J Ind Compet Trade
DOI 10.1007/s10842-016-0233-0

A Stochastic Production Frontier Estimator of the Degree of Oligopsony Power in the U.S. Cattle Industry

Dimitrios Panagiotou[1] · **Athanassios Stavrakoudis**[1]

Received: 15 October 2015 / Revised: 20 June 2016 / Accepted: 6 September 2016

Abstract The objective of this study is to estimate the degree of oligopsony power in the U.S. cattle industry with the use of the recently developed stochastic frontier estimator of market power. Unlike the seminal paper where estimation of the mark-up in an output market at firm level was the main objective, this work proposes a stochastic production frontier estimator in order to estimate the mark-down in an input market at aggregate level. Furthermore, with the help of the new estimator we derive and estimate the Lerner index of oligospony power for the U.S. cattle market. For the empirical part of the study we employed annual time series data from the U.S. cattle/beef industry for the time period 1970-2009. Our results suggest that beef packers exert market power when purchasing live cattle for slaughter.

Keywords Cattle · Stochastic frontier analysis · Oligopsony · Market power

JEL Classification Q11 · C13 · L66

1 Introduction

The U.S. agricultural sector has been revolutionized by a process called agricultural industrialization. This process refers to the production, coordination, and distribution of food products using modern methods typically associated with industrial manufacturing. In the beef sector, the benefits of industrialization include higher productivity and the availability of leaner and higher quality beef products.

✉ Dimitrios Panagiotou
dpanag@cc.uoi.gr

Athanassios Stavrakoudis
astavrak@uoi.gr

[1] Department of Economics, University of Ioannina, Ioannina, Greece

Published online: 22 September 2016

Despite these benefits, some aspects of industrialization raise questions about the performance of the beef marketing system. One particular aspect is rising concentration in the beef-packing industry and its effect on live cattle prices. Since the 1980s, the U.S. fed–cattle industry has experienced shifts of production to larger farms. At the same time, the beef-packing industry has become much more concentrated than cattle feeding (MacDonald and McBride 2009). Data from the United States Department of Agriculture – Packers and Stockyards Program (2014) show that both the number and the size distribution of beef-packing plants has changed dramatically in the recent years. Between 1980 and 2012 the number of plants decreased from 704 to 168 and the share of the top four firm in steer and heifer slaughter increased from 35.7 % to 85 %. During the years, the four-firm concentration ratio (CR4) reached the level of 85 percent in 2010, dropped to 84 percent in 2011, and raised again to 85 percent in 2012. According to the same report, the four-firm concentration ratio has remained around 80 % in the last ten years. In theory, the higher the CR4, meaning the closer it approaches 100 %, the greater the likelihood the four largest firms are exercising market power.

Whether such high levels of concentration are detrimental to competition in live cattle markets has been the subject of many studies using different economic models, time spans, and statistical techniques. More importantly, as more slaughter cattle is now procured through contracts, otherwise know as captive supplies, there is also concern that packers may also manipulate cash prices to influence the base price used to negotiate contracts.

Higher levels of concentration generally lead to lower prices paid for fed cattle indicating that the beef-packing industry exerts some degree of market power when procuring live cattle (Azzam, 1997; Cai et al., 2011a, b; Marion and Geithman, 1995). That degree of oligopsonistic power, according to some studies, is not large enough to warrant concern (Schroeter 1988; Azzam and Schroeter 1991). In most of these studies, the magnitude of market power is relatively small and seemingly within an acceptable public policy level (Ward 2010). On the other hand, since beef-packing is a high-volume/low-margin business (Ward 2002), some researchers argue that given the large volume of cattle slaughtered every year, even a small degree of market power can translate into large transfers from the cattle producers to beef-packers. Hence, a seemingly small impact in dollars per hundredweight ($/cwt) can make a substantial difference (losses) to livestock producers (Ward 2010). Yet some authors report that losses to cattle producers are more than offset by the cost savings generated by increased concentration in the beef-packing industry, suggesting this way that structural changes are beneficial from an efficiency viewpoint (Sexton 2000; Azzam and Schroeter 1995). Lastly, some studies find no evidence of market power exercised by the beef packers during the time period considered in their study (Paul, 2001a, b).

Granted that there is merit to each of the preceding arguments, all of them hang to a large degree on the academic research that guides them. The most influential research in the past few years has been what is commonly known as the New Empirical Industrial Organization (NEIO). In a nutshell, NEIO is an econometric approach that treats market power as a parameter to be inferred from single industries data (Bresnahan 1989).

