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Structural Estimation of Rank-Order Tournament Games with Private Information

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Structural Estimation of Rank-Order Tournament Games with Private Information

In this paper we propose a game-theoretic model of a rank-order tournament with private information and characterize its equilibrium solution. The model captures many important features of the production contracts once observed in the poultry industry. We use the contract settlement data from a poultry company who used rank-order tournaments to remunerate their contract growers and estimate a fully structural model of a symmetric Nash-equilibrium of this game. We show that growers' equilibrium effort depends on three factors: the spread in piece rates between the performance brackets, the number of players in each tournament, and the number of performance brackets used. We use the estimates of the productivity shocks density to simulate how changes in these three tournament characteristics affect the total welfare and the distribution of welfare between the growers and the integrator.

1 Introduction

In most sporting events prizes are awarded, not on the basis of absolute performance, but based on the 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 is that 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 papers 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 papers on tournaments are all done with the 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 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, that cannot be influenced by the quantitative or qualitative changes in the incentive structure. Somehow, this type of work has not been done for the tournament-style labor contracts, but has been done in the context of individualized labor contracts. A good example is a paper 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 paper focuses on rank-order tournaments used to settle broiler production tournaments. Modern broiler industry in the U.S. represents a completely vertically integrated chain involving the production 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 modern contracts are virtually all 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 paper we propose a new game-theoretic model of a rank-order tournament with

private information and characterize its equilibrium solution. Our model extends the original Lazear and Rosen (1981) and Green and Stockey (1983) rank-order tournament models to capture many important features of production contracts observed in the broiler industry. Using Knoeber and Thurman (1994) data set we estimate a fully structural model of a symmetric Nash-equilibrium of this game. We show that growers' equilibrium effort depends on three factors: the spread in piece rates between the performance brackets, the number of players in each tournament, and the number of performance brackets used. We use the estimates of the productivity shocks density to simulate how changes in these three tournament characteristics affect the 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.

The paper is organized as follows. In the next section we describe the essential features of broiler production contracts and introduce the data set. In Section 3 we introduce the theoretical model. Section 4 is devoted for the estimation methodology. In Section 5, we perform policy simulations and Section 6 concludes.

2 Broiler Industry and Data Description

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 company's animals 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, medication, and the services of field personnel and makes decision about the frequency of flock rotations on any given farm. Most integrators nowadays require houses be built according to strict specifications regarding construction and equipment.

Virtually all modern broiler contracts are settled using a two-part cardinal tournament scheme consisting of a fixed base payment per pound of live meat produced and the 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 inputs costs, i.e. the number of chicks placed multiplied by 12 cents and the total feed intake (in kilo-calories) 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 quartile.

The data set include production information for 75 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 impossibility to figure 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 paper. 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, the difficulty is considerably mitigated by the fact the 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 10-day periods, the obvious number of participants in each tournament turned out to be 8.

Table 1 gives the summary statistics of the data. In total, we have 93 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 variation from 17.19 cents to 25.42 cents.¹ 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.

3 Rank-Order Tournament with Private Information

We model the integrator-grower relationship in the principal-agent framework. The effort exerted by the growers 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 ($i = 1, 2, \dots, N$) is given 1 baby broiler chick that she is supposed to tend for until the chick reaches the weight of M pounds.² 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,

¹Notice, that prices entering the settlement cost formula are 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.

²Assuming constant returns to scale production technology and the absence of mortality, this assumption is entirely innocuous.

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

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

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 $[\underline{\theta}, \bar{\theta}]$ 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 only 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 $[\underline{\eta}, \bar{\eta}]$ 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.³

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 effort, the grower can decrease the 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.⁴

³However, *ex-post*, growers represent a heterogeneous group, since their equilibrium efforts which are the function of received shocks could be different.

⁴Notice that animal husbandry is characterized by animals eating *ad libitum* (at will), that is, the feed is

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

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

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

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

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, $A_1 > A_2 > A_3 > A_4$.⁵

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

$$\pi_i = R_i - e_i. \quad (4)$$

3.1 Characterization of the Equilibrium

Given the performance measure $f_i = \frac{J + K \left(\frac{w}{1 + \theta_i \eta e_i} + \frac{\bar{w} - w}{1 + \theta_i \eta e_i} \right)}{M}$, in an increasing symmetric equilibrium, where $e_i(\theta_i)$ increases in θ_i for all i , grower i 's performance measure f_i being in the lowest

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.

