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Efficiency gains from organizational innovation: Comparing ordinal and cardinal tournament games in broiler contracts ☆

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Abstract

We analyze the contract settlement data of a poultry company who contracts the production of broiler chickens with a group of independent growers. The company originally used rank-order (ordinal) tournaments to compensate their contract growers and later switched to cardinal tournaments. Based on the observed payment mechanism we construct an empirical model of a rank-order tournament game and estimate structural parameters of the symmetric Nash equilibrium and then simulate growers' performance under the observed cardinal tournament contract. We found that the model with risk-averse agents fits the data better than the model with risk-neutral agents and that switching from a rank-order tournament to a cardinal tournament, while keeping the growers' ex-ante expected utility constant, improved efficiency. The principal (company) gains from the switch, whereas some of the agents (growers) gain and others lose depending on their realized productivity shocks.

JEL classification: C5; D4; D8; J4; L1; L2; Q1

Keywords: Rank order tournaments; Cardinal tounaments; Broiler production contracts

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1. Introduction

Poultry industry is often considered a precursor of future trends in the organization of agriculture. With its completely vertically integrated chain of production, processing and distribution, the industry has dominated the competitive scene in the meat complex. Over the last several decades, the poultry industry's market share has expanded dramatically as it improved efficiency, successfully maintained lower prices than its competitors, and improved its product offerings and variety. The industry's reliance on production contracts with independent farmers undoubtedly improved its efficiency and facilitated the responsiveness to consumers, transforming the industry into a formidable competitor in the global meat markets (Vukina, 2001). A more recent trend towards adoption of alternative marketing arrangements in the swine and beef cattle industries with decreasing dependence on the negotiated spot markets may be indicating that these industries are emulating some of the organizational innovations originally developed by the poultry industry.

Poultry production is characterized by high degree of uncertainty and the importance of relationship-specific assets (chicken houses, feed mills, processing plants), both of which make spot markets uneconomical. However, the anticipated need to adapt to changing or uncertain future should lead to vertically integrated production, yet contracts with individual farmers became nearly universal. The explanation for this puzzle lies in the adoption of tournaments based compensation mechanisms for contract growers.[1] The rationale for the use of tournaments as opposed to vertical integration via company owned production facilities has been explained by Knoeber (1989). First, compensation by tournaments reduces the cost of contracting by effectively adapting the payment scheme to technical change without contract renegotiation and by shifting the common production shock from growers to integrators which makes complicated contingency stipulations unnecessary. Second, the requirement that contract growers provide capital in the form of chicken houses creates a bond that assures growers' performance, makes the relationship implicitly long-term, and induces self-selection of high ability growers.

According to Murphy (2002), firm-level organizational changes include three broad areas: restructuring of production and efficiency processes (e.g. re-engineering, downsizing, outsourcing, decentralization), human resource management practices (e.g., performance-based pay, flexible job design and employee involvement), and product/service quality related practices (total quality management, improving coordination with customers/suppliers). In this paper we focus on one aspect of the human resource management practices, notably the performance-based compensation schemes. Our objective is to analyze the welfare effects of replacing an ordinal (rank-order) tournament with a cardinal tournament, where the latter represents a labor contract with the reward being a continuous function (typically linear) of the difference between the individual player's performance and the average performance. We are primarily interested in measuring the contribution of this organizational innovation on agent productivity and firm performance.

The motivation for this research comes from studying the historical development of broiler production contracts in the U.S. (see: Martin, 1994). At some point in the evolution of broiler contracts the industry started using feed conversion contracts that compensated growers according to a specified schedule of feed conversion (pounds of feed per pound of live weight).

[1] 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).

Such contracts were often used with a flat fee payment, which made them similar to the contract we observe today. Those pre-specified feed conversion schedules were subsequently replaced by feed conversion or production cost tournaments, where some of those early tournaments were based on the ordinal rankings of growers. Modern broiler contracts are all settled using a two-part cardinal tournament scheme consisting of a fixed base payment per pound of live weight produced and a variable bonus payment based on grower's relative performance, such that rank-order tournaments are nowadays virtually extinct (Vukina, 2001).

To the best of our knowledge an empirical estimation of the efficiency gains associated with replacing one relative performance compensation schemes by another has not been done. Most of the existing theoretical literature on tournaments has been concerned primarily with the comparison of tournaments and 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 (for a survey see: McLaughlin, 1988). In the empirical literature on tournaments, a paper related to ours is Shum (2005) who employs a similar structural estimation methodology to explain intra-firm wage differentials in the retail industry using an elimination tournament model. Somewhat related are also the attempts to quantify the welfare losses associated with moral hazard and risk aversion in various labor contracts. For example, Ferrall and Shearer (1999) estimated the cost of incomplete information due to insurance (worker risk aversion) and incentives consideration and found that the two costs are of similar magnitudes. In the context of managerial compensation, Margiotta and Miller (2000) found that the costs of aligning hidden managerial actions to shareholders' goals through the compensation schedule are much less than the benefits from the resulting managerial performance. Paarsch and Shearer (2000) 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 represents valuable output because workers respond to incentives by reducing quality.

In this paper, we use Knoeber and Thurman (1994) data set to estimate a fully structural model of a symmetric Nash-equilibrium of the rank-order tournament game between a risk-neutral principle and risk-averse growers. The main objective is to measure the efficiency gains resulting from switching from a rank-order to a cardinal tournament in an ex-ante homogeneous contestants environment. This is accomplished by using the estimated parameters of the rank-order model to simulate the outcome of the cardinal tournament contract. The main advantage of this approach is that it is completely immune to the "Lucas Critique" (Lucas, 1976) in the sense that both quantitative and qualitative changes in the incentives scheme cannot possibly influence the estimated model primitives, notably the curvature of the growers utility function, the disutility of effort parameter, and the conditional density of random shocks. The main criticism of this approach is that the obtained results depend upon the model assumptions, some of which can be tested while other must be maintained. In particular, here we assume that growers are ex ante identical, with the same absolute risk aversion parameter and the same cost of effort. The usual defense against this criticism is to check whether the obtained results are empirically plausible. We found that the model with risk-averse agents fits the data better than the model with risk-neutral agents and that switching from a rank-order tournament to a cardinal tournament, while keeping the growers' ex-ante expected utility constant, improved efficiency by the technologically reasonable amount. The principal (company) gains from the switch, whereas some of the agents (growers) gain and others lose depending on their realized productivity shocks.

