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Measuring the Degree of Oligopsony Power in the Beef Packing Industry in the Absence of Marketing Input Quantity Data

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We develop a model to measure the degree of oligopsony power in the beef packing industry, while accommodating variable proportions technology, that can be estimated with fewer data requirements. In particular, nonspecialized input quantities, which are often not available, are not needed. Through application of the envelope theorem, we show that the relationship between value marginal product and marginal factor cost can be defined over the prices of the nonspecialized inputs rather than their corresponding quantities. When applied to the beef packing industry, we find no evidence of oligopsony power over our 1967–93 sample period.

Key words: beef industry, envelope theorem, oligopsony power, variable proportions

Introduction

Since Appelbaum first demonstrated an econometric method to measure the degree of oligopoly power in imperfectly competitive markets, a number of models under alternative assumptions have been developed and estimated. Schroeter showed how this model could be extended to measure the degree of oligopoly and oligopsony power. However, Schroeter's model assumed fixed proportions technology, an assumption that one may wish to relax in some applications. In particular, there is evidence that the food processing industries are characterized by substantial input substitutability (Wohlgenant; Goodwin and Brester); thus the assumption of variable proportions is more appropriate. In this case, if the price of a specialized input increases, firms may maintain output while reducing their purchases of the input by substituting the nonspecialized inputs in its place.

More recently, Murray developed a model to measure the degree of oligopsony power in the pulpwood and sawlogs markets under the assumption of a variable proportions technology. Application of this method requires data on the quantities of nonspecialized inputs (e.g., labor and materials); however, in many cases, these data are not available at an individual product level. In this study, we develop a model to measure the degree of oligopsony power, while accommodating variable proportions technology, that can be

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applied to markets in which data on nonspecialized input quantities are not available. Through application of the envelope theorem, we show that the relationship between value marginal product and marginal factor cost can be defined over the prices of the nonspecialized inputs rather than their corresponding quantities.

The model is applied to the beef packing industry—an industry that has generated much interest of late as measures of market concentration reach high levels.[1] Recently, concern has focused on market power on the input side due to the spatial characteristics of the market. Because live cattle can be transported a limited distance to slaughter, cattle producers in a particular location may face few buyers for their cattle. The results of most previous structural models of the beef packing industry have concluded that beef packing firms, at least part of the time, are exercising market power in the purchase of finished cattle for slaughter (Schroeter; Schroeter and Azzam; Azzam; Azzam and Park; Koontz, Garcia, and Hudson). These results are in contrast to a Grain Inspection, Packers and Stockyards Administration (GIPSA) report issued in 1996 that found little evidence of market power in beef packing. In fact, it found that larger beef packing firms paid higher prices for cattle after adjusting for differences in cattle quality [U.S. Department of Agriculture (USDA)/GIPSA 1996b].

This contradiction in results may be due, in part, to inappropriate restrictions on the structural models. Specifically, all of the studies listed above assume a fixed proportional relationship between live cattle inputs and processed beef output. However, Wohlgenant found evidence of substantial substitution possibilities between farm inputs and marketing inputs for beef and veal. In addition, Goodwin and Brester concluded that technological changes in the food industry as a whole have allowed for greater input substitutability. Other restrictions found in these models include the use of prior point estimates or estimated series of the input supply elasticities (Schroeter and Azzam; Azzam and Park), yet it is likely that these input supply elasticities have changed over time. Also, the standard errors of the estimated coefficients in these studies have not been adjusted for the use of prior estimates, thus overstating the level of significance of the market power components.

The model we develop in this analysis allows for variable proportions technology, yet does not require marketing input quantity data. Quantity data are available for some of the nonspecialized production inputs for the meat packing industry as a whole. However, they are not available for individual animal species such as beef. When we apply this model to the beef packing industry, we find no evidence of oligopsony power over the sample period. These results confirm those of the model in Muth and Wohlgenant (1999) which tests for market power in either the input or output market but does not measure the degree of market power. This model may be applied in similar situations where imperfect competition in the input market is of concern, but where data limitations on input quantities might preclude one from using a more general specification of oligopsony behavior.

