower with θ_i has equal probability to be placed into any of the four quartiles in terms of performance if she plays the strategy $h_i = z$, and her expected profit by playing the equilibrium strategy will be $\frac{(A_1 + A_2 + A_3 + A_4)}{4}M - \frac{z}{\theta_i}$. However, if she plays the strategy $h_i = z + \varepsilon$, she will end up in the top quartile and her expected profit will be $A_1 M - \frac{z+\varepsilon}{\theta_i}$. As long as $A_1 M - \frac{z+\varepsilon}{\theta_i} > \frac{(A_1 + A_2 + A_3 + A_4)}{4}M - \frac{z}{\theta_i}$, she has incentives to deviate from the equilibrium. Therefore, in equilibrium, if $\theta_i > \theta_i'$, then $h_i > h_i'$. ■

As one can see from equation (6), the key elements of the *ex ante* profit function are the probabilities that a grower's h_i would fall into each of the four quartiles. Since Proposition 1 implies that $h_i = p(\theta_i)$ increases in θ_i for all i, these probabilities can be expressed in terms of the distribution of θ_i. For example,

$$(12) \quad \begin{aligned} &\Pr(h_i \text{ is in the highest quartile}) \\ &= \Pr(h_i \geq h_1) \\ &= \Pr(h_i \geq p(\theta_1)) \\ &= \Pr\left(p^{-1}(h_i) \geq \theta_1\right) \\ &= G_{\theta_1}\left(p^{-1}(h_i)\right) \end{aligned}$$

where θ_1 is the highest realization of the private productivity shock outside the best category and $G_{\theta_1}(\cdot)$ is the cumulative distribution function for θ_1. Also, $p^{-1}(\cdot)$ denotes the inverse function of $p(\cdot)$ and $h_1 = p(\theta_1)$ is the equilibrium level of h for a grower with private productivity shock θ_1. As an illustrating example, in our application, the number of growers in one tournament is eight, with two growers in each category. Therefore, from grower i's point of view, there are seven other competitors and in order for her to be in the best category, her shock must be higher than second-highest shock out of seven shocks of her competitors. In this case, θ_1 is the second-highest order statistic among seven realizations from the distribution $G(\cdot)$. Following David (1981), $G_{\theta_1}(\theta_i)$ can be written as

$$(13) \quad G_{\theta_1}(\theta_i) = \sum_{j=6}^{7} \binom{7}{j} G(\theta_i)^j (1 - G(\theta_i))^{7-j}.$$

The intuition behind equation (13) is the following. $G_{\theta_1}(\theta_i)$, the probability that θ_1 is less than or equal to θ_i can be obtained by considering two events. The first event is that all seven realizations from the distribution $G(\cdot)$ are less than or equal to θ_i. The probability of this event is $\binom{7}{7} G(\theta_i)^7 (1 - G(\theta_i))^0$. The second event is that one realization (i.e., the highest-order statistic) among the seven realizations from the distribution $G(\cdot)$ is greater than θ_i and other realizations are less than or equal to θ_i. The probability of the second event is $\binom{7}{6} G(\theta_i)^6 (1 - G(\theta_i))^1$ since there are $\binom{7}{6}$ possible combinations for six out of the seven realizations to be less than or equal to θ_i. The density $g_{\theta_1}(\theta_i)$ of equation (13) can be obtained easily by differentiation.

Similarly,

$$(14) \quad \begin{aligned} &\Pr(h_i \text{ is in the second highest quartile}) \\ &= \Pr(p(\theta_1) \geq h_i \geq p(\theta_2)) \\ &= G_{\theta_2}\left(p^{-1}(h_i)\right) - G_{\theta_1,\theta_2}\left(p^{-1}(h_i), p^{-1}(h_i)\right) \\ &= G_{\theta_2}\left(p^{-1}(h_i)\right) - G_{\theta_1}\left(p^{-1}(h_i)\right) \end{aligned}$$

where θ_2 is the highest realization of the private productivity shock outside the first two best categories, $G_{\theta_2}(\cdot)$ is the cumulative distribution function for θ_2 and $G_{\theta_1,\theta_2}(\cdot,\cdot)$ is the joint distribution for θ_1 and θ_2. And the last equality comes from the fact that $\theta_1 \geq \theta_2$ by the definition, which leads to

$$(15) \quad \begin{aligned} G_{\theta_1,\theta_2}(\theta_i, \theta_i) &= \Pr(\theta_1 \leq \theta_i, \theta_2 \leq \theta_i) \\ &= \Pr(\theta_1 \leq \theta_i) = G_{\theta_1}(\theta_i). \end{aligned}$$