Against this background, the objective of the present work is to revisit the econometric problem of estimating the degree of oligopsony power in the U.S. cattle industry with the use of the recently developed stochastic frontier (SFA) estimation technique by Khumbhakar, Baardsen and Lien (2012). In their article, Kumbhakar et al. (2012) propose a new method of estimating market power in an output market at firm level. They draw on the stochastic frontier methodology from the efficiency literature in order to estimate markups in the Norwegian sawmilling industry. The authors use both primal and dual specifications to represent the technology and consequently estimate the degree of oligopoly power. Both approaches reveal statistically significant evidence of market power. The primal and dual specifications of the technology is a big advantage of the stochastic frontier approach of market power estimation: in an output market, based on duality theory of cost and input distance functions, either input price data or quantity price data can be used. On the other hand, duality of revenue functions and output distance functions can be utilized for the case of the input market. Furthermore, the stochastic frontier estimation technique allows us to estimate market power under constant or variable returns to scale, which is not always the case in the NEIO approach, providing us with more flexibility in the measurement of mark-ups/downs of an industry.

In the most recent paper, Bairagi and Azzam (2014) used the stochastic frontier estimator in order to test if the Grammen Bank exercises market power over borrowers. The authors employed a stochastic translog cost function. More specifically, the authors used annual time series for the 1985-2012 period in order to test whether the Grameen Bank's lending rates are consistent with marginal cost pricing. Their results indicated that on average the lending rate is about 3 % above marginal cost.

This study proposes a stochastic production frontier estimator in order to estimate the mark-down in an input market at industry level. The input market under investigation is the U.S. cattle industry. To the best of our knowledge, there has been no published work which has used the stochastic frontier approach in order to estimate the degree of oligopsony power exercised by the U.S. beef–packing industry when procuring live cattle.

The present work is structured as follows: Section 2 contains the theoretical framework. Section 3 presents the empirical model to be estimated at aggregate level and Section 4 the data and estimation results. Section 5 provides a summary and conclusion.

2 Theoretical Framework

2.1 Beef packing firm

The starting point of this work is the profit maximizing beef packing firm. The profits for a beef processor (i) are given by:

$$\begin{aligned}\Pi_i &= R_i(P, x_i, z_i) - W_x(X)\, x_i - W_z\, z_i \\ &= P\, q_i(x_i, z_i) - W_x(X)\, x_i - W_z\, z_i \\ &= P\, f(x_i, z_i) - W_x(X)\, x_i - W_z\, z_i \end{aligned} \tag{1}$$

where x_i is the cattle input and z_i the rest of the inputs employed by firm i in order to produce beef (q_i). Beef is a homogeneous good sold at price P. In this study, we assume that the packer has no degree of market power when selling the beef output. On the other hand, the packer has some degree of oligopsonistic power when purchasing live cattle. The price of cattle is W_x, where $W_x = W_x(X)$. The rest of the inputs employed by the processor in the production of beef are competitively priced (W_z).

Profit maximization with respect to the livestock input means that:

$$\frac{\mathrm{d}\Pi_i}{\mathrm{d}x_i} = 0 \tag{2}$$

Using (1) we get:

$$\frac{d\Pi_i}{dx_i} = \frac{d(P\,f(x_i, z_i))}{dx_i} - W_x - \frac{dW_x(X)}{dX}\frac{dX}{dx_i}x_i = 0$$
$$\frac{P\,df(x_i, z_i)}{dx_i} - W_x = \frac{dW_x(X)}{dX}\frac{dX}{dx_i}x_i \tag{3}$$

The expression $\frac{dX}{dx_i}$ captures the increase in total cattle supply induced by an increase in processor i's demand for cattle. After rearrangement of (3) we get:

$$P\,\frac{df(x_i, z_i)}{dx_i} = W_x\,(1 + \frac{\phi_i}{\epsilon})$$
$$P\,\times MP_{x_i} = W_x\,(1 + \frac{\phi_i}{\epsilon})$$
$$MVP_{x_i} = W_x\,(1 + \frac{\phi_i}{\epsilon}) \tag{4}$$

where ϵ is the elasticity of cattle supply and is positive, and $\phi_i = \frac{dX}{dx_i}\frac{x_i}{X}$ is the conjectural variation elasticity parameter. The values of the parameter ϕ_i range from zero to one. This means that from (4) we get the following inequality:

$$W_x < MVP_{x_i}$$
$$W_x < P \times MP_{x_i} \tag{5}$$

If we multiply both sides of the above equation by $(\frac{1}{P}\frac{x_i}{q_i})$ we get:

$$\frac{1}{P}\frac{x_i}{q_i}W_x < \frac{1}{P}\frac{x_i}{q_i}P\,\frac{dq_i}{dx_i}$$
$$\frac{x_i\,W_x}{P\,q_i} < \frac{d\ln q_i}{d\ln x_i} \tag{6}$$