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 of the rank-order tournament. Section 4 is devoted to the estimation methodology and the presentation of results. In Section 5, we simulate grower performance under the cardinal tournament using estimated rank-order model primitives. Finally, 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. An individual grower's bonus payment is determined as a percentage (bonus factor) of the difference between the average settlement costs of all growers in the same tournament group and a grower's individual settlement costs. The tournament groups are formed by the growers whose flocks were harvested at approximately the same time (within a 1–2 week period). Settlement costs are obtained by adding chick, feed, medication, and other customary flock costs divided by total pounds of live poultry produced. For the below average settlement costs (above average performance), the grower receives a bonus and for the above average settlement costs, he receives a penalty. The bonus factor ranges from 0.5 and 1. The total revenue to the grower is the sum of the base and bonus payments, multiplied by the live pounds of poultry moved from the grower's farm.

As mentioned earlier, 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 similar to the modern contracts described above. This latter part of the data (June 1984–December 1985) is not usable for the purposes of our paper, because the exact composition of the tournament groups is

Table 1
Summary statistics[a]

Variable	Number of observations	Mean	Standard deviation	Min	Max
Pounds	744	4.7809	0.1575	3.9336	5.8173
Base	93	0.0263	0.0017	0.0198	0.0285
Temperature	93	0.6178	0.1313	0.4006	0.8335
Quality	93	0	0.0123	−0.0161	0.0683

[a]Variable definitions: *pounds* = number of pounds produced per dollar worth of inputs; *base* = base payment per pound of chicken produced in dollars; *temperature* = mean tournament temperature in 100°F; *quality* = mean tournament deviation of first-week mortality rate from the long-run average.

unknown.[2] We faced the similar problem in the rank-order tournament part of the data set as well. However, the difficulty is considerably mitigated by the fact that this 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 "pounds" denotes the number of pounds of chickens produced per dollar worth of production inputs (chicks and feed). On average, growers in the data set produced 4.78 lb of chickens per dollar of inputs, with variation from 3.93 lb to 5.82 lb.[3] The variation in output is mainly caused by weather, fluctuations in quality of inputs supplied by the integrator (chicks and feed) and growers' idiosyncrasies.

To capture the sources of variation in output, for each tournament in the data set we construct two variables. First, weather is believed to be an important factor influencing production efficiency through feed conversion and morbidity. Departures from ideal temperature and humidity cause increased feed conversion, diseases and excess mortality. For this purpose, we collected temperature data from the National Oceanic and Atmospheric Administration (NOAA) for the region where the growers are located. We then calculate the average daily temperature for each flock and the mean for all eight flocks in the same tournament.[4] Finally, our "temperature" variable represents the tournament mean temperature in degrees Fahrenheit divided by a 100.

Second, the quality of integrator supplied inputs can vary significantly across growers and tournaments (see Leegomonchai and Vukina, 2005). To capture the difference in the quality of chicks we use the first week mortality rate. We argue that low quality chicks will tend to have high mortality rate in the first week after they arrived on the farm and that there is very little that a grower can do to prevent this from happening. The variable "quality" represents the deviation of each tournament's mean first week mortality rate from the long-run average calculated as the mean of first week mortality rates for all flocks in the data set.

[2] In more recent broiler contracts, the settlement date is typically every Saturday, which means that all growers whose chickens were harvested during that week (Monday–Friday) would form one tournament. The settlement date in our data set is unknown and hence it was impossible to place growers into their respective tournament groups.

[3] Notice, 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.

[4] Flocks in this data set are typically harvested 6–7 weeks after they were placed. Each grower grows only one flock of birds at the same time, although the flock sizes can be different depending on the number of chicken houses that a grower owns and operates.

3. Rank-order tournament

Consider an N-player tournament game in which N risk-averse growers contract with a risk-neutral integrator the production of broiler chickens. Each grower i (i=1, 2,..., N) is given the same combination of inputs (chicks and feed) denoted by D and normalized to \$1.[5] Given D, the output of grower i is specified as

$$y_i = \theta_i e_i \tag{1}$$

where y_i is the pounds of live chicken weight, e_i is effort, and θ_i is the productivity shock, which materializes slowly during the production process. Higher θ_i implies that a grower can combine inputs and effort more efficiently to produce more broiler meat. Each grower's productivity shock is assumed to be drawn from a distribution $G(\cdot)$ with support $[\underline{\theta}, \overline{\theta}]$ 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 doesn't know her own productivity shock nor does she know the shocks of other growers in the same tournament. Each grower only knows that all shocks are independently drawn from $G(\cdot)$, which is common knowledge to all growers. As a result, all growers are *a priori* identical and the game is symmetric. Productivity shocks θ_i and θ_j are correlated as they are coming from the same distribution but are independent conditional on the distribution. This setup captures both the common production and grower idiosyncratic nature of production uncertainties.

The grower performance is determined by

$$f_i = \frac{D}{y_i} = \frac{1}{\theta_i e_i}, \tag{2}$$

that is, by measuring how much output (pounds of live chicken weight) can she produce with \$1 worth of inputs, and the payment is determined as

$$\begin{aligned} R_1 &= A_1 y_i \text{ if } f_i \text{ (the performance measure) is in the lowest quartile} \\ &= A_2 y_i \text{ if } f_i \text{ is in the second lowest quartile} \\ &= A_3 y_i \text{ if } f_i \text{ is in the third lowest quartile} \\ &= A_4 y_i \text{ if } f_i \text{ is in the highest quartile} \end{aligned} \tag{3}$$

where A_1 is the per pound piece rate if the grower's performance is in the lowest quartile (the best 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 grower i has the utility function

$$U(R_i - C(e_i)) \tag{4}$$

where R_i denotes the monetary compensation and $C(e_i)$ denotes the cost of effort. All standard assumptions regarding the utility and cost functions apply, that is, $U' > 0$, $U'' < 0$, $C' > 0$ and $C'' > 0$.