With the setup, the grower's *ex ante* expected profit can be rewritten as

$$(16) \quad \begin{aligned} E\pi_i = &\left(A_1 M - \frac{h_i}{\theta_i}\right) G_{\theta_1}\left(p^{-1}(h_i)\right) \\ &+ \left(A_2 M - \frac{h_i}{\theta_i}\right)\left[G_{\theta_2}\left(p^{-1}(h_i)\right) - G_{\theta_1}\left(p^{-1}(h_i)\right)\right] \\ &+ \left(A_3 M - \frac{h_i}{\theta_i}\right)\left[G_{\theta_3}\left(p^{-1}(h_i)\right) - G_{\theta_2}\left(p^{-1}(h_i)\right)\right] \\ &+ \left(A_4 M - \frac{h_i}{\theta_i}\right)\left[1 - G_{\theta_3}\left(p^{-1}(h_i)\right)\right] \end{aligned}$$

and the first-order condition with respect to h_i is

$$(17) \quad \begin{aligned} &-\frac{1}{\theta_i} + \left(A_1 M - \frac{h_i}{\theta_i}\right) g_{\theta_1}\left(p^{-1}(h_i)\right) \frac{1}{\frac{\partial p(p^{-1}(h_i))}{\partial p^{-1}(h_i)}} \\ &+ \left(A_2 M - \frac{h_i}{\theta_i}\right)\left[g_{\theta_2}\left(p^{-1}(h_i)\right) - g_{\theta_1}\left(p^{-1}(h_i)\right)\right] \frac{1}{\frac{\partial p\left(p^{-1}(h_i)\right)}{\partial p^{-1}(h_i)}} \\ &+ (A_3 M - \frac{h_i}{\theta_i})\left[g_{\theta_3}\left(p^{-1}(h_i)\right) - g_{\theta_2}\left(p^{-1}(h_i)\right)\right] \frac{1}{\frac{\partial p\left(p^{-1}(h_i)\right)}{\partial p^{-1}(h_i)}} \\ &+ \left(A_4 M - \frac{h_i}{\theta_i}\right)\left[-g_{\theta_3}\left(p^{-1}(h_i)\right)\right] \frac{1}{\frac{\partial p(p^{-1}(h_i))}{\partial p^{-1}(h_i)}} \\ &= 0 \end{aligned}$$

where g_{θ_1}, g_{θ_2}, and g_{θ_3} are densities corresponding to G_{θ_1}, G_{θ_2}, and G_{θ_3}. Using the fact that

$\theta_i = p^{-1}(h_i)$ and rearranging, the first-order condition (17) can be rewritten as

$$\text{(18)} \quad \frac{\partial p(\theta_i)}{\partial \theta_i} = M[(A_1 - A_2)g_{\theta_1}(\theta_i) + (A_2 - A_3)g_{\theta_2}(\theta_i) + (A_3 - A_4)g_{\theta_3}(\theta_i)]\theta_i.$$

Replacing $\frac{h_i}{\theta_i}$ with e_i and $h_i = \theta_i e_i$ in the objective function (16) and maximizing the objective function with respect to e_i will give exactly the same first-order condition as in equation (18). This verifies the fact that choosing the optimal effort strategy e_i^* is equivalent to choosing the optimal strategy for h_i^*. Now, integrating equation (18) back, we get the unique solution of the following form:

$$\text{(19)} \quad h_i^* = p(\theta_i) = M\int_{\underline{\theta}}^{\theta_i} [(A_1 - A_2)g_{\theta_1}(x) + (A_2 - A_3)g_{\theta_2}(x) + (A_3 - A_4)g_{\theta_3}(x)]\, x\, dx$$

with the boundary condition $p(\underline{\theta}) = 0$.[7]

The corresponding optimal effort is given by

$$\text{(20)} \quad e_i^* = s(\theta_i) = \frac{h_i^*}{\theta_i} = \frac{M\int_{\underline{\theta}}^{\theta_i}[(A_1 - A_2)g_{\theta_1}(x) + (A_2 - A_3)g_{\theta_2}(x) + (A_3 - A_4)g_{\theta_3}(x)]\, x\, dx}{\theta_i}.$$