We can transform the inequality in (6) to an equality by adding a non–negative, one–sided term u_i:

$$\frac{x_i\,W_x}{P\,q_i} + u_i = \frac{d\ln q_i}{d\ln x_i}, \quad u_i \geqslant 0$$

or

$$\frac{x_i\,W_x}{P\,q_i} = \frac{d\ln q_i}{d\ln x_i} - u_i \tag{7}$$

2.2 Translog representation of a stochastic frontier production function for the beef packing firm

Azzam and Pagoulatos (1990) used a translog production function in order to estimate the indices of market power in the U.S. red meat industry. As the authors point out, a translog production function does not impose severe a priori constraints on the production characteristics in the industry. By employing a translog production function the authors dispense with the necessity of assuming fixed proportions for the input of interest. There is well documented research that food processing industries are characterized by input substitutability. Wohlgenant (1989) found evidence of substantial substitution possibilities between farm inputs and marketings inputs for beef and veal. In addition, Wohlgenant (1989) concluded that technological changes in the food industries have allowed for greater input substitutability. In the light of the preceding we employ a variable proportions technology in order to represent the production process in the beef packing sector. More specifically, for a beef processor i, the production process is captured by the following translog production function:

$$\begin{aligned}\ln q_i = {} & \beta_0 + \beta_t\, t + \frac{1}{2}\,\beta_{tt}\, t^2 + \beta_{xt}\, \ln x_i\, t + \beta_{Kt}\, \ln K_i\, t + \beta_{Lt}\, \ln L_i\, t \\ & + \beta_{Et}\, \ln E_i\, t + \beta_x\, \ln x_i + \beta_K\, \ln K_i + \beta_L\, \ln L_i + \beta_E\, \ln E_i \\ & + \frac{1}{2}\,\beta_{xx}\, (\ln x_i)^2 + \frac{1}{2}\,\beta_{KK}\, (\ln K_i)^2 + \frac{1}{2}\,\beta_{LL}\, (\ln L_i)^2 \\ & + \frac{1}{2}\,\beta_{EE}\, (\ln E_i)^2 + \frac{1}{2}\, lnx_i\, (\beta_{xK}\, \ln K_i + \beta_{xL}\, \ln L_i + \beta_{xE}\, \ln E_i) \\ & + \frac{1}{2}\, \ln K_i\, (\beta_{Kx}\, \ln x_i + \beta_{KL}\, \ln L_i + \beta_{KE}\, \ln E_i) \\ & + \frac{1}{2}\, \ln L_i\, (\beta_{Lx}\, \ln x_i + \beta_{LK}\, \ln K_i + \beta_{LE}\, \ln E_i) \\ & + \frac{1}{2}\, \ln E_i\, (\beta_{Ex}\, \ln x_i + \beta_{EK}\, \ln K_i + \beta_{EL}\, \ln L_i) \end{aligned} \tag{8}$$

where x_i=cattle input, L_i=labor, K_i=capital, and E_i=energy are employed by processor i in order to produce q_i=beef output. The time index t is included to account for technological progress. The above function is assumed to satisfy the following restrictions: $\beta_{xL} = \beta_{Lx}$, $\beta_{xE} = \beta_{Ex}$, $\beta_{xK} = \beta_{Kx}$, $\beta_{LK} = \beta_{KL}$, $\beta_{LE} = \beta_{EL}$, and $\beta_{KE} = \beta_{EK}$.

From (8), the expression for $\frac{\mathrm{d}\ln q_i}{\mathrm{d}\ln x_i}$ becomes:

$$\frac{\mathrm{d}\ln q_i}{\mathrm{d}\ln x_i} = \beta_x + \beta_{xt}\, t + \beta_{xx}\, \ln x_i + \beta_{xL}\, \ln L_i + \beta_{xK}\, \ln K_i + \beta_{xE} \ln E_i \tag{9}$$

Substituting (9) into (7) we get the stochastic version of the profit maximizing relationship for the beef packing firm:

$$\frac{W_x\, x_i}{P\, q_i} = \beta_x + \beta_{xt}\, t + \beta_{xx}\, \ln x_i + \beta_{xL}\, \ln L_i + \beta_{xK}\, \ln K_i + \beta_{xE}\, \ln E_i - u_i + e_i \tag{10}$$

The composed error term $(-u_i + e_i)$ in (10) is no different than the one from a stochastic production frontier model.[1] Hence, (10) can be estimated using the maximum likelihood method which is commonly used to estimate a stochastic production frontier. The maximum likelihood method is based on the distributional assumption of the errors. Following the literature, the distributional assumptions are that u_i is a normal variable truncated at zero from below, i.e. $u_i \sim N^+(0, \sigma^2_{u_i})$, and e_i is the usual two-sided normal noise term, i.e. $e_i \sim N(0, \sigma^2_{e_i})$. In this work, unlike the stochastic frontier analysis approach, the one-sided term u_i in (10) does not account for the inefficiency in production, but for the mark-down in the cattle market for a beef packing firm.