[1] For 1994, the Grain Inspection, Packers and Stockyards Administration reported a four-firm concentration ratio (CR4) of 80.9 and a Herfindahl index of 2096 (USDA/GIPSA 1996a).

A Theoretical Model of an Imperfectly Competitive Input Market

Assume that the inverse input supply equation for a specialized input can be represented by

$$(1) \qquad w_1 = g(x_1, \mathbf{z}),$$

where w_1 is the deflated input price, x_1 is the input quantity, and $\mathbf{z}$ is a vector of supply shifters. Given this representation of input supply, the profit equation for a representative firm can be written as

$$(2) \qquad \Pi = p \bullet f(x_1, \mathbf{x}) - w_1 x_1 - \mathbf{w}'\mathbf{x},$$

where p is the deflated output price (at the wholesale level), $f(\cdot)$ is the production function, $\mathbf{x}$ is a vector of quantities of other inputs in the production process (e.g., labor and energy), and $\mathbf{w}$ is a vector of deflated prices of other inputs.

If the market for the specialized input is perfectly competitive, then the first-order condition with respect to the level of the input is such that the input price equals its value marginal product. That is,

$$(3) \qquad w_1 = p \frac{\partial f(x_1, \mathbf{x})}{\partial x_1}.$$

A more general form of the first-order condition that allows for imperfect competition is

$$(4) \qquad w_1 + \theta \frac{\partial g(x_1, \mathbf{z})}{\partial x_1} x_1 = p \frac{\partial f(x_1, \mathbf{x})}{\partial x_1},$$

where θ is a parameter that indexes the degree of market power. If the market is perfectly competitive, then $\theta = 0$, and the first-order condition reduces to equation (3) above. If the market is monopsonistic, then $\theta = 1$, and equation (4) represents marginal factor cost (the input price plus a monopsony markdown) equaling value marginal product. Intermediate values of θ are taken to mean some degree of less than complete market power, in which case the interpretation of this first-order condition is that the "perceived" marginal factor cost equals the value marginal product of finished cattle.

The interpretation of θ in equation (4) from the viewpoint of an individual firm depends on the assumptions made about aggregation. If it is assumed that the aggregate marginal product term is obtained by averaging over all firms' marginal products, then θ is interpreted as the average input conjectural elasticity of firms in the industry. Alternatively, if it is assumed that the aggregate marginal product term is a share-weighted average, θ takes on the interpretation of an input market Herfindahl index. Each of these interpretations is derived in the appendix.

An Empirical Model with Fewer Data Requirements

The joint estimation of empirical specifications of equations (1) and (4) allows us to measure the degree of oligopsony power in a particular market. As specified, however, data on the quantities of nonspecialized inputs (i.e., inputs other than x_1) are necessary to estimate the degree of oligopsony power because they are components of the marginal product. While such data were available for Murray's analysis of the pulpwood and sawlogs markets, they may not be available for other markets that are of interest. In this section, we derive a model that does not require data for these input quantities. In addition, since identifying the degree of oligopsony power requires specifying an input supply equation, we discuss the empirical specification of the input supply equation for our particular application to the beef packing industry.

First, note that the marginal product term, $\partial f(x_1, \mathbf{x})/\partial x_1$, requires the quantities of nonspecialized inputs used in the production process. The need for these nonspecialized input quantities can be circumvented by applying the envelope theorem to a redefined profit equation. Thus, we rewrite the profit equation for beef packing firms, substituting the optimal quantities of the noncattle inputs conditional on the level of cattle input, x_1, in place of the previously specified unconditional quantities. Assuming that there are two nonspecialized inputs in the production process, labor (x_2) and energy (x_3), equation (2) can be rewritten as

$$\text{(5)} \qquad \Pi(p, x_1, \mathbf{z}, w_2, w_3) = p \bullet f(x_1, x_2^*, x_3^*) - g(x_1, \mathbf{z})x_1 - w_2 x_2^* - w_3 x_3^*,$$

where x_2^* and x_3^* are the optimal quantities of x_2 and x_3 conditional on the level of the specialized input, x_1.[2] Specifically, $x_2^* = x_2(x_1, w_2, w_3, p)$ and $x_3^* = x_3(x_1, w_2, w_3, p)$.