[5] Here we assume constant returns to scale production technology and therefore this normalization is innocuous. We also assume that the combination of chicks and feed is feasible, i.e. that it reflects the target weight of finished broilers and nutritionally meaningful feed-conversion ratio.

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

3.1. Characterization of the equilibrium

Given the performance measure $f_i = \frac{D}{y_i} = \frac{1}{\theta_i e_i}$, grower i's performance measure f_i being in the lowest quartile is equivalent to the product of her productivity shock θ_i and her effort e_i, that is, θ_i being in the highest quartile. Therefore, the payment schedule (3) can be rewritten as

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

However, when growers make decisions on how much effort to exert, the productivity shocks θ_i (i=1,…, N) have not yet been realized. In a symmetric equilibrium, the optimal strategy is based on each grower's maximizing her ex ante expected utility with respect to e_i, given all other growers exert the same optimal effort e_j=e*, for $j \neq i$. Having said this, the expected utility function can be written as

$$\begin{aligned} E\pi_i = & \int U(A_1\theta_i e_i - C(e_i))\Pr(\theta_i e_i \text{ is in the highest quartile})g(\theta_i)d\theta_i \\ & + \int U(A_2\theta_i e_i - C(e_i))\Pr(\theta_i e_i \text{ is in the 2nd highest quartile})g(\theta_i)d\theta_i \\ & + \int U(A_3\theta_i e_i - C(e_i))\Pr(\theta_i e_i \text{ is in the 3rd highest quartile})g(\theta_i)d\theta_i \\ & + \int U(A_4\theta_i e_i - C(e_i))\left[\begin{array}{l} 1 - \Pr(\theta_i e_i \text{ is in the highest quartile}) \\ -\Pr(\theta_i e_i \text{ is in the 2nd highest quartile}) \\ -\Pr(\theta_i e_i \text{ is in the 3rd highest quartile}) \end{array}\right] g(\theta_i)d\theta_i \end{aligned} \tag{6}$$

As one can see, the key elements in the ex ante expected utility are the probabilities that a grower's efficiency shock would fall into one of the four quartiles. For example,

$$\begin{aligned} & \Pr(\theta_i e_i \text{ is in the highest quartile}) \\ & \quad = \Pr(\theta_i e_i \geq \theta_1 e^*) \\ & \quad = G_{\theta_1}\left(\frac{\theta_i e_i}{e^*}\right). \end{aligned} \tag{7}$$

The first equality in (7) follows from the fact that in a symmetric equilibrium, when solving her maximization problem, grower i assumes that all other growers exert the same optimal effort, e_j=e*, for $j \neq i$. From the perspective of grower i, θ_1 is the highest realization outside the best quartile and $G_{\theta_1}(\cdot)$ is the cumulative distribution function of θ_1. More specifically, the number of growers in each of our tournaments is 8, with 2 growers in each bracket. Therefore, from grower i's perspective, there are 7 other competitors and in order for her performance to end up in the best quartile, her shock must be higher than the 2nd highest shock among 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), $G_{\theta_1}\left(\frac{\theta_i e_i}{e^*}\right)$ can be written as

$$G_{\theta_1}\left(\frac{\theta_i e_i}{e^*}\right) = \sum_{j=6}^{7}\binom{7}{j} G\left(\frac{\theta_i e_i}{e^*}\right)^j \left(1 - G\left(\frac{\theta_i e_i}{e^*}\right)\right)^{n-j}. \tag{8}$$

Similarly,

$$\begin{aligned}
&\Pr(\theta_i e_i \text{ is in the 2nd highest quartile}) \\
&\quad = \Pr\left(\theta_1 \geq \frac{\theta_i e_i}{e^*} \geq \theta_2\right) \\
&\quad = G_{\theta_2}\left(\frac{\theta_i e_i}{e^*}\right) - G_{\theta_1,\theta_2}\left(\frac{\theta_i e_i}{e^*}, \frac{\theta_i e_i}{e^*}\right) \\
&\quad = G_{\theta_2}\left(\frac{\theta_i e_i}{e^*}\right) - G_{\theta_1}\left(\frac{\theta_i e_i}{e^*}\right)
\end{aligned} \tag{9}$$

where θ_2 is the highest realization outside the first two best quartiles, $G_{\theta_2}(\cdot)$ 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. The last equality comes from the fact that by definition $\theta_1 \geq \theta_2$, which leads to

$$G_{\theta_1,\theta_2}\left(\frac{\theta_i e_i}{e^*}, \frac{\theta_i e_i}{e^*}\right) = \Pr\left(\theta_1 \leq \frac{\theta_i e_i}{e^*}, \theta_2 \leq \frac{\theta_i e_i}{e^*}\right) = \Pr\left(\theta_1 \leq \frac{\theta_i e_i}{e^*}\right) = G_{\theta_1}\left(\frac{\theta_i e_i}{e^*}\right). \tag{10}$$

Finally,

$$\begin{aligned}
&\Pr(\theta_i e_i \text{ is in the 3rd highest quartile}) \\
&\quad = G_{\theta_3}\left(\frac{\theta_i e_i}{e^*}\right) - G_{\theta_2,\theta_3}\left(\frac{\theta_i e_i}{e^*}, \frac{\theta_i e_i}{e^*}\right) \\
&\quad = G_{\theta_3}\left(\frac{\theta_i e_i}{e^*}\right) - G_{\theta_2}\left(\frac{\theta_i e_i}{e^*}\right)
\end{aligned} \tag{11}$$

where θ_3 is the highest realization outside the first three best quartiles, $G_{\theta_3}(\cdot)$ is the cumulative distribution function for θ_3, and $G_{\theta_2,\theta_3}(\cdot\,,\,\cdot)$ is the joint distribution for θ_2 and θ_3.