2.3 A stochastic production frontier estimator of oligopsony power for the beef packing firm

In this work we define the degree of market power exerted by the i^{th} beef packing firm as:

$$\theta_i = \frac{MVP_{x_i} - W_x}{MVP_{x_i}} \tag{11}$$

[1] For a translog representation of a stochastic production frontier one can refer to Ray (1999), Kumbhakar and Lovell (2003), Kumbhakar (2011).

Re-arranging (11) we get:

$$\begin{aligned}\theta_i &= \frac{MVP_{x_i} - W_x}{P \times MP_{x_i}} = \frac{MVP_{x_i} - W_x}{P\,(\frac{\mathrm{d}q_i}{\mathrm{d}x_i})} \\ &= \frac{MVP_{x_i} - W_x}{(\frac{q_i}{x_i})\,P\,(\frac{\mathrm{d}q_i}{\mathrm{d}x_i})(\frac{x_i}{q_i})} = \frac{(\frac{x_i}{P\,q_i})(MVP_{x_i} - W_x)}{(\frac{\mathrm{d}\ln q_i}{\mathrm{d}\ln x_i})} \\ &= \frac{(\frac{x_i}{P\,q_i})[P\,(\frac{\mathrm{d}q_i}{\mathrm{d}x_i})] - (\frac{x_i}{P\,q_i})\,W_x}{(\frac{\mathrm{d}\ln q_i}{\mathrm{d}\ln x_i})} \\ &= \frac{(\frac{\mathrm{d}\ln q_i}{\mathrm{d}\ln x_i}) - (\frac{x_i\,W_x}{R_i})}{(\frac{\mathrm{d}\ln q_i}{\mathrm{d}\ln x_i})} = \frac{(\frac{\mathrm{d}\ln q_i}{\mathrm{d}\ln x_i}) - (\frac{\mathrm{d}\ln q_i}{\mathrm{d}\ln x_i} - u_i)}{(\frac{\mathrm{d}\ln q_i}{\mathrm{d}\ln x_i})} = \frac{u_i}{(\frac{\mathrm{d}\ln q_i}{\mathrm{d}\ln x_i})}\end{aligned}$$

Hence, the relationship between the degree of market power θ_i and the mark down term u_i is given by the equation below:

$$\theta_i = \frac{u_i}{(\frac{\mathrm{d}\ln q_i}{\mathrm{d}\ln x_i})} \tag{12}$$

After estimating u_i from (10) and with the help of the expression in (9), we can proceed with the estimation of θ_i as:

$$\hat{\theta}_i = \frac{\hat{u_i}}{(\hat{\beta}_x + \hat{\beta}_{xt}\,t + \hat{\beta}_{xx}\,\ln x_i + \hat{\beta}_{xL}\,\ln L_i + \hat{\beta}_{xK}\,\ln K_i + \hat{\beta}_{xE}\,\ln E_i)} \tag{13}$$

The mark-down parameter θ_i of (11) can be expanded as:

$$\theta_i = \frac{MVP_{x_i} - W_x}{MVP_{x_i}} = \frac{(\frac{MVP_{x_i}}{MVP_{x_i}}) - (\frac{W_x}{MVP_{x_i}})}{(\frac{MVP_{x_i}}{MVP_x})} = 1 - \frac{W_x}{MVP_{x_i}}$$

Solving the above equation we get:

$$(1 - \theta_i) = \frac{W_x}{MVP_{x_i}} \tag{14}$$

Equation (14) will be used in order to derive the relationship between the Lerner index of market power and the degree of market power θ_i for the case of a single beef processor i:

$$\begin{aligned}L_i &= \frac{MVP_{x_i} - W_x}{W_x} = \frac{(\frac{MVP_{x_i}}{MVP_{x_i}}) - (\frac{W_x}{MVP_{x_i}})}{(\frac{W_x}{MVP_{x_i}})} \\ &= \frac{1 - (1 - \theta_i)}{(1 - \theta_i)} = \frac{\theta_i}{1 - \theta_i}\end{aligned}$$

Hence, after estimating θ_i with the help of (13), the Lerner index of oligopsony power for the beef packer i can be estimated as:

$$\hat{L}_i = \frac{\hat{\theta}_i}{1 - \hat{\theta}_i} \tag{15}$$

3 Aggregation and Empirical Model

The absence of panel data on firm-level suggests that we can neither estimate the mark down term u_i nor the degree of market power θ_i. As a consequence, we cannot proceed with the estimation of the Lerner index of oligopsony power exercised by the U.S. beef packing firms when purchasing live cattle. This limitation leads us to consider the problem at aggregate level. In order to achieve this we make the assumption that in equilibrium the conjectural variation elasticities do not vary across firms (Appelbaum 1982). This means that ϕ_i=Φ for every beef-packer in the industry. As Azzam and Pagoulatos (1990) point out, maintaining the invariance of the conjectural variation across firms enables us to drop the subscript i on the marginal products and consider the result as a weighted industry marginal product, where the weights are each firm's share in the cattle market.