Now, the first-order condition with respect to the choice of x_1 is

$$\text{(6)} \qquad \frac{\partial \Pi}{\partial x_1} = p\frac{\partial f(x_1, x_2^*, x_3^*)}{\partial x_1} + p\frac{\partial f(\cdot)}{\partial x_2^*}\frac{\partial x_2^*}{\partial x_1} + p\frac{\partial f(\cdot)}{\partial x_3^*}\frac{\partial x_3^*}{\partial x_1}$$
$$- \theta\frac{\partial g(x_1, \mathbf{z})}{\partial x_1}x_1 - w_1 - w_2\frac{\partial x_2^*}{\partial x_1} - w_3\frac{\partial x_3^*}{\partial x_1} = 0,$$

which can be rearranged as

$$\text{(7)} \qquad w_1 + \theta\frac{\partial g(x_1, \mathbf{z})}{\partial x_1}x_1 = p\frac{\partial f(\cdot)}{\partial x_1} + \left(p\frac{\partial f(\cdot)}{\partial x_2^*} - w_2\right)\frac{\partial x_2^*}{\partial x_1}$$
$$+ \left(p\frac{\partial f(\cdot)}{\partial x_3^*} - w_3\right)\frac{\partial x_3^*}{\partial x_1}.$$

[2] Capital costs are not included because they are generally a small share of food processing costs (Morrison).

Assuming that the nonspecialized inputs are purchased in perfectly competitive markets, equation (7) reduces to

$$(8) \qquad w_1 = -\theta \frac{\partial g(x_1, \mathbf{z})}{\partial x_1} x_1 + p \frac{\partial f[x_1, x_2(x_1, w_2, w_3, p), x_3(x_1, w_2, w_3, p)]}{\partial x_1}.$$

That is, the first-order condition for profit maximization can be derived by simply differentiating equation (5) with respect to x_1, holding x_2 and x_3 at their optimally determined levels (an application of the envelope theorem). Note that now the marginal product is defined over the prices of the nonspecialized inputs rather than the corresponding quantities.

In an output market counterpart to our model, Lau establishes that only the reduced-form parameters of the marginal cost function are necessary for identifying oligopoly power. Applying the same logic to the input market model, the degree of oligopsony power can be identified with a reduced-form value marginal product specification. Inserting a linear reduced-form value marginal product, for example, and solving for w_1 results in the following expression:

$$(9) \qquad w_1 = -\theta \frac{\partial g(\cdot)}{\partial x_1} x_1 + \alpha_1 x_1 + \alpha_2 w_2 + \alpha_3 w_3 + \alpha_4 p.$$

To complete the model, the input supply equation must be specified. The supply specification we employ is intended to characterize the short-run supply response of cattle producers whereby the supply of finished cattle is expressed as a function of the price of cattle (w_1), beginning-of-year inventories of finished cattle (I), and the price of feed corn (C) (Rosen; Brester and Wohlgenant; Marsh). Based on a preliminary plotting of the data, this short-run supply relationship is specified in terms of the slaughter-inventory ratio as a linear function of the beef-corn price ratio as follows:

$$(10) \qquad \frac{x_1}{I} = \delta_0 + \delta_1 \frac{w_1}{C} + \delta_2 \frac{w_1}{C} T + \delta_3 T,$$

where T is a linear time trend to account for technical change and other unaccounted for factors affecting short-run supply response of beef. As indicated below, one advantage of this specification is that it allows for identification of the degree of market power.[3]