With the setup, the grower's ex ante expected utility (6) can be rewritten as

$$\begin{aligned}
E\pi_i = &\int U(A_1\theta_i e_i - C(e_i))G_{\theta_1}\left(\frac{\theta_i e_i}{e^*}\right)g(\theta_i)d\theta_i \\
&+ \int U(A_2\theta_i e_i - C(e_i))\left[G_{\theta_2}\left(\frac{\theta_i e_i}{e^*}\right) - G_{\theta_1}\left(\frac{\theta_i e_i}{e^*}\right)\right]g(\theta_i)d\theta_i \\
&+ \int U(A_3\theta_i e_i - C(e_i))\left[G_{\theta_3}\left(\frac{\theta_i e_i}{e^*}\right) - G_{\theta_2}\left(\frac{\theta_i e_i}{e^*}\right)\right]g(\theta_i)d\theta_i \\
&+ \int U(A_4\theta_i e_i - C(e_i))\left[1 - G_{\theta_1}\left(\frac{\theta_i e_i}{e^*}\right) - G_{\theta_2}\left(\frac{\theta_i e_i}{e^*}\right) + G_{\theta_1}\left(\frac{\theta_i e_i}{e^*}\right) - G_{\theta_3}\left(\frac{\theta_i e_i}{e^*}\right) + G_{\theta_2}\left(\frac{\theta_i e_i}{e^*}\right)\right]g(\theta_i)d\theta_i
\end{aligned} \tag{12}$$

and the first order condition with respect to e_i is given by

$$\begin{aligned}
&\int\left[U'(A_1\theta_i e_i - C(e_i))(A_1\theta_i - C'(e_i))G_{\theta_1}\left(\frac{\theta_i e_i}{e^*}\right) + U(A_1\theta_i e_i - C(e_i))g_{\theta_1}\left(\frac{\theta_i e_i}{e^*}\right)\frac{\theta_i}{e^*}\right]g(\theta_i)d\theta_i \\
&+ \int\left[U'(A_2\theta_i e_i - C(e_i))(A_2\theta_i - C'(e_i))\left(G_{\theta_2}\left(\frac{\theta_i e_i}{e^*}\right) - G_{\theta_1}\left(\frac{\theta_i e_i}{e^*}\right)\right) + U(A_2\theta_i e_i - C(e_i))\left(g_{\theta_2}\left(\frac{\theta_i e_i}{e^*}\right) - g_{\theta_1}\left(\frac{\theta_i e_i}{e^*}\right)\right)\frac{\theta_i}{e^*}\right]g(\theta_i)d\theta_i \\
&+ \int\left[U'(A_3\theta_i e_i - C(e_i))(A_3\theta_i - C'(e_i))\left(G_{\theta_3}\left(\frac{\theta_i e_i}{e^*}\right) - G_{\theta_2}\left(\frac{\theta_i e_i}{e^*}\right)\right) + U(A_3\theta_i e_i - C(e_i))\left(g_{\theta_3}\left(\frac{\theta_i e_i}{e^*}\right) - g_{\theta_2}\left(\frac{\theta_i e_i}{e^*}\right)\right)\frac{\theta_i}{e^*}\right]g(\theta_i)d\theta_i \\
&+ \int\left[U'(A_4\theta_i e_i - C(e_i))(A_4\theta_i - C'(e_i))\left(1 - G_{\theta_3}\left(\frac{\theta_i e_i}{e^*}\right)\right) - U(A_4\theta_i e_i - C(e_i))g_{\theta_3}\left(\frac{\theta_i e_i}{e^*}\right)\frac{\theta_i}{e^*}\right]g(\theta_i)d\theta_i = 0.
\end{aligned} \tag{13}$$

and in equilibrium, $e_i = e^*$.

The existence and uniqueness of the above equilibrium can be easily established if the second order condition were to hold. Unfortunately, the sign of the second order condition cannot be analytically determined. However, during the estimation, for every iteration of the parameter estimates, we checked whether the second order conditions are satisfied and found that they always hold for all 93 tournaments in the dataset. Therefore, our results are based on an economic model that describes growers' rational behavior and the equilibrium exists and is unique.

4. Estimation procedure and results

In the econometric analysis used in this paper the statistical inference is based on the assumption that the number of tournaments approaches infinity. Therefore, possible heterogeneity across tournaments needs to be taken into account. This issue can be addressed by modeling the distribution of the productivity shocks as varying across tournaments. Specifically, let $G^t(\cdot)$ denote the distribution of productivity shocks for the t-th tournament, $t=1,\ldots, T$, where T is the number of tournaments. Assume that $G^t=G(\cdot|x_t,\beta)$, where x_t is a vector of variables that represents the observed tournament heterogeneity affecting growers' production efficiency, and β is an unknown parameter vector. Let $g(\cdot|x_t,\beta)$ denote the corresponding density of growers' productivity shocks and N_t denote the number of growers in tournament t.

The estimation is based on the following parametric assumptions about the model primitives. First, the preferences of grower i in tournament t are assumed to be represented by the negative-exponential utility function

$$U(R_{it}-C(e_{it})) = 1-\exp(-\alpha(R_{it}-C(e_{it}))) \tag{14}$$

with a property that the absolute risk aversion parameter $\alpha>0$ is constant. Second, the cost function is assumed to be quadratic, $C(e_{it}) = \frac{\gamma e_{it}^2}{2}$, with $\gamma>0$. Finally, the density of growers' productivity shocks is assumed to be represented by

$$g(\theta_{it}|x_t,\beta) = \frac{1}{\exp(x_t\beta)}\exp\left(-\frac{1}{\exp(x_t\beta)}\theta_{it}\right) \tag{15}$$

for $\theta_{it}\in(0,\infty)$. The exponential distribution is convenient because it conforms with the theoretical model requirement that the productivity shocks are positive. The purpose of the structural estimation is to recover the model primitives, i.e., the growers' utility and cost functions and the density of the productivity shocks. More specifically, we need to estimate the parameter vector $\varphi=(\alpha,\gamma,\beta)$ from the data on individual contract settlements.