As seen from equation (20) the equilibrium level of effort depends on four factors: the spread in piece rates between the performance brackets, the number of players in each tournament, the number of performance brackets used, and the density of growers' private shocks. Finally, $e_i^* = s(\theta_i)$ is a nonmonotone function of θ_i. This sign of $\frac{\partial s(\theta_i)}{\partial \theta_i}$ depends on the value of θ_i as well as other parameters in $s(\theta_i)$. In cases where the comparative statics results cannot be evaluated analytically, we use the estimates of the productivity shocks density to simulate how changes in the tournament characteristics affecting equilibrium effort impact the growers' and the integrator's welfare.

[7] When $(A_1 - A_2) = (A_2 - A_3) = (A_3 - A_4)$ as is the case in the rank-order tournament that generated our data, then $h_i^* = M(A_1 - A_2)\int_{\underline{\theta}}^{\theta_i}[g_{\theta_1}(x) + g_{\theta_2}(x) + g_{\theta_3}(x)]x\, dx$.

Structural Econometric Framework and Estimation

The purpose of the structural estimation is to recover the model primitives, in this case the distribution of the private productivity shock, $G(\cdot)$, which determines the equilibrium level of h^* from equation (19) and the equilibrium level of grower effort from equation (20). As is standard in this type of econometric analyses, the statistical inference is based on the assumption that the number of tournaments approaches infinity. In order to formulate the structural econometric model, notice that the performance measure in equation (2) can be rewritten as

$$\text{(21)} \quad h_{it}^* = \frac{y_{it}}{\eta_t} = \theta_{it} e^*(\theta_{it}) = p(\theta_{it})$$

where $y_{it} = \frac{\bar{w} - \underline{w}}{Mf_{it} - J - K\underline{w}} - 1$, and the subscript indicates grower i in tournament t. Taking expectations on both sides yields

$$\text{(22)} \quad E(h_{it}^*) = E[p(\theta_{it})].$$

As we do not observe θ_{it} directly, a simulated nonlinear least squares (SNLLS) estimation method naturally follows from the moment condition in equation (22). If we denote $\varphi = (\mu, \sigma^2)$ to be the parameter vector that characterizes $G(\cdot)$, then the SNLLS estimator can be defined as

$$\text{(23)} \quad \hat{\varphi} = \arg\min_{\varphi} \frac{1}{T}\sum_{t=1}^{T}\frac{1}{N_t}\sum_{i=1}^{N_t} \times \left[h_{it}^* - \frac{1}{S}\sum_{s=1}^{S} p_{it}\left(\theta_{it}^{(s)}\right)\right]^2,$$

where S is the number of simulations, $\theta_{it}^{(s)}$ ($s = 1, \ldots, S$) is the *sth* draw from the distribution $G(\cdot \mid \varphi)$, T is the number of tournaments in the data, and N_t is the number of growers in tournament t. Following Gourieroux and Monfort (1996), as both T and S tend to infinity and

$\frac{\sqrt{T}}{S}$ tends to 0, the asymptotic variance of the SNNLS estimator can be obtained as follows

(24)

$$\widehat{Avar}(\hat{\varphi}) = \left(\frac{1}{T}\sum_{t=1}^{T}\frac{1}{N_t}\sum_{i=1}^{N_t}\nabla_\varphi \hat{m}_{it}'\nabla_\varphi \hat{m}_{it}\right)^{-1} \times \left(\frac{1}{T}\sum_{t=1}^{T}\frac{1}{N_t}\sum_{i=1}^{N_t}\hat{u}_{it}^2\nabla_\varphi \hat{m}_{it}'\nabla_\varphi \hat{m}_{it}\right) \times \left(\frac{1}{T}\sum_{t=1}^{T}\frac{1}{N_t}\sum_{i=1}^{N_t}\nabla_\varphi \hat{m}_{it}'\nabla_\varphi \hat{m}_{it}\right)^{-1}$$

where $\hat{m}_{it} = \frac{1}{S}\sum_{s=1}^{S} p(\theta_{it}^{(s)})$, $\theta_{it}^{(s)}(s = 1, \ldots, S)$ is the s^{th} draw from the distribution $G(\cdot \mid \hat{\varphi})$, $\hat{u}_{it} = h_{it}^* - \hat{m}_{it}$, and $\nabla_\varphi \hat{m}_{it} = \frac{\partial \hat{m}_{it}}{\partial \varphi}$.