To complete the specification, $\partial g(\cdot)/\partial x_I$ is derived from the empirical specification of the input supply equation above. Solving equation (10) for w_1 and differentiating with respect to x_1 yields the following expression for the marginal effect of the input level on cattle prices:

[3] One potential problem with a short-run supply model for cattle is that it can produce a negative supply response. As discussed by Rosen, the reason is that, in the short run, higher cattle prices can induce farmers to delay the slaughter age of cattle to increase the weight at which they are sold. In addition, if cattle prices are rising and farmers expect higher prices to prevail in the future, then they will retain heifers to add to the breeding stock rather than marketing them immediately. The reason a negative supply response is problematic when estimating the degree of market power is that it switches the sign of the markdown term to that of a markup term instead. For our particular data set, this situation does not seem to be of concern because graphical analysis strongly suggests a positive supply response in the short run.

$$(11)\qquad \frac{\partial g(\cdot)}{\partial x_1} = \frac{C}{I}\left(\frac{1}{\delta_1 + \delta_2 T}\right).$$

Note that equation (10) allows for identification of θ because the slope of the supply function, given by equation (11), is a function of C/I and T.[4] Substituting this expression into equation (9) yields the final empirical specification of the first-order condition, or the demand relation:

$$(12)\qquad w_1 = -\left(\frac{\theta}{\delta_1 + \delta_2 T}\right)\frac{C}{I}x_1 + \alpha_1 x_1 + \alpha_2 w_2 + \alpha_3 w_3 + \alpha_4 p.$$

Equations (10) and (12) make up the system of equations that will allow for determination of whether beef packing firms have been exercising market power in their purchases of finished cattle. Estimates of the model are obtained assuming both that θ remained constant over the sample period and, because the structure of the industry has changed over time, that θ varied as a function of trend (i.e., $\theta = \theta_0 + \theta_1 T$).[5]

We also investigate whether the results regarding oligopsony power are sensitive to the choice of functional form for the reduced-form expression of the marginal product function in equation (8). Two alternative functional forms are considered: a log-linear form and a functional form in which the variables are replaced by their square roots. In a general sense, these functional forms may be viewed as first-order approximations of the unknown functional form. In the first case, the derivative may be viewed as the first-order partial derivative of a translog function, and in the second case, the first-order partial derivative of the generalized Leontief.[6]

Assuming the log derivative of $f(\cdot)$ with respect to x_1 in equation (8) is linear in the logarithms, the marginal product of x_1 can be written as

$$(13)\qquad \frac{\partial f(\cdot)}{\partial x_1} = \frac{q}{x_1}\left(\alpha_1 + \gamma_{11}\ln(x_1) + \gamma_{12}\ln(w_2) + \gamma_{13}\ln(w_3) + \gamma_{1p}\ln(p)\right).$$

Substituting this expression into the first-order condition, equation (8), and multiplying through by $x_1/(pq)$ results in the following demand relation:

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[4] Bresnahan demonstrated graphically the requirement for identifying oligopoly power: the slope of the demand curve for the product must be changing over time. The input market analog to Bresnahan's analysis is demonstrated in Muth and Wohlgenant (1997), and is similar conceptually to Just and Chern except that Just and Chern assumed monopoly in the output market for the product in question (processing tomatoes) and analyzed the effect of a one-time change in input supply. In either case, changes in the slope of the input supply equation allow for the identification of market power. The implication for the model presented here is that the input supply equation must be modeled in such a way that its slope, $\partial g(x_1, \mathbf{z})/\partial x_1$, varies over time.

[5] Another possibility is to specify θ as a function of the Herfindahl index, but the series is only available beginning in 1980. The CR4, which could be used as a proxy, is highly correlated with time and hence yields results similar to a time trend.