More specifically, multiplying through (3) by $\frac{x_i}{X}$ and summing across the N firms of the industry we obtain the aggregate supply relation:

$$\sum_{i=1}^{N} \frac{x_i}{X} \, P \, MP_{x_i} = \sum_{i=1}^{N} \frac{x_i}{X} \, W_x + \sum_{i=1}^{N} \frac{x_i}{X} \, W_x \, \frac{\Phi}{\epsilon} \tag{16}$$

move the constant terms out of the summations:

$$P \sum_{i=1}^{N} \frac{x_i}{X} \, MP_{x_i} = W_x \sum_{i=1}^{N} \frac{x_i}{X} + W_x \, \frac{\Phi}{\epsilon} \sum_{i=1}^{N} \frac{x_i}{X} \tag{17}$$

and since $\sum_{i=1}^{N} \frac{x_i}{X} = 1$, we get:

$$P \times MP_x = W_x + W_x \, \frac{\Phi}{\epsilon} \tag{18}$$

where $MP_x = \sum_{i=1}^{N} \frac{x_i}{X} \, MP_{x_i}$ is the weighted industry marginal product (Azzam and Pagoulatos 1990).

Hence, the industry analogue of (4) is:

$$MVP_x = W_x \, (1 + \frac{\Phi}{\epsilon}), \tag{19}$$

where $\frac{\Phi}{\epsilon}$ represents the industry-wide index of market power in the livestock market. Since ϵ and Φ are positive, the equality of (19) can be written in the form of an inequality as:

$$W_x < MVP_x \tag{20}$$

The inequality in (20) has the same direction as the inequality in (5). Multiplying through by $(\frac{1}{P}\frac{X}{Q})$, adding a positive term u in order to transform the above inequality to an equality and following the same procedure described in Section 2, but at market level, we arrive at the following relationship:

$$\frac{W_X \, X}{P \, Q} = B_X + B_{Xt} \, t + B_{XX} \, \ln X + B_{XL} \, \ln L + B_{XK} \, \ln K + B_{XE} \, \ln E - u + e \tag{21}$$

The main difference between (10) and (21) is that the former is at firm level while the latter is at industry level. Estimation of (21) will provide us with estimates of the term u

at market level. After estimating u, we can estimate the degree of market power θ for the industry as:

$$\hat{\theta} = \frac{\hat{u}}{(\hat{B}_X + \hat{B}_{Xt}\, t + \hat{B}_{XX}\ \ln X + \hat{B}_{XL}\ \ln L + \hat{B}_{XK}\ \ln K + \hat{B}_{XE}\ \ln E)} \tag{22}$$

It is clear from (22) that the estimate of the parameter θ depends on the estimated values of u as well as on the relevant parameters of the translog production function.

Finally, the Lerner index of market power exercised by the U.S. beef-packing industry when procuring live cattle will be estimated as:

$$\hat{L} = \frac{\hat{\theta}}{1 - \hat{\theta}} \tag{23}$$

4 Data and Estimation Results

The data used for the empirical analysis are annual aggregate time series for the U.S. beef–packing and cattle industies. Data were obtained from the National Bureau of Economic Research–Manufacturing Industry Database (2015) for SIC2011 (meatpacking) and from the United States Department of Agriculture Economic Research Service (2015a, b). Observations refer to the period 1970–2009. The sample period was dictated by data availability. The year 2009 is the most recent year for which data from the National Bureau of Economic Research (NBER) are reported. A detailed description of the data and their sources can be found in the Appendix.

Inputs at the processing stage are divided into three categories: labor (L), capital (K) and energy (E). Data for these three factors of production are available for the U.S. red meat industry as a whole (NBER–SIC 2011).[2] In order to quantitatively account for the levels of labor, capital and energy employed specifically for the production of beef, we multiply the aggregate levels of the above mentioned factors of production with the percentage of the beef product in relationship with the rest of the meat products.

Capital is taken into account as a quasi-fixed input. The annual user cost of capital was calculated as the sum of the real interest rate and the depreciation rate.[3] Energy was deflated in order to obtain an approximation to the physical quantity used in this study. Time accounts for technological change and assumes the values between one (for the observation year of 1970) and forty (for the last observation year of 2009). Table 1 provides the definition of variables used in estimating (21) and presents their respective descriptive statistics.

The estimates of the parameters of the translog production function employed in estimating (21) are presented in Table 2.[4] All estimates are statistically significant at the 1 % level of significance or less with the exception of the time parameter.