⁵Notice 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.

quartile is equivalent to her effort level e_i being in the highest quartile.⁶ Therefore, the payment schedule can be rewritten as

$$\begin{aligned}
R_i &= A_1 M \text{ if } e_i \text{ is in the highest quarter} \\
&= A_2 M \text{ if } e_i \text{ is in the second highest quarter} \\
&= A_3 M \text{ if } e_i \text{ is in the third highest quarter} \\
&= A_4 M \text{ if } e_i \text{ is in the lowest quarter.}
\end{aligned} \tag{5}$$

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 $j \neq i$. The expected profit function can be written as follows

$$\begin{aligned}
E\pi_i &= (A_1 M - e_i) \Pr(e_i \text{ is in the highest quarter}) \\
&+ (A_2 M - e_i) \Pr(e_i \text{ is in the 2nd highest quarter}) \\
&+ (A_3 M - e_i) \Pr(e_i \text{ is in the 3rd highest quarter}) \\
&+ (A_4 M - e_i) \begin{bmatrix} 1 - \Pr(e_i \text{ is in the highest quarter}) \\ - \Pr(e_i \text{ is in the 2nd highest quarter}) \\ - \Pr(e_i \text{ is in the 3rd highest quarter}) \end{bmatrix}.
\end{aligned} \tag{6}$$

As one can see, the key elements of the ex-ante profit function are the probabilities that a grower's equilibrium effort would fall into each of the four quartiles. For example,

$$\begin{aligned}
&\Pr(e_i \text{ is in the highest quartile}) \\
&= \Pr(e_i(\theta_i) \geq e_1) \\
&= \Pr(e_i(\theta_i) \geq s(\theta_1)) \\
&= \Pr(s^{-1}(e_i) \geq \theta_1) \\
&= G_{\theta_1}(s^{-1}(e_i))
\end{aligned} \tag{7}$$

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, $s^{-1}(\cdot)$ denotes the inverse

⁶We acknowledge the fact that there may exist other asymmetric equilibria for this model. The symmetric increasing equilibrium we focus on surely exists and is unique as shown later.

function of $s(\cdot)$ and e_1 is the equilibrium effort level for a grower with private productivity shock θ_1 . As an illustrating example, in our application, the number of growers in one tournament is 8, with 2 growers in each category. Therefore, from grower i 's point of view, there are 7 other competitors and in order for her to be in the best category, her shock must be higher than the 2nd highest shock out of 7 shocks of her competitors. In this case, θ_1 is the 2nd highest order statistic among 7 realizations from the distribution $G(\cdot)$. Following David (1981), $G_{\theta_1}(\theta_i)$ can be written as

$$G_{\theta_1}(\theta_i) = \sum_{j=6}^7 \binom{7}{j} G(\theta_i)^j (1 - G(\theta_i))^{7-j}. \quad (8)$$

Similarly,

$$\begin{aligned} & \Pr(e_i \text{ is in the 2nd highest quartile}) \\ &= \Pr(s(\theta_1) \geq e_i(\theta_i) \geq s(\theta_2)) \\ &= G_{\theta_2}(s^{-1}(e_i)) - G_{\theta_1, \theta_2}(s^{-1}(e_i), s^{-1}(e_i)) \\ &= G_{\theta_2}(s^{-1}(e_i)) - G_{\theta_1}(s^{-1}(e_i)) \end{aligned} \quad (9)$$

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

$$G_{\theta_1, \theta_2}(\theta_i, \theta_i) = \Pr(\theta_1 \leq \theta_i, \theta_2 \leq \theta_i) = \Pr(\theta_1 \leq \theta_i) = G_{\theta_1}(\theta_i). \quad (10)$$