[6] As a referee pointed out, it is important to recognize that $\partial f(\cdot)/\partial x_1$ in equation (8), when expressed in terms of x_1, w_2, w_3, and p, is a reduced-form expression for the marginal product of x_1. Therefore, it cannot be derived directly by partially differentiating a function in which x_1, w_2, w_3, and p appear as arguments. However, it is valid to consider this reduced-form marginal product function as a function in its own right, and therefore to utilize a flexible functional form as an approximating function to the true, unknown functional form. The functional forms chosen for this application cover a wide range of flexible forms and satisfy the requirement for identification set forth by Lau.

$$s_1 = \frac{w_1 x_1}{pq} = -\theta \frac{\partial g(x_1, \mathbf{z})}{\partial x_1} \frac{x_1^2}{pq} + \alpha_1 + \gamma_{11}\ln(x_1) + \gamma_{12}\ln(w_2) + \gamma_{13}\ln(w_3) + \gamma_{1p}\ln(p), \tag{14}$$

where s_1 is the cost share of input x_1 in the production of beef, and $q = f(\cdot)$. This second form of the demand relation is then estimated jointly with the input supply equation.

In the third functional form considered, the reduced-form marginal product in equation (8) is approximated by:

$$\frac{\partial f(\cdot)}{\partial x_1} = \beta_{10} + \beta_{11}x_1^{1/2} + \beta_{12}w_2^{1/2} + \beta_{13}w_3^{1/2} + \beta_{1p}p^{1/2}. \tag{15}$$

By substituting this expression for marginal product into the first-order condition, equation (8), and dividing through by p, the following third specification of the demand relation is obtained:

$$r_1 = \frac{w_1}{p} = -\theta \frac{\partial g(x_1, \mathbf{z})}{\partial x_1} \frac{x_1}{p} + \beta_{10} + \beta_{11}x_1^{1/2} + \beta_{12}w_2^{1/2} + \beta_{13}w_3^{1/2} + \beta_{1p}p^{1/2}, \tag{16}$$

where r_1 is the ratio of the price of cattle to the wholesale price of beef. Again, this equation was estimated jointly with the input supply equation. In each of these alternative specifications, the market power parameter (θ) was estimated both as a constant and a linear time trend.

Data Description

The data used to estimate the preceding model are aggregate annual time-series data for the years 1967 through 1993. Farm beef quantities and inventories of beef cattle were obtained from the USDA's *Red Meats Yearbook* and *Livestock and Meat Statistics*. The farm price for cattle is the series "slaughter steer prices, Choice grade 2–4, Omaha, 1,000–1,100 pounds" in both of the above publications. These prices were adjusted for by-product allowances, which were obtained, along with wholesale beef prices, from the USDA's Animal Products Branch of the Economic Research Service. Corn prices were taken from the USDA's *Feed Situation and Outlook Report*, the energy price index from the USDA's *Food Cost Review*, and the average hourly meat packing wage from the U.S. Department of Labor's *Employment, Hours, and Earnings, United States, 1909–1994*. Per capita personal consumption expenditures and population data (which were used as instrumental variables for the endogenously determined wholesale beef price) and the consumer price index were obtained from the *Economic Report of the President* (Congress of the U.S.). The additional instrumental variables, the retail poultry CPI and the retail pork CPI, were taken from the USDA's *Food Consumption, Prices, and Expenditures*. All price and income data were deflated using the consumer price index.

Table 1. Summary of Values and 95% Confidence Intervals for the Market Power Coefficient

Model Specification	Value	95% Confidence Interval
1. Reduced-Form Value Marginal Product Specification:		
(a) Constant θ	0.00001	[-0.00005, 0.00007]
(b) $\theta = \theta_0 + \theta_1 T$		
$T = 1$	0.00115	[-0.00460, 0.00690]
$T = 27$	-0.00067	[-0.01145, 0.01011]
2. Translog Conditional Production Function Specification:		
(a) Constant θ	0.00008	[-0.00139, 0.00155]
(b) $\theta = \theta_0 + \theta_1 T$		
$T = 1$	0.00135	[-0.00375, 0.00645]
$T = 27$	-0.00016	[-0.00108, 0.00076]
3. Generalized Leontief Conditional Production Function Specification:		
(a) Constant θ	-0.00015	[-0.00090, 0.00059]
(b) $\theta = \theta_0 + \theta_1 T$		
$T = 1$	-0.00036	[-0.00073, 0.00001]
$T = 27$	0.00006	[-0.00008, 0.00020]