We parameterize the density of growers' productivity shocks as

(25)

$$g(\theta_{it} \mid \mu, \sigma) = \frac{1}{\sigma\theta_{it}\sqrt{2\pi}} \exp\left[-\frac{(\ln\theta_{it} - \mu)^2}{2\sigma^2}\right]$$

for $\theta_{it} \in (0, \infty)$. The log-normal distribution is convenient since it captures the fact that the productivity shocks must be positive as required by our theoretical model. The goal is to estimate the parameter vector $\varphi = (\mu, \sigma^2)$ from the data on individual contract settlements. Also, in order to obtain the dependent variable h_{it}^* used in the estimation, we estimate the common shock for each tournament as

$$(26) \qquad \hat{\eta}_t = \frac{1}{N_t}\sum_{i=1}^{N_t} y_{it}.$$

The mean of the common productivity shock in the data is 0.98 with the standard deviation 0.22, the minimum of 0.54, and the maximum of 2.34. Next, we perform the SNLLS estimation by setting the number of simulations S to 5,000.[8] The estimation results for the private productivity shock are summarized in table 1. The estimated log mean of the private productivity shock is −0.28 and the estimated log variance is 0.49. From the property of the log-normal distribution, this implies that the private productivity shock has the mean of 0.97 and the standard deviation of 0.77. These results indicate that the common productivity shock slightly dominates the private productivity shock in magnitude, but the private productivity shock has larger variance.

Table 1. Estimation Results for the Private Shock

Variable	Estimate	t-stat
μ	−0.28	−451.89
σ^2	0.49	3233.00

To assess how well our model fits the data, we simulated the private productivity shocks from its estimated log-normal distribution and then calculate the level of h^* according to the equilibrium function (19) and then obtain a simulated sample of h_{it}^*. The model fits the data reasonably well as the value of the simulated mean of h_{it}^* is 1.06, which differs from the actual mean of h_{it}^*, which is 1.0, by only 6%.

Welfare Evaluations

The main advantage of the structural econometrics approach is to allow the investigation of theoretically ambiguous results through counterfactual experiments. In situations when comparative statistics results cannot be evaluated analytically, one can use the estimates of the model primitives to simulate how changes in the tournament mechanism affect the total welfare and the distribution of welfare between the growers and the integrator.

Increasing the Piece Rate Spread

From equation (20) it is easy to see that the equilibrium effort depends only on the difference rather than the absolute value of the bonuses, which is the same result as in Lazear and Rosen (1981). As the spread goes up, growers exert more effort. The intuition behind this is straightforward. Increasing the spread of the bonuses makes the stake of the tournament larger and hence induces growers to exert more effort to try to win the tournament. The increased effort lowers the settlement costs (i.e., the cost of inputs the integrator needs to supply to growers in order for them to grow chickens to target weight) and the integrator benefits if the reduction in settlement costs outweighs the possible increase in aggregate grower payments. If we restrict our attention to those tournaments where the differences in piece rates across

[8] By setting $S = 10,000$ the estimates of μ and σ^2 changed less than 1%.

brackets are the same, as is the case in the data, the integrator always has a way to increase the spread and hence induce more effort from the growers without incurring any extra cost in terms of increased grower payment.[9] This can be seen by noting that in the rank-order tournament analyzed in this article, there are 4 performance brackets (quartiles) with two growers in each. Therefore, the total payment from the integrator to the growers can be written as $2(A_1 + A_2 + A_3 + A_4)M$. In tournaments where the differences in piece rates across brackets are equal, the total payments to growers can be written as $4(A_2 + A_3)M$. In this case, the integrator can change the spread $A_2 - A_3$ without changing the sum of the piece rates $A_2 + A_3$.

Changing the Number of Players

Unlike the change in piece rate spreads where the direction of welfare change was theoretically discernible from the model, changing the number of contestants in a given tournament produces theoretically ambiguous welfare results. Intuitively, when the number of players in a tournament increases, there are two opposite effects on growers' incentives to exert effort. First, as the number of growers increases, holding the number of performance brackets constant, each bracket will have more players. Therefore, the number of slots in the best brackets increases, but at the same time, the number of competitors who compete for those slots also increases. As a result, it is not clear whether the chance for a given grower to be in the top performance bracket increases or decreases, but the overall effect of changing the number of players while holding the number of brackets constant is likely to be very small.