Table 2
Estimation results

Variable	Estimate	*t*-stat	Estimate	*t*-stat	Estimate	*t*-stat	Estimate	*t*-stat
	Exponential density				Log-normal density			
	Risk neutral		Risk averse		Risk neutral		Risk averse	
α	N.A.	N.A.	19.8219	6.7340	N.A.	N.A.	25.2208	2.5898
γ	0.0535	7.0581	0.0264	14.3921	0.1117	0.5877	0.0565	1.4487
Constant	1.8732	19.0686	1.8459	46.0931	1.5704	1.4809	1.4829	0.3846
Temperature	0.0373	3.1523	−0.0078	−0.7389	0.0519	4.3288	0.0043	0.3579
Quality	−0.2676	−2.8776	−0.4845	−4.8786	−0.2886	−2.6695	−0.3739	−2.9481
σ^2	N.A.	N.A.	N.A.	N.A.	1.4377	0.6238	0.9646	0.2783

The model is estimated using nonlinear least squares (NLS). Since the performance equation is specified as $y_{it}=\theta_{it}e_{it}$, in equilibrium $y_{it}=\theta_{it}e_t^*$, which implies the following moment condition

$$\begin{aligned} E(y_{it}) &= E(\theta_{it})e_t^* \\ &= \exp(x_t\beta)e_t^*(\varphi). \end{aligned} \tag{16}$$

The moment condition follows from the specification of the productivity shock and the fact that, given the parameter vector φ, the optimal effort e_t^* can be recovered from the first order condition (13) for a grower's utility maximization. The NLS estimator $\hat{\varphi}$ is defined as

$$\hat{\varphi} = \arg\min_{\varphi} \frac{1}{T}\sum_{t=1}^{T} \frac{1}{N_t}\sum_{i=1}^{N_t}[y_{it}-\exp(x_t\beta)e_t^*(\varphi)]^2. \tag{17}$$

Following Wooldridge (2002), the asymptotic variance of the NLS estimator can be obtained as follows

$$\begin{aligned} A\widehat{\text{var}}(\hat{\varphi}) = {} & \left(\frac{1}{T}\sum_{t=1}^{T}\frac{1}{N_t}\sum_{i=1}^{N_t}\nabla_{\varphi}\hat{m}_{it}'\nabla_{\varphi}\hat{m}_{it}\right)^{-1} * \left(\frac{1}{T}\sum_{t=1}^{T}\frac{1}{N_t}\sum_{i=1}^{N_t}\hat{u}_{it}^2\nabla_{\varphi}\hat{m}_{it}'\nabla_{\varphi}\hat{m}_{it}\right) \\ & * \left(\frac{1}{T}\sum_{t=1}^{T}\frac{1}{N_t}\sum_{i=1}^{N_t}\nabla_{\varphi}\hat{m}_{it}'\nabla_{\varphi}\hat{m}_{it}\right)^{-1} \end{aligned} \tag{18}$$

where $\hat{m}_{it} = \exp(x_t\hat{\beta})e_t^*(\hat{\varphi})$, $\hat{u}_{it}=y_{it}-\hat{m}_{it}$ and $\nabla_{\varphi}\hat{m}_{it} = \frac{\partial\hat{m}_{it}}{\partial\varphi}$.

4.1. Results

The estimation results are summarized in Table 2. To assess the validity of our assumptions, we also estimated the cases where growers are assumed to be risk-neutral and the density of the growers' productivity shocks is assumed to be log-normal, with log mean $x_t\beta$ and log variance σ^2.[7] As mentioned in Section 2, to account for possible systematic differences across tournaments, we choose $x=\{\text{constant, temperature, quality}\}$. Several estimation results are worth emphasizing.

First, note that in the distribution of productivity shocks, the constant term is highly significant and quantitatively dominates other variables. This is reflective of the fact that broiler production efficiency is mainly determined by technological parameters such as genetics, nutrition, and housing design, and is considerably less influenced by other factors (such as weather).

Among other variables, only the variable "quality" has a large negative effect on the mean of growers' productivity shocks. The deviations of the mean tournament first-week mortality rate from the long run average seem to be a good indicator of the chicks quality. In the risk-averse case with exponential density, the estimated coefficient is −0.4845, indicating that one unit increase in this variable will decrease the mean of growers' productivity shocks by 36%.

Third, the estimated risk aversion parameter α (19.8219 in the exponential density case and 25.2208 in the log-normal density case) is highly significant. Based on the estimated value of this coefficient one can calculate the implicit risk premium that a grower would be willing to pay to avoid the risk associated with the volatility of her income. Using $\alpha=19.8219$, we found that in equilibrium, the ex ante expected income for the growers in the representative tournament is \$0.1415 and the

[7] We do not allow variance σ^2 to depend on covariates as this is likely to overparameterize the model and cause estimation difficulties.

Table 3
Model selection results

	Exponential density		Log-normal density	
	Risk neutral	Risk averse	Risk neutral	Risk averse
Actual mean	4.7805			
Predicted mean	4.7693	4.7803	4.7680	4.7786

certainty equivalent income is \$0.0660. Therefore, the implied risk premium is \$0.0755, or 53.36% of the expected income.[8] Therefore, it turns out that growers are fairly risk averse.

Finally, in the risk neutral case the cost of effort parameter $\gamma=0.0535$ ($\gamma=0.1117$ in the log-normal density case) is more than twice larger than in the risk aversion case where $\gamma=0.0264$ ($\gamma=0.0565$ in the log-normal density case). The comparison of these results is quite interesting. Intuitively, given the same level of competition and the same distribution of productivity shocks, risk averse growers should exert higher effort because they cannot tolerate large losses in utility associated with placing in the worst performance bracket. Higher effort is afforded by the lower marginal cost of effort, relative to the risk neutral types. Therefore the estimated disutility of effort parameter must be smaller for risk-averse types then for the risk-neutral types.