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

$$\begin{aligned} E\pi_i &= (A_1 M - e_i) G_{\theta_1}(s^{-1}(e_i)) \\ &+ (A_2 M - e_i) [G_{\theta_2}(s^{-1}(e_i)) - G_{\theta_1}(s^{-1}(e_i))] \\ &+ (A_3 M - e_i) [G_{\theta_3}(s^{-1}(e_i)) - G_{\theta_2}(s^{-1}(e_i))] \\ &+ (A_4 M - e_i) \left[1 - G_{\theta_3}(s^{-1}(e_i)) \right] \end{aligned} \quad (11)$$

and the first order condition with respect to e_i is

$$\begin{aligned}
& -1 + (A_1 M - e_i) g_{\theta_1}(s^{-1}(e_i)) \frac{1}{s'(s^{-1}(e_i))} \\
& + (A_2 M - e_i) [g_{\theta_2}(s^{-1}(e_i)) - g_{\theta_1}(s^{-1}(e_i))] \frac{1}{s'(s^{-1}(e_i))} \\
& + (A_3 M - e_i) [g_{\theta_3}(s^{-1}(e_i)) - g_{\theta_2}(s^{-1}(e_i))] \frac{1}{s'(s^{-1}(e_i))} \\
& + (A_4 M - e_i) \left[-g_{\theta_3}(s^{-1}(e_i)) \right] \frac{1}{s'(s^{-1}(e_i))} \\
& = 0
\end{aligned} \tag{12}$$

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} . After solving the ordinary differential equation, we get the unique solution of the following form

$$\begin{aligned}
e_i^* &= s(\theta_i) = M \int_{\underline{\theta}}^{\theta_i} [A_1 g_{\theta_1}(x) + A_2 (g_{\theta_2}(x) - g_{\theta_1}(x)) + A_3 (g_{\theta_3}(x) - g_{\theta_2}(x)) - A_4 g_{\theta_3}(x)] dx \\
&= M \int_{\underline{\theta}}^{\theta_i} [(A_1 - A_2) g_{\theta_1}(x) + (A_2 - A_3) g_{\theta_2}(x) + (A_3 - A_4) g_{\theta_3}(x)] dx \\
&= M \{(A_1 - A_2) G_{\theta_1}(\theta_i) + (A_2 - A_3) G_{\theta_2}(\theta_i) + (A_3 - A_4) G_{\theta_3}(\theta_i)\}
\end{aligned} \tag{13}$$

with the boundary condition $s(\underline{\theta}) = \underline{\theta}$.⁷ Since $A_1 > A_2 > A_3 > A_4$, the integrand is always positive and therefore, $\frac{\partial s(\theta_i)}{\partial \theta_i} > 0$ can be proved trivially. Notice 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). The intuition behind that is straightforward. Increasing the spread of the bonuses makes the stake of the tournament larger and hence induce growers to exert more effort to try to win the tournament. Also, the equilibrium effort depends on N , the number of players in the tournament. This can be seen clearly from the fact that the equilibrium effort is a function of terms such as $G_{\theta_1}(\theta_i)$, $G_{\theta_2}(\theta_i)$ and $G_{\theta_3}(\theta_i)$. These are the cumulative distributions of order statistics, which changes as N changes.

⁷When $(A_1 - A_2) = (A_2 - A_3) = (A_3 - A_4)$ as is the case in the rank-order tournament that generated our data, then $e_i^* = s(\theta_i) = M (A_1 - A_2) [G_{\theta_1}(\theta_i) + G_{\theta_2}(\theta_i) + G_{\theta_3}(\theta_i)]$.

4 Structural Econometric Framework and Estimation Strategy

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 grower effort (13). 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 (2) can be rewritten as

$$y_{it}^* = \frac{y_{it}}{\eta_t} = \theta_{it} e_{it}^*(\theta_{it}) = \theta'_{it} \quad (14)$$

where $\theta'_{it} = \theta_{it} e_{it}^*(\theta_{it})$ and $y_{it} = \frac{\bar{w} - \underline{w}}{M f_{it} - J - K \underline{w}} - 1$. Taking expectations on both sides yields

$$E(y_{it}^*) = E[\theta_{it} e_{it}^*(\theta_{it})]. \quad (15)$$

As we do not observe θ_{it} directly, a simulated nonlinear least squares (SNLLS) estimation method naturally follows from the moment condition in (15). If we denote $\varphi = (\mu, \sigma^2)$ to be the parameter vector that characterizes $G(\cdot)$, then the SNLLS estimator can be defined as

$$\hat{\varphi} = \arg \min_{\varphi} \frac{1}{T} \sum_{t=1}^T \frac{1}{N_t} \sum_{i=1}^{N_t} \left[y_{it}^* - \frac{1}{S} \sum_{s=1}^S \theta_{it}^{(s)} e_{it}^*(\theta_{it}^{(s)}) \right]^2, \quad (16)$$