We run the counterfactual experiment for every tournament in the data set and then report the average results across tournaments. The counterfactual simulation consists of two types of variations, one directly from the simulation and the other indirectly from the parameter estimates. We can capture the variation in the simulation error by repeating the simulation a sufficiently large number of times. The variation resulting from the errors in the parameter estimates can be accounted for by bootstrapping. For each set of the parameter estimates from the bootstrap, we carry out the simulation. Thus, we collect the bootstrap sample of simulation results that incorporate variations from both the simulation and the parameter estimates' errors. Each reported statistic is the mean of the bootstrap sample, and its standard error is the standard deviation of the bootstrap sample. All results are based on 1,000 bootstrap iterations.

For each tournament in each bootstrap simulation, we do the following. After simulating the private productivity shocks for eight growers in each tournament, we split them into two tournaments with four growers in each tournament (1 from each bracket in terms of performance). We then compute their new equilibrium efforts according to equation (20) by changing the number of growers from eight to four. Table 2 collects the results of the counterfactual experiment. Growers with good private shocks (top two brackets), gain from the decrease in the number of players and growers in the lower two brackets either experience no change in profit (third bracket) or lose (worst bracket). This can be explained intuitively in the following way. As the number of growers in the tournament decreases, the growers with good private shocks tend to exert less effort in equilibrium. This is because as they receive a good shock and face fewer competitors, it will be easier for them to place in the top brackets. For growers with bad shocks, the story is opposite. With bad shocks and fewer slots in the top brackets, they tend to work harder to try to avoid falling into the worst brackets. Since exerting effort is costly, growers with good shocks gain and growers with bad shocks lose with this structural change. Second, the integrator loses from this change with the total settlement costs increasing by about 0.29%.

Changing the Number of Brackets

Next, we investigate the welfare effects of changing the number of performance brackets, holding the piece rate spreads between adjacent brackets and other things constant. Intuitively, more brackets will widen the differences in pay between the highest bracket and the lowest bracket creating a positive effect on growers' incentives to exert effort. As the pay for the best bracket increases, growers with good shocks have more incentives to exert effort as they will try to win the biggest prize. Growers with bad shocks will also have incentives to exert more effort because the pay for the worst bracket decreases and they try

[9] Of course there are limits on the magnitude of the spread that the integrator can use. The limits are imposed by the production technology (1), as well as the agents' participation constraints (if the spread is too large some growers may not accept the contract).

Table 2. Welfare Effects of Changing the Number of Players

	8 Growers	4 Growers	Change (%)
Total settlement Cost (cents)	173.16 (0.7488)	173.66 (0.7015)	0.29 (0.0339)
Profit (cents) for grower:			
1 (best settlement)	12.00 (0.0297)	12.08 (0.0218)	0.70 (0.0701)
2	11.85 (0.0168)	11.98 (0.0124)	1.10 (0.0404)
3	10.78 (0.0216)	10.90 (0.0169)	1.16 (0.0456)
4	10.93 (0.0308)	11.02 (0.0242)	0.86 (0.0628)
5	10.01 (0.0361)	10.06 (0.0284)	0.50 (0.0787)
6	10.25 (0.0388)	10.25 (0.0310)	0.00 (0.0765)
7	9.39 (0.0337)	9.34 (0.0282)	−0.52 (0.0636)
8 (worst settlement)	9.65 (0.0249)	9.58 (0.0240)	−0.72 (0.0416)

Note: Results are based on 1,000 iterations of bootstrap and bootstrap standard errors are reported in the parentheses.

to avoid falling into the worst bracket. This change in incentives will definitely benefit the integrator. For growers, however, the outcome depends on how much effort they exert. Since exerting effort is costly, they can end up better off or worse off.

We run a similar counterfactual experiment as in the last subsection by increasing the number of brackets from four as in the data set to eight. In order to keep the final payments the growers get from the integrator unchanged, we set the pay for the lowest bracket to be $(b - 0.6)$ cents per pound of chicken produced (where b is the base piece rate in the data) and the pay for the highest performance bracket to be $(b + 1.5)$ cents, with the piece rate spread unchanged at 0.3 cents. The results presented in table 3 confirm what we expected. First, the growers exert more effort, which brings down the total settlement costs for the tournament from 173.16 cents to 161.47 cents, a 6.75% reduction, and benefits the integrator. On the growers' side, the cost of exerting additional effort outweighs the benefit for most of the growers. The profits for all growers except the grower with the best private shock decrease, and for those growers with bad shocks, the welfare loss is the biggest. This is because growers with bad productivity shocks are harmed twice. Once by the lower piece rate for worst brackets and again by the higher equilibrium effort they exert due to the change in incentives.