4.2. Model selection and model fit

To assess which of the four estimated models, risk-neutral agents or risk-averse agents, and exponential density or log-normal density of the shocks, fit the data better, we perform two tasks. The first involves a simple comparison between the actual data and the model predictions, and the second involves a formal statistical model selection test. In Table 3, we report the actual and the predicted mean of outputs for all models. In general, the predicted mean outputs correspond to the actual mean outputs reasonably well, with the risk aversion models fitting the data much better. The best model is the risk aversion model with exponential density of the shocks.

Since each of the four models is estimated using NLS method, the formal model selection test follows Davidson and MacKinnon (1981).[9] The test is carried out in a pairwise fashion. As an illustration, we present the test results for the two best models: the risk aversion model with exponential density (*E*) and the risk aversion model with log-normal density (*N*). From the two competing models with moment conditions

$$E(y) = m^E(x, \varphi^E) \tag{19}$$

$$E(y) = m^N(z, \varphi^N). \tag{20}$$

where the superscript *E* and *N* denote the risk-averse model with exponential density and the risk-averse model with log-normal density respectively, we can obtain estimators $\hat{\varphi}^E$ and $\hat{\varphi}^N$ and then estimate the following regression

$$y - m^N(x,\hat{\varphi}^N) + \nabla_\varphi m^N(x,\hat{\varphi}^N)\hat{\varphi}^N = \nabla_\varphi m^N(x,\hat{\varphi}^N)\delta = \rho[m^E(z,\hat{\varphi}^E) - m^N(x,\hat{\varphi}^N)] + \varepsilon. \tag{21}$$

If $\hat{\rho}$ turns out to be significantly different from 0, then the risk aversion model with log-normal density $E(y)=m^N(x,\varphi_N)$ is rejected in favor of the alternative model. As it happens, $\hat{\rho}=-32.6517$

[8] The discussion about the choice of the representative tournament is found in the welfare simulation section.

[9] This test only tells us which of the four models is better in terms of fitting the data. We do not claim that the selected model is the true model.

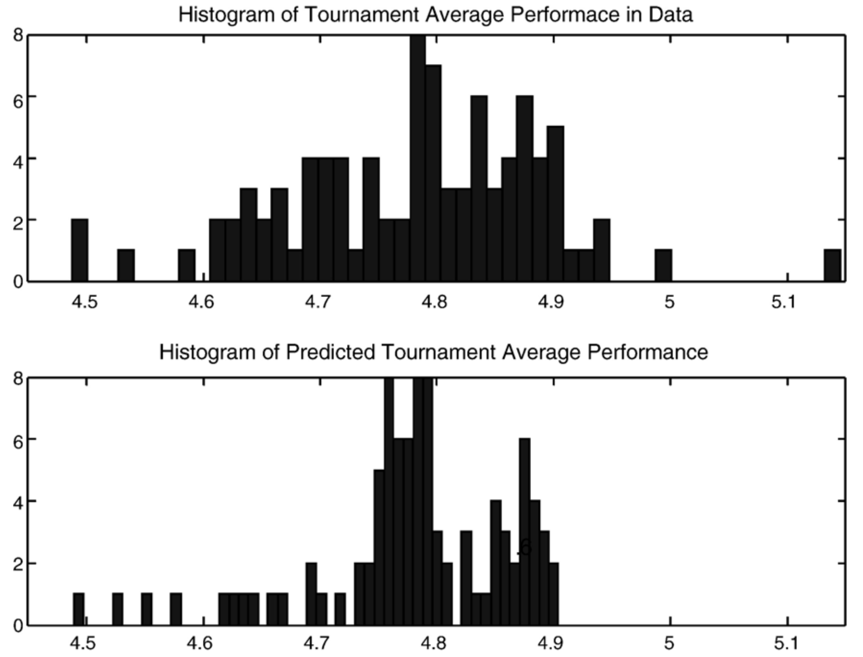

Fig. 1. Model fit.

(with t-stat=−3.5990), hence we reject the risk aversion model with log-normal density in favor of the risk aversion model with exponential density and base all policy simulations on the latter.

The comparison of the actual average tournament performance with the predicted average tournament performance, $\exp(x_t\hat{\beta})e_t^*(\hat{\varphi})$, is presented in Fig. 1. The upper panel displays the histogram of the actual average tournament performance and the lower panel displays the histogram of the predicted average tournament performance. The picture shows that, although this is not a perfect match, the two histograms are very similar in shape, indicating that our model fits the data reasonably well.

5. Welfare simulation under cardinal tournament

In this section we use the estimates of the productivity shocks density, the utility function, and the cost of effort function to simulate how changing the payment mechanism affects the total welfare and the distribution of welfare between the growers and the integrator. When the payment mechanism changes, growers will change their equilibrium effort levels in response to the changes in incentives, which will have with both efficiency and distributional consequences.

In a cardinal tournament, the payment to a grower no longer exclusively depends on her rank, but also depends on the absolute performance level. In cardinal tournaments used to settle broiler production contracts the grower payment is calculated using the following formula

$$R_i = \left[\left(a + b\left(\frac{1}{N}\sum_{j=1}^{N}\frac{1}{y_j} - \frac{1}{y_i}\right)\right)\right] y_i \tag{22}$$

where a is the base payment per pound of live weight produced and $0<b\leq 1$ is the slope parameter that determines the relative importance of the bonus payment in the total grower compensation. Under a cardinal tournament, grower i will receive a bonus if her performance is better than the group average performance and will receive a penalty if her performance is worse than the group average. Extending the same basic assumptions from the rank-order model the payoff to grower i in cardinal tournament t becomes

$$\begin{aligned}\pi_{it} &= U\left(\theta_{it}e_{it}\left[a+b\left(\frac{1}{N_t}\sum_{j=1}^{N_t}\frac{1}{\theta_{jt}e_{jt}}-\frac{1}{\theta_{it}e_{it}}\right)\right]-C(e_{it})\right)\\ &= U\left(\theta_{it}e_{it}a+b\frac{1-N_t}{N_t}+\theta_{it}e_{it}b\frac{1}{N_t}\sum_{j\neq i}\frac{1}{\theta_{jt}e_{jt}}-C(e_{it})\right).\end{aligned} \tag{23}$$