where S is the number of simulations and $\theta_{it}^{(s)}$ ($s = 1, \dots, S$) is the s th draw from the distribution $G(\cdot|\varphi)$. Following Gouriéroux 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

$$\widehat{Avar}(\hat{\varphi}) = \left(\frac{1}{T} \sum_{t=1}^T \frac{1}{N_t} \sum_{i=1}^{N_t} \nabla_{\varphi} \hat{m}'_{it} \nabla_{\varphi} \hat{m}_{it} \right)^{-1} * \left(\frac{1}{T} \sum_{t=1}^T \frac{1}{N_t} \sum_{i=1}^{N_t} \hat{u}_{it}^2 \nabla_{\varphi} \hat{m}'_{it} \nabla_{\varphi} \hat{m}_{it} \right) * \left(\frac{1}{T} \sum_{t=1}^T \frac{1}{N_t} \sum_{i=1}^{N_t} \nabla_{\varphi} \hat{m}'_{it} \nabla_{\varphi} \hat{m}_{it} \right)^{-1} \quad (17)$$

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

4.1 Results

We parameterize the density of growers' productivity shocks as

$$g(\theta_{it}|\mu, \sigma) = \frac{1}{\sigma\theta_{it}\sqrt{2\pi}} \exp \left[-\frac{(\ln \theta_{it} - \mu)^2}{2\sigma^2} \right] \quad (18)$$

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 φ from the data on individual contract settlements. Also, in order to obtain the dependent variable y_{it}^* used in the estimation, we estimate the common shock for each tournament as

$$\hat{\eta}_t = \frac{1}{N_t} \sum_{i=1}^{N_t} y_{it}. \quad (19)$$

As seen from Table 2, the mean of the common productivity shock in the data is 0.98 with a standard deviation 0.22. 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 3. The estimated log mean of the private productivity shock is -1.08 and the estimated log variance is 0.46. From the property of the log normal distribution, this implies that the private productivity shock has the mean of 0.43 and the standard deviation of 0.33. These results indicate that the common productivity shock dominates the private productivity shock in magnitude, but the private productivity shock has larger variance.

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 effort according to the equilibrium effort function (13) and then obtain a simulated sample of y_{it}^* . From Table 4, we can see that the model fits the data reasonably well as the simulated mean of y_{it}^* differs from the actual mean of y_{it}^* only slightly.

⁸By setting $S = 10,000$ the results changed only slightly.

5 Policy Simulations

In this section we use the estimates of the productivity shocks density from the previous section to simulate how changes in the tournament mechanism affect the total welfare and the distribution of welfare between the growers and the integrator. 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. From the equilibrium effort function in (13), we can see that the growers' equilibrium effort depends on three factors: the difference in piece rates between the performance brackets (in this case quartiles), the number of players (growers) in each tournament, and the number of performance brackets used. We quantify the welfare effects of changing each one of those three factors one at the time.

5.1 Increasing the Piece Rate Spread

In the rank-order tournament analyzed in this paper, there are 4 performance brackets (quartiles) with 2 growers in each. Therefore, the total payment from the integrator to the growers can be written as $2(A_1 + A_2 + A_3 + A_4)M$. If we restrict our attention to those tournaments where the differences in piece rates across brackets are the same as is the case in the data, the total payments to growers can be written as $4(A_2 + A_3)M$.⁹ In this case, the integrator can change the spread $A_2 - A_3$ without changing the sum of the piece rates $A_2 + A_3$. As the result, the growers' equilibrium effort will increase as predicted by the equilibrium effort function (13). The increased effort would lower 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 would benefit without incurring any extra cost in terms of increased grower payment.

⁹Our approach can also be used to analyze the tournaments where the spreads in piece rates differ among brackets.