Next we examine which bracket structure works best for the integrator in terms of minimizing the settlement costs. The counterfactual experiment is designed by fixing the piece rate spread between brackets to 0.3 cents, the number of players to eight, and the total payment to growers in each tournament to be the same as in the data. Table 4 lists all the bracket structures that satisfy the above restrictions. Some of the bracket structures are symmetric like the two-bracket, four-bracket and eight-bracket structures, others are asymmetric (six-bracket). The results indicate that the total settlement costs monotonically decrease as the number of brackets increase, so the eight-bracket structure dominates. In light of this result it is interesting to consider why the integrator has not used an eight-bracket structure instead of a four-bracket structure. As with increasing the spread between brackets, the answer lies in the optimal contract design which requires the participation constraint of the agent to be *ex ante* satisfied, otherwise the agent will refuse the contract. Other reasons may have to with transaction costs of administering the contract, or some long run or implicit incentives not apparent in the data.

Changing the Density of Private Shocks

Finally, to see the dependence of the growers' equilibrium efforts on the underlying density

Table 3. Welfare Effects of Changing the Number of Brackets

	4 Brackets	8 Brackets	Change (%)
Total settlement cost (cents)	173.16 (0.7488)	161.47 (0.7899)	−6.75 (0.0856)
Profit (cents) for grower:			
1 (best settlement)	12.00 (0.0297)	12.80 (0.0509)	6.72 (0.1625)
2	11.85 (0.0168)	11.44 (0.0290)	−3.42 (0.1093)
3	10.78 (0.0216)	10.43 (0.0395)	−3.23 (0.1736)
4	10.93 (0.0308)	9.58 (0.0564)	−12.32 (0.2691)
5	10.01 (0.0361)	8.83 (0.0663)	−11.74 (0.3433)
6	10.25 (0.0388)	8.15 (0.0723)	−20.48 (0.4038)
7	9.39 (0.0337)	7.54 (0.0658)	−19.71 (0.4139)
8 (worst settlement)	9.65 (0.0249)	6.98 (0.0561)	−27.70 (0.3983)

Note: Results are based on 1,000 iterations of bootstrap and bootstrap standard errors are reported in the parentheses.

of the private shocks, we plot the equilibrium effort functions (20) by varying the log mean and log variance of the estimated private shock density. The solid line in figure 1 is the growers' equilibrium effort function with the estimated density; that is, $g(\cdot)$ is the log-normal density with log mean −0.28 and log variance 0.49. The dotted line is the case where the log mean of log-normal density is increased to −0.18 (the log variance is fixed at the estimated value of 0.49) and the dashed line is the case where the log variance of the log-normal density is decreased to 0.39 (the log mean is fixed at the estimated value of −0.28).

Several results are worth mentioning. First, it is clear that given the density, the equilibrium effort is a nonmonotone function of the private shock. As the private shock becomes larger (better), growers' equilibrium effort first increases and then decreases. A good shock has two opposite effects on growers' incentives to exert effort. On one hand, with a good shock, the grower's effort becomes more efficient and hence she exerts more effort. On the other hand, a good shock also indicates to the grower that she is lucky and induces her to relax and exert less effort. As the shocks become better and better, the second effect

Table 4. Analysis of Alternative Bracket Structures

No. of brackets	2	4	6 (Case 1)	6 (Case 2)	6 (Case 3)	8
			Piece Rates			
1 (best settlement)	b[a] + 0.6	b + 0.9	b + 1.2	b + 1.2	b + 1.2	b + 1.5
2	b + 0.6	b + 0.9	b + 1.2	b + 0.9	b + 0.9	b + 1.2
3	b + 0.6	b + 0.6	b + 0.9	b + 0.9	b + 0.6	b + 0.9
4	b + 0.6	b + 0.6	b + 0.6	b + 0.6	b + 0.6	b + 0.6
5	b + 0.3	b + 0.3	b + 0.3	b + 0.3	b + 0.3	b + 0.3
6	b + 0.3	b + 0.3	b	b	b + 0.3	b
7	b + 0.3	b	b − 0.3	b	b	b − 0.3
8 (worst settlement)	b + 0.3	b	b − 0.3	b − 0.3	b − 0.3	b − 0.6
Total settlement costs	186.76 (0.5661)	173.16 (0.7488)	166.22 (0.8558)	166.40 (0.7714)	166.40 (0.7168)	161.47 (0.7899)

[a] b denotes the base piece rate.
Note: Results are based on 1,000 iterations of bootstrap and bootstrap standard errors are reported in the parentheses.