When growers make decisions, the efficiency shocks have not yet been realized, hence each grower maximizes her ex ante expected utility $E\pi_{it}$ with respect to e_{it}, given all other growers exert the same effort $e_{jt}=e_t^*$ for $j\neq i$,

$$\begin{aligned}E\pi_{it} = \int\ldots\int & U\left(\theta_{it}e_{it}a+b\frac{1-N_t}{N_t}+\theta_{it}e_{it}b\frac{1}{N_t}\sum_{j\neq i}\frac{1}{\theta_{jt}e_t^*}-C(e_{it})\right)\\ & *g(\theta_{it}|x_t,\beta)\prod_{j\neq i}g(\theta_{jt}|x_t,\beta)d\theta_{1t\ldots}d\theta_{N_t t}.\end{aligned} \tag{24}$$

The equilibrium solution to this problem can be characterized by the first order condition

$$\begin{aligned}\int\ldots\int & U'\left(\theta_{it}e_{it}a+b\frac{1-N_t}{N_t}+\theta_{it}e_{it}b\frac{1}{N_t}\sum_{j\neq i}\frac{1}{\theta_{jt}e_t^*}-C(e_{it})\right)\\ * & \left(\theta_{it}a+\theta_{it}b\frac{1}{N_t}\sum_{j\neq i}\frac{1}{\theta_{jt}e_t^*}-C'(e_{it})\right)g(\theta_{it}|x_t,\beta)\prod_{j\neq i}g(\theta_{jt}|x_t,\beta)d\theta_{1t\ldots}d\theta_{N_t t}=0\end{aligned} \tag{25}$$

and in equilibrium $e_{it}=e_t^*$. Furthermore, the second order sufficient condition is

$$\begin{aligned}\int\ldots\int & U''\left(\theta_{it}e_{it}a+b\frac{1-N_t}{N_t}+\theta_{it}e_{it}b\frac{1}{N_t}\sum_{j\neq i}\frac{1}{\theta_{jt}e_t^*}-C(e_{it})\right)\\ * & \left(\theta_{it}a+\theta_{it}b\frac{1}{N_t}\sum_{j\neq i}\frac{1}{\theta_{jt}e_t^*}-C'(e_{it})\right)^2 g(\theta_{it}|x_t,\beta)\prod_{j\neq i}g(\theta_{jt}|x_t,\beta)d\theta_{1t\ldots}d\theta_{N_t t}\\ -\int\ldots\int & U'\left(\theta_{it}e_{it}a+b\frac{1-N_t}{N_t}+\theta_{it}e_{it}b\frac{1}{N_t}\sum_{j\neq i}\frac{1}{\theta_{jt}e_t^*}-C(e_{it})\right)\\ * & C''(e_{it})g(\theta_{it}|x_t,\beta)\prod_{j\neq i}g(\theta_{jt}|x_t,\beta)d\theta_{1t\ldots}d\theta_{N_t t}<0.\end{aligned} \tag{26}$$

Again, with usual assumptions that $C'>0$, $C''>0$, $U'>0$ and $U''<0$, the second order condition is satisfied for all values of e_{it}. Hence, the symmetric equilibrium is unique.

To quantify the welfare effects of a switch from the ordinal tournament to the cardinal tournament, we run a counterfactual experiment for a representative tournament. We pick the 46th tournament in our data set. We chose this tournament because the sum of the absolute deviations

Table 4
Welfare effects of switching from ordinal to cardinal tournaments

	Ordinal tournament	Cardinal tournament	
Equilibrium effort	0.7799	0.7905	
Total output (pounds)	39.0116	39.5418	
Total payment ($)	1.2889	1.2276	
Grower's profits ($)			Profit increase (%)
1 (best)	0.1774	0.1612	−9.12
2	0.1773	0.1610	−9.23
3	0.1618	0.1559	−3.63
4	0.1606	0.1482	−7.74
5	0.1458	0.1467	0.62
6	0.1452	0.1420	−2.17
7	0.1306	0.1420	8.73
8 (worst)	0.1261	0.1047	−16.97

of its covariates from their averages is the smallest in the entire data set. Therefore, we expect that if we were to conduct the counterfactual experiments for all tournaments in the data set and average them out, the final result would be very similar to the result reported below.[10]

The experiment is carried out as follows. First, with the estimated model primitives, we compute the equilibrium effort level e^*_{rank} using the rank order tournament model. With e^*_{rank}, we then recover the productivity shocks for each grower in this tournament. Second, we compute the new equilibrium effort level e^*_{cardinal} for this group of growers under the new cardinal mechanism. We set $a=\$0.031$ and $b=1$ such that the growers' ex ante expected utility remains the same after the mechanism switch. Keeping the ex-ante utility constant does not change the growers' participation constraint and therefore guarantees that the pool of growers that signed the old contract would not change because some growers who didn't like the new contract would have refused to sign it.[11] Finally, with the productivity shocks recovered from the first step and the new equilibrium effort level computed from the second step, we can compute the performance of each grower in the new cardinal tournament and hence their payments and other welfare measures.

Table 4 collects the simulation results, several of which are worth emphasizing. First, with the mechanism switch, the equilibrium effort increases from 0.7799 to 0.7905. This implies that everything else being equal, the cardinal tournament leads to a higher equilibrium effort. Second, as a result of higher equilibrium effort, the total output from this tournament given the same inputs increases from 39.0116 lb to 39.5418 lb, or an 1.36% increase. At the same time, the total payment from the principal to all eight growers decreases from $1.2889 to $1.2276 as the result of a decrease in the average payment per pound of chicken from $0.033 to $0.031. Assuming that the principal operates in a perfectly competitive broiler meat market, he can sell all his additional output at the prevailing market price. In this case his profit margin would go up by $0.002 per pound and he can also sell more pounds. Hence, the principal clearly gains from the mechanism switch.