Estimation Results and Specification Testing

The input supply equation and the perceived demand equation were estimated jointly with additive error terms using nonlinear three-stage least squares. Three alternative specifications of the market power component were considered: one in which θ was estimated as a constant parameter, one in which θ was specified as a linear function of time, and one in which θ was restricted to zero. In this last case, the perceived demand equation represents the competitive condition that the input price is equal to its value marginal product. The price of finished cattle (w_1), the quantity of finished cattle (x_1), the price of processed beef (p), and the ratio x_1/I are endogenous. The instrument set included the exogenous variables in the model in addition to variables that influence the final demand for beef, and thus the price of processed beef—namely, population, consumer expenditures, the retail price of pork, and the retail price of poultry.

Initially, equations (10) and (12) were overfitted with first-order autoregressive terms. In both equations in each specification, the estimated autoregressive parameter was close to one, thus indicating the presence of a unit root error process. Therefore, both equations were reestimated in first differences, and the resulting error process was stationary. Visual inspection of the autocorrelation and partial autocorrelation plots of the residuals revealed no remaining evidence of autocorrelation. All of the estimated autocorrelations and partial autocorrelations were within two standard errors of zero for 12 lags. Ljung and Box statistics calculated at six and 12 lags failed to reject the null

Table 2. Results of Nonlinear 3SLS Estimation of Cattle Input Supply and Perceived Demand Equations: Reduced-Form VMP Specification (1967–93)

Variable / (Coefficient)	Market Power Models: Constant θ	Market Power Models: $\theta = \theta_0 + \theta_1 T$	Competition Model
Input Supply Equation (dependent variable = x_1/I):			
$\frac{w_1}{C}$ (δ_1)	0.00307	0.00048	0.00303
	(0.00227)	(0.00122)	(0.00234)
$\frac{w_1}{C}T$ (δ_2)	-0.00016	-0.00001	-0.00016
	(0.00012)	(0.00003)	(0.00012)
T (δ_3)	0.00602	0.00279	0.00608
	(0.00396)	(0.00303)	(0.00408)
Perceived Demand Equation (dependent variable = w_1):			
Constant (θ_0)	0.00001	0.00122	—
	(0.00003)	(0.00312)	
T (θ_1)	—	-0.00007	—
		(0.00017)	
x_1 (α_1)	-0.00010	-0.00013	-0.00010
	(0.00016)	(0.00016)	(0.00015)
w_2 (α_2)	-0.23722	0.13139	-0.25077
	(0.61050)	(0.62566)	(0.57394)
w_3 (α_3)	-0.00601	-0.00573	-0.00616
	(0.00402)	(0.00410)	(0.00375)
p (α_4)	0.54608	0.54842	0.54642
	(0.02460)	(0.02434)	(0.02323)
Objective Value	1.5836	1.5283	1.6150

Notes: Numbers in parentheses are standard errors. Both equations are estimated in first differences. Endogenous variables are w_1, x_1, p, and x_1/I.

hypothesis (at the 5% level) that the residual series are white noise. Consequently, no further corrections for autocorrelation were made.

Regardless of the model specification, estimates of the market power component (θ) were close to zero and insignificant. The results are summarized in table 1. For the specifications in which θ varied over time, its values were calculated at the first and last observations of the sample. Overall, estimates of θ range from -0.00067 to 0.00135.[7] For each estimate, 95% confidence intervals (which appear in table 1 as well) contained the value zero. Furthermore, for the linear value marginal product specification, each of the models containing the market power component was tested against the perfect competition model using Gallant and Jorgenson's method of testing nonlinear restrictions. In each case, the restriction that θ is zero could not be rejected at the 5% level. Hence, it appears from these data that beef packers were not exercising market power in the purchase of finished cattle over the 1967–93 time period. These results are opposite

[7] Although the negative values of θ are not theoretically possible, they arise in this situation from sample variation.