Table 3 presents estimates and (bootstrap) standard errors of the relevant parameters of the model: the mark-down term u, the degree of market power θ as expressed in (22), and the Lerner index of oligopsony power (L) as measured in (23). All estimates are statistically different than zero. The estimated value of the mark-down parameter u is 0.9680.

[2] Red meat includes beef, pork, lamb and veal.

[3] Assuming a 20-year equipment working life in the food processing industry and a linear form, a value of 0.05 was applied to the depreciation rate (Lopez et al. 2015).

[4] Due to non-convergence, the labor parameter has been omitted.

Table 1 Variable definition and descriptive statistics (21)

Variable	Description	Mean	St. Dev.	Min	Max
wX	Cost of livestock input (billion \$)	34.1	9.7	14	52.8
PQ	Wholesale value of beef (billion \$)	39.8	11.7	16.5	62.4
X	Cattle (billion lbs)	24.3	1.7	21.3	27.3
L	Production workers(million hrs)	245.8	27.8	197.6	299.8
K	Real capital stock(million physical units)	4244.7	337.6	3452.9	4962.2
E	Electricity and fuels(million Kws+gallons)	185.9	46	129.4	301.9
t	Time trend (1=1970, 40=2009)	20.5	11.7	1	40

The estimate of the degree of market power θ of 0.1862, suggesting that, on average, the price received by the cattle producers is 18.62 % lower than the net value of the marginal product of cattle. Lastly, the estimate of the Lerner index of market power takes the value of 0.2289, indicating that, on average, the cattle's net marginal value product is 1.229 times above the price of cattle.

Qualitatively, our results are comparable to studies that have concluded that U.S. beef-packers exert market power when purchasing finished cattle for slaughter. More specifically, Schroeter (1988) finds evidence of oligopsonistic distortions in the fed cattle market. Schroeter and Azzam (1990) conclude that market power is exerted by U.S. beef packers in the cattle as well as in the beef output markets. Koontz et al. (1993) find evidence of oligopsonistic power in regional fed cattle markets. In the same year, Stiegert et al. (1993) and Azzam and Park (1993) suggest that oligopsonistic power is exercised in the livestock market by the beef–packing industry at national level for the time periods 1972-1986 and 1978-1987, respectively. Azzam (1996) constructs an empirical bilateral oligopoly model and results reveal evidence of market power in the beef slaughter industry. In the following year, Azzam (1997) and Koontz and Garcia (1997) conclude that beef packers exert oligopsonistic power when procuring live cattle, at national and regional levels, respectively. Azzam (1998) suggests that the empirical relationship between captive supplies and the price of cattle paid to producers is negative, a result that might be attributed to the presence of oligopsonistic conduct in the livestock sector. After 2000, there are also quite a few studies that confirm the presence of oligopsonistic power in the U.S. cattle industry. Hunnicutt and Aadland (2003) find evidence of olipsonistic power exerted by beef–packing firms while accounting for inventory dynamics into a standard conjectural variations model of market power. Panagiotou (2005) finds evidence of oligopsonistic power in the short-run as well as in the long-run in the U.S. cattle market. Empirical results are statistically significant but not big enough to warrant any concern. Cai et al. (2009) conclude that oligopsonistic power is exerted in three regional fed-cattle markets in the central United States as well as

Table 2 Parameter estimates (21)

Parameter	Est. value	Std. error
$\hat{B}_X$	11.4316	2.2667*
$\hat{B}_{Xt}$	0.0001	0.0005
$\hat{B}_{XX}$	−0.4841	0.1084*
$\hat{B}_{XK}$	0.2702	0.0733*
$\hat{B}_{XE}$	−0.1247	0.0196*

(*): 1 % or less level of significance.

Table 3 Estimates of mark-down, degree of market power and Lerner index

Parameter	Est. value	Std.error	95 % Confidence Interval
Mark-down, $\hat{u}$	0.9680	0.0004	(0.9672, 0.9688)
Degree of market power, $\hat{\theta}$	0.1862	0.0026	(0.1810, 0.1914)
Lerner index, $\hat{L}$	0.2289	0.0049	(0.2191, 0.2387)

Note: Standard errors have been estimated with bootstrap.

the whole U.S. market. Panagiotou and Azzam (2010) conclude that the U.S. cattle industry is characterized by imperfectly competitive conduct in the procurement of cattle, before and after the 2003-2006 ban on imports and exports of cattle and beef, respectively. In a recent study, Cai, Stiegert and Koontz (2011b) find evidence of oligopsonistic power being exercised in fed cattle markets before and after the implementation of the Livestock Mandatory Reporting Act in 2001.