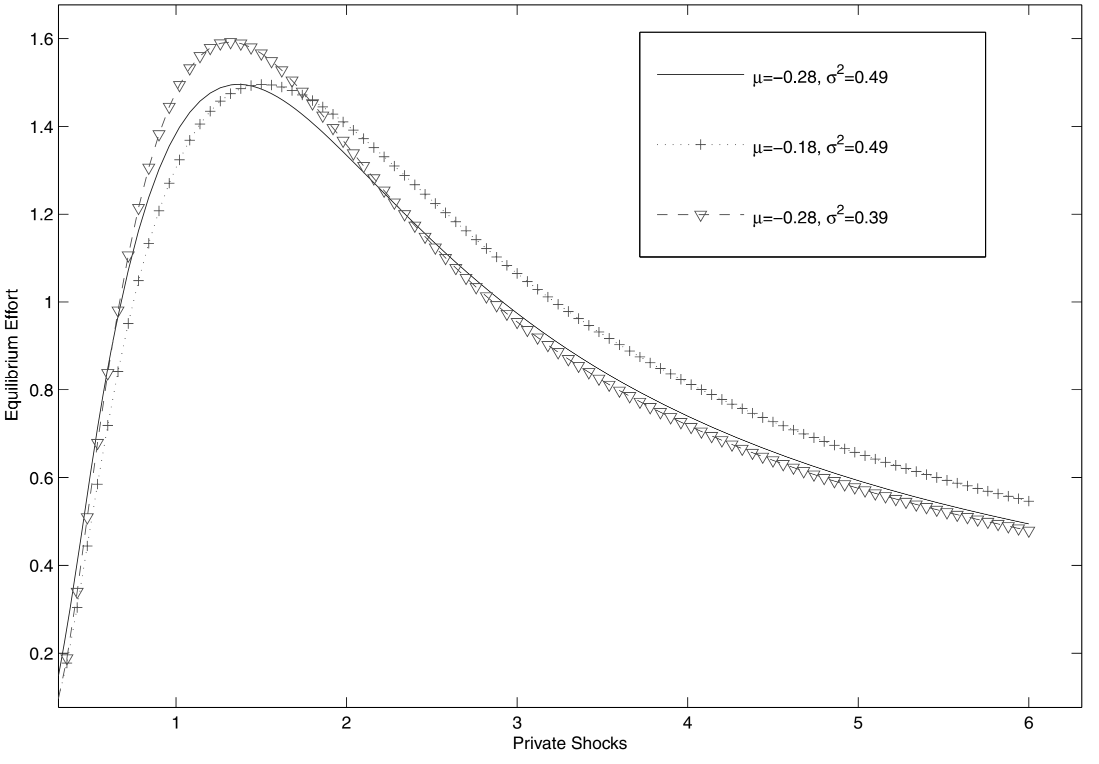

Figure 1. Equilibrium effort function for different private shocks densities

dominates the first effect. Second, when the log mean of the private shocks is increased (compare the solid line with the dotted line), the equilibrium effort function shifts to the right, but the maximum equilibrium effort remains roughly the same. Third, when the log variance of the private shocks is decreased (compare the solid line with the dashed line), the equilibrium effort function becomes more tight. Those growers whose shocks are in the center of the density exert a lot more effort and those growers with extreme shocks exert slightly less effort. Moreover, the maximum equilibrium effort increases. These comparisons suggest that the integrator might benefit by contracting with a more homogenous group of growers, that is, a group whose private shocks density has a smaller variance.

Conclusion

This article presents the first attempt to estimate a structural model of an empirically observed rank-order tournament as a strategic game with private information.[10] The presented model is a simplified version of the actual games played in poultry production tournaments, yet it is still realistic enough to capture some of the most important features of broiler production technology and the actual payment scheme observed in the industry. Different tournament features create different incentives for the growers to exert effort. Therefore, when the payment mechanism changes, growers will change their equilibrium effort levels in response to the changes in the incentives, which then impacts the welfare distribution and the total social surplus.