Table 3. Results of Nonlinear 3SLS Estimation of Cattle Input Supply and Perceived Demand Equations: Log-Linear Marginal Product Specification (1967–93)

Variable / (Coefficient)	Market Power Models: Constant θ	Market Power Models: $\theta = \theta_0 + \theta_1 T$	Competition Model
Input Supply Equation (dependent variable = x_1/I):			
$\frac{w_1}{C}$ (δ_1)	0.00007	0.00084	0.00298
	(0.00061)	(0.00149)	(0.00233)
$\frac{w_1}{C}T$ (δ_2)	0.00000	-0.00002	-0.00016
	(0.00001)	(0.00004)	(0.00012)
T (δ_3)	0.00261	0.00352	0.00612
	(0.00306)	(0.00305)	(0.00406)
Perceived Demand Equation (dependent variable = *SHARE*):			
Constant (θ_0)	0.00008	0.00140	—
	(0.00075)	(0.00271)	
T (θ_1)	—	-0.00006	—
		(0.00011)	
$\ln(x_1)$ (γ_{11})	0.15319	0.15010	0.13862
	(0.08632)	(0.07915)	(0.07990)
$\ln(w_2)$ (γ_{12})	-0.13211	-0.07766	-0.12167
	(0.07684)	(0.08211)	(0.07396)
$\ln(w_3)$ (γ_{13})	-0.01368	-0.00350	-0.02659
	(0.02768)	(0.02679)	(0.02605)
$\ln(p)$ (γ_{1p})	0.10038	0.10790	0.10257
	(0.04141)	(0.03925)	(0.04064)
Objective Value	1.6739	1.6252	1.6752

Notes: Numbers in parentheses are standard errors. Both equations are estimated in first differences. Endogenous variables are $w_1, x_1, p, x_1/I$, and $SHARE = w_1x_1/pq$.

those noted earlier in which fixed proportions was assumed, and have implications for the market conduct investigation activities of the USDA's Grain Inspection, Packers and Stockyards Administration.

The complete results for the reduced-form value marginal product (VMP) specification are presented in table 2. For the most part, the results of estimation appear reasonable. The relationship between the ratio of prices (w_1/C) and the marketing ratio (x_1/I) is positive. The slopes, given by the inverse of equation (11), and standard errors of the input supply equation were calculated conditional on the sample means for each model specification. The corresponding elasticities, which ranged from 0.017 to 0.042 depending on the model specification, indicate nearly fixed cattle supply, as does the estimate of 0.14 obtained by Ospina and Shumway over an earlier time period (1956–79).

The remaining results of the perceived demand equation are dominated by the effect of output prices (p) on input prices (w_1). As expected, an increase in output prices for processed beef has a strongly positive effect on the price of finished cattle. For the most

Table 4. Results of Nonlinear 3SLS Estimation of Cattle Input Supply and Perceived Demand Equations: Square-Root Marginal Product Specification (1967–93)