We run the counterfactual experiment for a representative tournament by increasing the spread from 0.3 cents as in the data to 0.4 cents without changing the sum of $A_2 + A_3$. Since the original lowest piece rate for this tournament is \$0.0285 per pound and the highest rate is \$0.0375, in the experiment we set $A_1 = 0.027$, $A_2 = 0.031$, $A_3 = 0.035$, and $A_4 = 0.039$. We pick the 52th tournament in our data set. We chose this tournament because its estimated common shock is the closest to the mean of the common shocks. Therefore, we expect that if we conduct the counterfactual experiments for all tournaments in the data set and average the results across tournaments, the final result will be very similar to the result reported below for this representative tournament. The experiment is carried out as follows. First, with the estimated density for the private productivity shock, we simulate the private productivity shocks for all 8 growers in this tournament. We then compute the equilibrium efforts for these 8 growers according to the equilibrium effort function (13). Finally, we compute the settlement costs and profits for each grower in the tournament using equations (2) and (4).

Table 5 summarizes a couple of the interesting results. The increase in piece rate spread, as predicted by our theoretical model, causes growers to exert more effort. As a result, the total settlement costs for this tournament decrease from 178.37 cents to 174.45 cents, or a 2.20% reduction. Since the new mechanism does not change the total payments the growers receive, the integrator reaps all the benefits. This is because the growers respond to this change in the incentives by increasing their efforts to try to win the tournament, but since increasing the effort is costly, their profits decrease between 1.61% and 7.55%.¹⁰

5.2 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

¹⁰In light of this result, it may be appropriate to ask what was preventing the integrator from widening the spreads to extremes. For one thing, based on (1) it is obvious that the feed utilization cannot drop below $\underline{u}$ no matter how large the effort. The other limitation comes via the grower participation/bankruptcy constraints because by observing the spread being too high, growers would refuse to sign the contract fearing ending up on the losing end of the 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's 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. The main advantage of the structural econometrics approach is to allow the investigation of theoretically ambiguous results through counterfactual experiments.

We run the counterfactual experiment for the same representative tournament as in the previous exercise. After simulating the private productivity shocks for 8 growers in this tournament, we split them into 2 tournaments with 4 growers in each tournament (1 from each bracket in terms of performance). We then compute their new equilibrium efforts according to equation (13) by changing the number of growers from 8 to 4. Finally, we calculate all other welfare measures of interest.

Table 6 collects the results from the experiment. First, the growers with good private shocks, that is, those growers in the top two brackets, gain from the decrease in the number of growers. But at the same time, those growers in the lower two brackets lose. 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 placing into the worst brackets. Since exerting effort is costly, growers with good shocks gain and growers with bad shocks lose with this structural change. On the other hand, the integrator gains from this change with the total settlement costs decreasing by about 0.12%.

5.3 Changing the Number of Brackets

Finally, we investigate the welfare effects of changing the number of performance brackets in rank-order tournaments. More brackets will widen the differences in pay between the highest bracket and the lowest bracket, holding the piece rate spreads between adjacent brackets constant. Intuitively, this should create 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 to avoid placing 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 for the same representative tournament by increasing the number of brackets from 4 as in the data set to 8. In order to keep the final payments the growers get from the integrator unchanged, we set the pay for the lowest bracket to be 2.25 cents per pound of chicken produced and the pay for the highest performance bracket to be 4.35 cents, with the piece rate spread unchanged at 0.3 cents. The results presented in Table 7 confirm the theoretical predictions. First, the growers exert more effort, which brings down the total settlement costs for the tournament from 178.37 cents to 171.40 cents, or a 3.91% reduction and benefits the integrator. On the growers' side, the cost of exerting additional effort outweighs the benefit. As can be seen from the table, the profits for all growers 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.

6 Conclusion

This paper presents the first attempt to estimate a structural model of an empirically observed rank-order tournament as a strategic game with private information. This approach has been used for quite some time in the empirical literature on auctions but not on tournaments. 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. Using the estimates of the model primitives we simulated how changes in the tournament characteristics affect the total welfare and the distribution of welfare between the growers and the integrator. All attempted counterfactual simulations produced plausible results.

First, our model shows that the growers' equilibrium effort depends only on the difference in piece rates between the performance brackets and not the absolute value of the piece rate. Increasing the spread between performance brackets by 33% from 0.3 cents to 0.4 cents per pound of live chicken keeping the total payment to growers constant caused the total settlement costs (in essence, the feed conversion ratio) for the representative tournament to decrease by 2.2%.