The main advantage of the structural econometrics approach is to allow the investigation of theoretically ambiguous results through counterfactual experiments. In situations when comparative statistics results could not be theoretically evaluated, we used the estimates of the productivity shocks to simulate how changes in the tournament mechanisms affect efficiency and the distribution of welfare among the contracting parties. All attempted counterfactual simulations produced plausible results. For example, our results showed that on average the total effect of reducing the number of players from eight to four caused negligible increase in the settlement cost by 0.29% per tournament as a whole, but the

[10] Examples employing the reduced form approach to tournaments include Main, O'Reilly, and Wade (1993); Ericksson (1999); and Gibbons and Murphy (1990).

individual growers' profits varied depending on whether they received a positive or a negative private shock. Another counterfactual experiment showed that increasing the number of brackets from four to eight while keeping the piece-rate spread unchanged, induces growers to exert more effort, which would bring down the total settlement costs for the tournament by 6.75% with all benefits appropriated by the integrator. Finally, we showed that for a fixed spread between brackets, number of players, and the total payment to growers, the total settlement costs monotonically decreased as the number of brackets increased.

In our approach we made three types of simplifications in order to make the problem tractable. First, the competition in our model is only about feed conversion (i.e., settlement costs), whereas in real life the growers are in fact competing on three margins: feed utilization, mortality prevention, and the production of live weight. The actual payment mechanisms used by the poultry industry reflect all three of those margins. We assume that each grower receives one baby chick, which will surely survive, and will be grown precisely until it reaches the target weight. These assumptions are of course restrictive, but very much in line with the rest of the empirical literature on contracts. Modeling the grower response to incentives on two or more margins would require replacing the standard principal–agent model with a multitasking framework (see for example, Holmstrom and Milgrom 1991). Modeling a tournament as a game played on two margins would be even more difficult.

Second, we assume that all agents are *ex ante* identical but before exerting effort each agent receives a private productivity signal. In light of the existing literature on broiler production tournaments, the assumption about homogenous growers is controversial. Knoeber and Thurman (1994) and Levy and Vukina (2004) have shown that broiler growers are heterogeneous. These results were obtained using a reduced form approach by showing that individual growers' fixed effects are significant. We mitigate this problem by allowing growers to be *ex post* heterogeneous, such that their equilibrium efforts depend on the private information that they receive. This private signal may be the information about the quality of inputs they received from the integrator or about their own idiosyncrasies. For example, the grower may factor in the knowledge that her husband will have a knee surgery next month or that they planned a vacation trip to Las Vegas and the chickens will be tended for by their teenage children. The structural estimation of a rank-order tournament games with heterogenous ability contestants is outside the scope of this article as this assumption results in equilibrium strategies that are nonsymmetric, which are very difficult, if not impossible, to characterize and estimate, in general.

Finally, we assume that growers are risk neutral, which is somewhat controversial but convenient and has been frequently assumed in the literature on agricultural contracts. In particular Knoeber and Thurman (1994) testing some theoretical predictions about rank-order tournaments in broiler contracts ignore considerations of risk aversion as well.[11] In the principal–agent framework the standard risk exposure—incentives tradeoff is replaced by potentially binding agent's bankruptcy constraint which prevents the principal from *selling the store to the agent*. The gradual relaxation of the above assumptions presents a multitude of challenging opportunities for future research.

At the end what can we say about the relevance of this research in light of the fact that the data set that we use is more than twenty years old First, the article offers a methodological contribution on how to structurally estimate a rank-order tournament game with private information. Second, the policy relevance of this article should be judged in light of the fact that rank-order tournaments are frequently used in many other labor contracts as well. For example, pharmaceutical sales representatives frequently compete with their regional counterparts to determine their annual bonuses. Also, the competitions for top executive positions in corporations are considered to be rank-order tournaments, as are the promotion and tenure decisions in academia. Thus the method illustrated in this article may find applications to the design of rank-order tournaments in agricultural and labor contracts in general.

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[11] There exists the entire strain of literature originating within the transactions costs paradigm that minimizes the importance of risk in contract choice, see, for example, Allen and Lueck (1992).

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