In the aforementioned studies, distortions in cattle prices due to oligopsonistic power exercised in the cattle market were as low as 1 % (Schroeter 1988). On the other hand, Schroeter and Azzam (1990) estimate that 55 % of the farm–to–retail price spread in the beef market can be attributed to market power with oligopsonistic and oligopolistic power having almost an equal contribution.

The empirical results of this work suggest that fed cattle were priced 18.62 % lower than their net marginal value product, indicating evidence of non–competitive behavior in the U.S. cattle industry. Spatial characteristics of the cattle market can be employed to provide a possible explanation for the findings of this article. Live cattle can be transported only a limited distance to slaughter. Shipping live animals long distances is quite costly and can cause high levels of mortality. Hence, cattle producers to a particular location may face few buyers who might exert market power when purchasing cattle for slaughter. The statistical significant findings of this study support the above statement. Furthermore, the value of the mark-down parameter u is positive for each observation in the sample, strengthening this way our argument for the potential presence of non-competitive behavior in the U.S. cattle industry over the period examined in this work.

5 Summary and Conclusion

The objective of this paper was to measure the degree of oligopsony power in the U.S. cattle industry with the use of the recently developed stochastic frontier estimator of market power. In this work, unlike the seminal paper that measures the mark-up in an output market at firm level, we develop a stochastic production frontier estimator in order to estimate the mark-down in an input (cattle) market at industry level.

The starting point of this work is the profit maximizing beef-packing firm. Optimizing and using elements from the SFA literature we derive a stochastic production frontier estimator of market power for the individual beef packer. Unfortunately, firm specific data are rarely available. We resolve this difficulty by providing a method in order to produce market power estimates at aggregate level.

Our empirical results indicate that the U.S. beef–packing industry exercises market power when procuring live cattle. The value of the mark-down term u is positive and statistically significant. The estimated value of the Lerner index of oligopsonistic power is 0.2289 and is statistically different than zero. The specific finding suggests that, on average, the net value of the marginal product of cattle is 22.9 % higher than the price of cattle. Hence, based on the empirical outcome of this study, one can conclude that there is significant evidence that cattle feeders receive lower prices due to the fact that the U.S. market for live cattle might be imperfectly competitive.

The outcome of this study should be interpreted in light of data limitations and model construction. A more appropriate data set would contain information on the exact number of inputs employed only for beef production. Unfortunately, annual data from the Census are available only for aggregate red meat output. Furthermore, the choice of the form of the production function can affect the empirical results of the model.

Finally, the relevant unit of observation in an oligopsonistic model for the U.S. beef industry is the beef packing firm. Until data on firm level become available, aggregation is the only avenue in order to estimate the degree of market power exercised by beef packers when procuring live cattle. As Azzam and Pagoulatos (1990) point out, little can be known about how the presence or absence of market power is obscured by too much or too little aggregation.

Appendix

Description of the variables and their sources are as follows:

$$Source: NBER\text{--}CES\ Manufacturing\ Industry\ Database/SIC2011\ (meatpacking)$$

$$L = \text{Production worker hours for SIC2011 (million hrs)}$$

$$K = \frac{\text{Real capital stock for SIC2011 (million \$)}}{\text{Cost of capital = interest rate + depreciation rate}}$$

$$E = \frac{\text{Cost of electricity and fuels for SIC2011 (million \$)}}{\text{Deflator for the energy input in SIC2011 (1987=1.00)}}$$

$$Source: United\ States\ Department\ of\ Agriculture\text{--}Economic\ Research\ Service$$

$$X = \text{Commercial cattle slaughter (1,000 heads) times dressed weight (pounds/head)}$$

$$W = \text{Beef net farm value (cents per retail pound equivalent)}$$

$$Q = \text{Commercial beef production (carcass weight, million pounds)}$$

$$P = \text{Beef wholesale value (cents per retail pound equivalent)}$$

References

Appelbaum E (1982) The estimation of the degree of oligopoly power. J Econ 19(2):287–299

Azzam A (1998) Captive supplies, market conduct, and the open-market price. Am J Agric Econ 80(1):76–83

Azzam A, Park T (1993) Testing for switching market conduct. Appl Econ 25(6):795–800

Azzam A, Schroeter J (1991) Implications of increased regional concentration and oligopsonistic coordination in the beef packing industry. West J Agric Econ 16(2):347–381

Azzam A (1996) Estimating the degree of dominance in a bilateral oligopoly. Appl Econ Lett 3(4):209–211

Azzam A (1997) Measuring market power and cost-efficiency effects of industrial concentration. J Ind Econ 45(4):377–386

Azzam A, Pagoulatos E (1990) Testing oligopolistic and oligopsonistic behaviour: An application to the us meat-packing industry. J Agric Econ 41(3):362–370