Second, our theoretical model generates no definitive predictions about the impact of changing the number of players in a tournament as we are not able to sign this comparative statics result. These are precisely the situations where simulations based on the estimates of the structural model prove to be very useful. Our counterfactual simulation showed that the total effect of changing the number of players from 8 to 4 caused negligible reduction in the settlement cost by only 0.12% for the tournament as a whole, as we intuitively expected, but the individual growers' profits varied depending on whether they received a positive or a negative private shock. For growers that received a positive shock the reduction in the number of contestants in the tournament was beneficial, whereas for those that received a negative signal the reduction in the number of players was harmful for their profits.

Finally, we explored the effect of changing the number of brackets in the rank-order tournament on the production efficiency and the welfare distribution between the contracting

parties. Increasing the number of performance brackets in a rank-order (ordinal) tournament, thereby increasing the resolution of the performance grid, moves a rank-order tournament closer to a cardinal tournament and should have similar welfare effects. The fact that rank-order tournaments exhibit some undesirable properties when implemented with heterogeneous ability contestants has been known since the seminal paper by Lazear and Rosen (1981). The reason is that low-ability contestants attempt to contaminate high-ability pools, resulting in adverse selection. With full knowledge of abilities, rank-order tournaments with heterogeneous agents still suffer from incentives problems requiring handicapping or sorting to secure efficient competition within the same organization. The intuition behind these results is straightforward. Because of the natural advantage that high ability contestants possess, they will not compete hard enough because they are likely to win anyway. Similarly, the low ability types will not compete hard enough because they know that they are likely to lose no matter how hard they try. The main feature of cardinal tournaments, where all players are rewarded based on the distance between their own result and the average result for the entire group, will mitigate the above mentioned incentives problems but it will not completely eliminate them (see Levy and Vukina (2002)). Our counterfactual experiment shows that increasing the number of brackets from 4 to 8 and keeping the piece rate spread unchanged, growers would exert more effort, which would bring down the total settlement costs for the tournament by 3.91% and all benefits will be picked up by the integrator.

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)), with, to the best of our knowledge, no prior empirical work done. Modeling a tournament as a game played on two margins would be even more difficult.

Secondly, we assume that before exerting effort each agent receives a private signal about the quality of inputs she received. This assumption makes all agents *ex-ante* identical and their equilibrium strategies symmetric. In light of the existing literature on broiler production tournaments, the assumption about *ex-ante* homogenous growers is controversial but defensible. 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. However, Leegomonchai and Vukina (2005) have argued that differences in individual growers' performances may result from integrator's strategic distribution of varying quality inputs among different growers. In this context it is hard to figure out whether some growers frequently win because they are high ability types or because they frequently receive better quality inputs. The possible differences in received input quality are adequately captured by the private productivity shock in our model.

Finally, we assume that growers are risk neutral, which is controversial but convenient and has been frequently used 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.

¹¹There 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).

References

- Allen, D.W. and D. Lueck (1992): "Contract Choice in Modern Agriculture: Cash Rent versus Cropshare," *Journal of Law and Economics* 35, 397-426.
- Bronars, S. and G. Oettinger (2001): "Effort, Risk-Taking, and Participation in Tournaments: Evidence from Professional Golf," Mimeo, University of Texas at Austin.
- David, H. (1981): *Order Statistics*, 2nd Edition, New York, NY: John Wiley & Sons, Inc.
- Ehrenberg, R.G. and M.L. Bognanno (1990): "Do Tournaments Have Incentive Effects," *Journal of Political Economy*, 98, 1307-1324.
- Ericksson, T. (1999): "Executive Compensation and Tournament Theory: Empirical Tests on Danish Data," *Journal of Labor Economics*, 17, 262-280.
- Gibbons, R. and K.J. Murphy (1990): "Relative Performance Evaluation for Chief Executive Officers", *Industrial and Labor Relations Review*, 43, 30S-51S.
- Gourieroux, C. and A. Monfort (1996): *Simulation-Based Econometric Methods*, Oxford: Oxford University Press.
- Green, J. and N. Stockey (1983): "A Comparison of Tournaments and Contracts," *Journal of Political Economy*, 91, 349-364.
- Holmstrom, B. and P. Milgrom (1991): "Multi-Task, Principal-Agent Analyses: Incentive Contracts, Asset Ownership and Job Design," *Journal of Law, Economics and Organization*, 7, 24-52.
- Knoeber, C. and W. Thurman (1994): "Testing the Theory of Tournaments: An Empirical Analysis of Broiler Production," *Journal of Labor Economics*, 12, 155-179.
- Lazear, E. and S. Rosen (1981): "Rank-Order Tournaments as Optimum Labor Contracts," *Journal of Political Economy*, 89, 841-864.
- Leegomonchai, P. and T. Vukina (2005): "Dynamic Incentives and Agent Discrimination in Broiler Production Tournaments," *Journal of Economics and Management Strategy*, 14, 849-877.
- Levy, A. and T. Vukina (2002): "Optimal Linear Contracts with Heterogeneous Agents," *European Review of Agricultural Economics*, 29, 205-217.