[10] We also ran the experiment for another tournament whose average tournament performance is closest to the mean performance of the entire dataset and obtained very similar results.

[11] To search for the parameters that keep the growers' ex ante expected utility the same in both tournament schemes, we fix $b=1$ and search for the corresponding value of the base payment a. In observed contracts, b is usually set to 1, but can sometimes vary between 0.5 and 1.

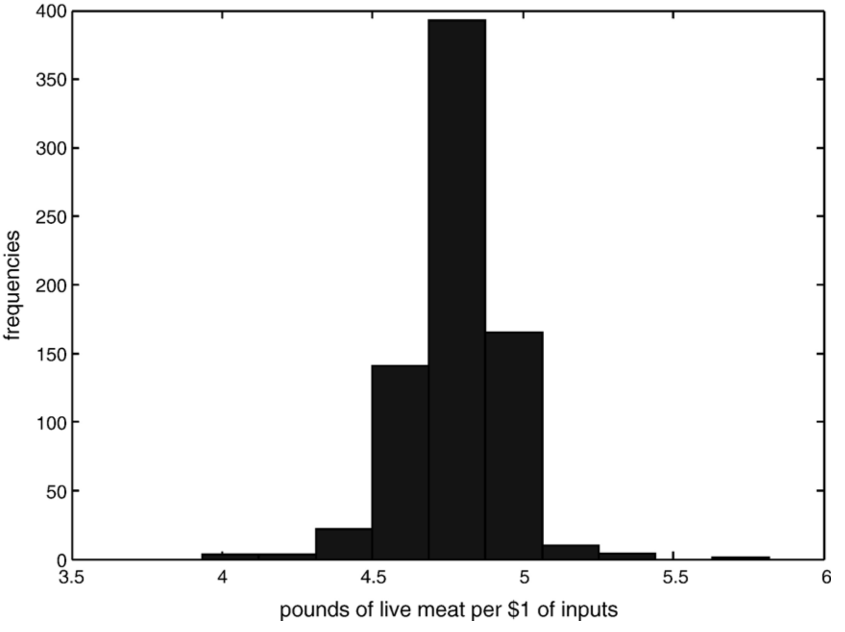

Fig. 2. Histogram of performance.

Looking at the growers' side, their profit changes range from −16.97% to 8.73%. Expressed in the utility terms, the interval ranges from −4.73% to 1.64%. As seen from Table 4, most growers lose substantially. This is caused by lowering of the average payment per pound of chicken (from \$0.033 to \$0.031) and the fact that in the cardinal tournament they exert higher equilibrium effort. However, the growers in the lower performance brackets (except the grower with the worst performance) either gain or do not lose very much. This is most likely caused by the fact that growers whose actual performances were ranked in the last two brackets might differ just slightly from the growers in the second-best or in the first-best bracket. Therefore, their losses due to the lower base payment and higher equilibrium effort are partially or fully compensated. In fact, as can be seen from Fig. 2, grower performances are tightly clustered around the mean,[12] and therefore it is obvious that agents can either gain or lose in the tournament switch, depending on their realized productivity shocks.

6. Conclusion

This paper was motivated by our studying of the historical developments in the organization of broiler industry in the U.S. and the evolution of payment mechanisms used by poultry firms to settle their production contracts with independent growers. The fact that modern broiler contracts are almost exclusively settled based on cardinal tournaments and all earlier schemes, such as rank-

[12] Note that Fig. 2 is different from the top panel of Fig. 1. The top panel of Fig. 1 is the histogram of average performance at the tournament level (93 observations) and Fig. 2 is a histogram of the performance at the grower level (744 observations).

order tournaments, became gradually extinct presents itself as an interesting research inquiry into the possible efficiency gains associated with this organizational innovation.

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 posses, 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 uniform (one type fits all abilities) 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. As shown by Levy and Vukina (2002), when the principal operates in a perfectly competitive environment such that zero profit condition binds and the agents are risk averse, the optimal linear contract is an individualized contract indexed by the abilities of the agents.

In this paper we maintain the assumption that growers are ex ante identical and proceed with estimating a structural model based on the symmetric Nash-equilibrium of a rank-order tournament game. In light of the existing literature on broiler production tournaments, this assumption is controversial but defendable. Knoeber and Thurman (1994) and Levy and Vukina (2004) have shown that broiler growers are heterogeneous. These results were obtained by showing that individual growers' fixed effects are significant. However, Leegomonchai and Vukina (2005) have shown 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.[13]

The estimated primitives of the model are then used to perform a counterfactual simulation of the cardinal tournament game where the growers' ex ante expected utility is kept the same as in the original rank-order tournament. The features of the cardinal tournament game correspond exactly to the payment mechanism that the same broiler company used after abandoning the rank-order tournament compensation scheme. We found that, even under the assumption of grower homogeneity, switching from a rank-order tournament to a cardinal tournament improved efficiency. The integrator gained by being able to increase output and by reducing the average grower payment. On the other hand, some of the contract growers gained and some lost depending on their realized productivity shocks.

This paper contributes to the literature in a couple of ways. First, to the best of our knowledge, the welfare comparison of rank-order and cardinal tournaments has not been done. There are many theoretical papers comparing relative performance schemes against piece rates, but the comparison of two different types of relative performance mechanisms has escaped the attention of both theorists and applied economists. In addition, our paper represents the first attempt to estimate a structural model of an empirically observed rank-order tournament as a strategic game played by the contestants. This approach has been widely used in the empirical literature on auctions as pioneered by Paarsch (1992), with recent additions by Guerre, Perrigne and Vuong

[13] Another reason for assuming ex-ante homogeneous players is the fact that modeling a rank-order tournament game with heterogenous players is extremely difficult. This is something that we will try to confront in our future research.

(2000), Haile, Hong and Shum (2002), Bajari and Hortaçsu (2003), Li and Zheng (2005), to name a few, but not in the empirical literature on labor tournaments.

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