Azzam A, Schroeter J (1995) The tradeoff between oligopsony power and cost efficiency in horizontal consolidation: An example from beef packing. Am J Agric Econ 77(4):825–836

Bairagi S, Azzam A (2014) Does the grameen bank exert market power over borrowers? Appl Econ Lett 21(12):866–869

Bresnahan TF (1989) Empirical studies of industries with market power. Handb Ind Organ 2:1011–1057

Cai X, Stiegert K, Koontz S (2011a) Regime switching and oligopsony power: the case of us beef processing. Agric Econ 42(1):99–109

Cai X, Stiegert KW, Koontz SR (2011b) Oligopsony fed cattle pricing: Did mandatory price reporting increase meatpacker market power? Appl Econ Perspect Policy 33(4):606–622

Cai X, Stiegert KW, Koontz SR, et al. (2009) Oligopsony power: Evidence from the us beef packing industry. In: Agricultural and Applied Economics Association 2009 AAEA & ACCI Joint Annual Meeting in Milwaukee, Wisconsin, pp 26-29

Hunnicutt L, Aadland D (2003) Inventory constraints in a dynamic model of imperfect competition: An application to beef packing. J Agric Food Ind Organ 1(1)

Koontz SR, Garcia P (1997) Meat-packer conduct in fed cattle pricing: multiple-market oligopsony power. J Agric Resour Econ:87–103

Koontz SR, Garcia P, Hudson MA (1993) Meatpacker conduct in fed cattle pricing: An investigation of oligopsony power. Am J Agric Econ 75(3):537–548

Kumbhakar SC (2011) Estimation of multiple output production functions Technical report. State University of New York, Binghamton

Kumbhakar SC, Baardsen S, Lien G (2012) A new method for estimating market power with an application to norwegian sawmilling. Rev Ind Organ 40(2):109–129

Kumbhakar SC, Lovell CK (2003) Stochastic frontier analysis. Cambridge University Press

Lopez R, Zheng H, Azzam A (2015) Oligopoly power in the food industries revisited: A stochastic frontier approach. AAEA and WAEA Joint Annual Meetings San Francisco, California, pp 26–28

MacDonald JM, McBride WD (2009) The transformation of us livestock agriculture scale, efficiency, and risks. Economic Information Bulletin 43

Marion BW, Geithman FE (1995) Concentration-price relations in regional fed cattle markets. Rev Ind Organ 10(1):1–19

National Bureau of Economic Research–Manufacturing Industry Database (2015) NBER-CES Manufacturing Industry Database. http://www.nber.org/nberces/. –Accessed

Panagiotou D (2005) Cointegration, error correction, and the measurement of oligopsony conduct in the us cattle market. In: 2005 Annual Meeting. Citeseer, Providence, RI, pp 24–27

Panagiotou D, Azzam A (2010) Trade bans, imperfect competition, and welfare: Bse and the us beef industry. Can J Agric Econ/Revue Can d'agroeconomie 58(1):109–129

Paul CJM (2001a) Cost economies and market power: the case of the us meat packing industry. Rev Econ Stat 83(3):531–540

Paul CJM (2001b) Market and cost structure in the US beef packing industry: a plant-level analysis. Am J Agric Econ 83(1):64–76

Ray SC (1999) Measuring scale efficiency from a translog production function. J Product Anal 11(2):183–194

Schroeter J, Azzam A (1990) Measuring market power in multi-product oligopolies: the us meat industry. Appl Econ 22(10):1365–1376

Schroeter J (1988) Estimating the degree of market power in the beef packing industry. The Review of Economics and Statistics:158–162

Sexton RJ (2000) Industrialization and consolidation in the us food sector: implications for competition and welfare. American Journal of Agricultural Economics:1087–1104

Stiegert KW, Azzam A, Brorsen BW (1993) Markdown pricing and cattle supply in the beef packing industry. Am J Agric Econ 75(3):549–558

United States Department of Agriculture – Economic Research Service (2015a). Livestock and meat domestic data. http://ers.usda.gov/data-products/livestock-meat-domestic-data. accessed, 2015

United States Department of Agriculture – Economic Research Service (2015b). Retail prices for beef, pork, poultry cuts, eggs, and dairy products. http://www.ers.usda.gov/data-products/meat-price-spreads.aspx. accessed

United States Department of Agriculture – Packers and Stockyards Program (2014). Grain Inspection, Packers and Stockyards Administration. http://www.gipsa.usda.gov. –2013 Annual Report

Ward CE (2002) Packer concentration and captive supplies. Oklahoma Cooperative Extension Service, AGEC-554:http://osufacts.okstate.edu

Ward CE (2010) Assessing competition in the US beef packing industry. Choices 25(2):1–14

Wohlgenant MK (1989) Demand for farm output in a complete system of demand functions. Am J Agric Econ 71(2):241–252