Levy, A. and T. Vukina (2004): “League Composition Effect in Tournaments with Heterogeneous Players: An Empirical Analysis of Broiler Contracts,” *Journal of Labor Economics*, 22, 353-377.

Lucas, R. (1976): “Econometric Policy Evaluation: A Critique,” in: R.E. Lucas (ed.), *Studies in Business Cycle Theory*, Cambridge, MA: The MIT Press, 104-130.

Main, B., C. O’Reilly and J. Wade (1993): “Top Executive Pay: Tournament or Teamwork?,” *Journal of Labor Economics*, 12, 606-628.

McLaughlin, K. (1988): “Aspects of Tournament Models: A Survey,” *Research in Labor Economics*, 9, 225-256.

Nalebuff, B. and J. Stiglitz (1983): “Prizes and Incentives: Toward a General Theory of Compensation and Competition,” *Bell Journal of Economics*, 14, 21-43.

Paarsch, H. J. and B. Shearer (2000): “Piece Rate, Fixed Wages, and Incentive Effects: Statistical Evidence from Payroll Records,” *International Economic Review*, 41, 1, 59-92.

Tsoulouhas, F. and T. Vukina (1999): “Integrator Contracts with Many Agents and Bankruptcy,” *American Journal of Agricultural Economics*, 81, 61-74.

Table 1: Summary Statistics¹²

Variable	Number of Observations	Mean	Standard Deviation	Min	Max
settlement	744	20.94	0.71	17.19	25.42

Table 2: Estimation Results for the Common Shock

Mean	Standard Deviation	Min	Max
0.98	0.22	0.54	2.34

Table 3: Estimation Results for the Private Shock

Variable	Estimate	t-stat
μ	-1.08	675
σ^2	0.46	35.94
Value of Objective Function	0.0458	

Table 4: Model Fit

Actual Mean of y_{it}^*	Simulated Mean of y_{it}^*
1.00	0.97

¹²Variable definitions: **settlement** = costs of inputs (in cents) used to grow 1 chick until it reaches the target weight.

Table 5: Welfare Effects of Increasing the Piece Rate Spread

	Old Spread	New Spread	Change (%)
Total settlement cost (cents)	178.37	174.45	-2.20
Profit (cents) for grower:			
1 (best settlement)	10.73	10.19	-5.03
2	11.81	11.62	-1.61
3	10.88	10.39	-4.50
4	11.09	10.66	-3.88
5	10.24	9.53	-6.93
6	10.79	10.27	-4.82
7	10.07	9.31	-7.55
8 (worst settlement)	10.67	10.11	-5.25

Table 6: Welfare Effects of Changing the Number of Players

	8 growers	4 growers	Change (%)
Total settlement cost (cents)	178.37	178.16	-0.12
Profit (cents) for grower:			
1 (best settlement)	10.73	10.85	1.12
2	11.81	11.89	0.68
3	10.88	10.94	0.55
4	11.09	11.11	0.18
5	10.24	10.22	-0.20
6	10.79	10.70	-0.83
7	10.07	9.92	-1.49
8 (worst settlement)	10.67	10.60	-0.66

Table 7: Welfare Effects of Changing the Number of Brackets

	4 brackets	8 brackets	Change (%)
Total settlement cost (cents)	178.37	171.40	-3.91
Profit (cents) for grower:			
1 (best settlement)	10.73	9.94	-7.36
2	11.81	11.25	-4.74
3	10.88	10.52	-3.31
4	11.09	9.80	-11.63
5	10.24	9.22	-9.96
6	10.79	9.15	-15.20
7	10.07	8.72	-13.41
8 (worst settlement)	10.67	8.42	-21.09