Variable / (Coefficient)	Market Power Models: Constant θ	Market Power Models: $\theta = \theta_0 + \theta_1 T$	Competition Model
Input Supply Equation (dependent variable = x_1/I):			
$\frac{w_1}{C}$ (δ_1)	0.00075	0.00238	0.00310
	(0.00156)	(0.00219)	(0.00234)
$\frac{w_1}{C}T$ (δ_2)	-0.00002	-0.00010	-0.00016
	(0.00005)	(0.00010)	(0.00012)
T (δ_3)	0.00260	0.00480	0.00613
	(0.00308)	(0.00358)	(0.00408)
Perceived Demand Equation (dependent variable = w_1/p):			
Constant (θ_0)	-0.00015	-0.00037	—
	(0.00038)	(0.00038)	
T (θ_1)	—	0.00002	—
		(0.00002)	
$x_1^{1/2}$ (β_{11})	-0.00022	-0.00044	-0.00010
	(0.00046)	(0.00040)	(0.00044)
$w_2^{1/2}$ (β_{12})	-0.01234	-0.00324	-0.02319
	(0.02885)	(0.02759)	(0.02607)
$w_3^{1/2}$ (β_{13})	-0.00211	-0.00462	-0.00233
	(0.00131)	(0.00145)	(0.00126)
$p^{1/2}$ (β_{1p})	0.00513	0.00152	0.00421
	(0.00399)	(0.00367)	(0.00389)
Objective Value	1.6526	1.5618	1.6789

Notes: Numbers in parentheses are standard errors. Both equations are estimated in first differences. Endogenous variables are w_1, x_1, p, x_1/I, and w_1/p.

part, the deflated noncattle input prices, labor (w_2) and energy (w_3), have negative effects on the input price for cattle. This result occurs because noncattle input prices cause two opposing effects on input demand for cattle. An increase in the price of an input causes a substitution away from the input and toward an increase in demand for cattle. However, the increase in the price of the input may also cause a decrease in production, and thus a decrease in demand for cattle. The negative coefficient estimates for the price of labor and the price of energy indicate that the latter effect dominates. Finally, the relationship between the finished cattle quantity (x_1) and finished cattle prices (w_1) is not significantly different from zero. This result most likely occurs because the technology approximates constant returns to scale; hence the effect of output prices on input prices dominates.

The results of the two alternative specifications of the value marginal product terms are similar to the reduced-form specification. The results of the specification derived from the translog conditional production function are presented in table 3. As noted previously, the estimates of θ are near zero and insignificant. The input supply elasticities are small, ranging from 0.004 to 0.039, again indicating nearly fixed cattle supply. Most of the coefficients on the value marginal product term have expected signs. However, with this specification, the effect of output prices on the input share is positive but less dominant than the effect of output prices on input prices in the previous specification. Noncattle input prices again have negative effects. Finally, the effect of the input quantity on the input share is positive, indicating that the input demand relation (holding output price constant) is elastic.

The results of the final specification using the generalized Leontief conditional production function are presented in table 4. As before, the estimates of θ are near zero and insignificant. Input supply elasticities ranged from 0.02 to 0.05, and all other results are similar to the reduced-form value marginal product specification.

Conclusions

Most models that allow for the estimation of the degree of oligopsony power assume fixed proportions technology. For some applications, the assumption of variable proportions technology is more appropriate. However, relaxing the assumption of fixed proportions increases the data requirements of the model. In particular, data on the quantities of nonspecialized input quantities that are needed are frequently not available.

We develop a general model that allows one to estimate the degree of oligopsony power without these data, yet still allows for variable proportions technology. When applied to the beef packing industry, we find no evidence of oligopsony power over the 1967–93 sample period. This general framework has applications beyond those presented here. For example, it may be appropriate if one is interested in regional measures of oligopsony power and data are available for regional prices, but the only regional quantities that are available are those of the output and the specialized input.

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References

Appelbaum, E. "The Estimation of the Degree of Oligopoly Power." *J. Econometrics* 19(1982):287–99.

Azzam, A. M. "Testing the Competitiveness of Food Price Spreads." *J. Agr. Econ.* 43(1992):248–56.

Azzam, A. M., and T. Park. "Testing for Switching Market Conduct." *Appl. Econ.* 25(1993):795–800.

Bresnahan, T. F. "The Oligopoly Solution Concept Is Identified." *Econ. Letters* 10(1982):87–92.

Brester, G. W., and M. K. Wohlgenant. "Correcting for Measurement Error in Food Demand Estimation." *Rev. Econ. and Statis.* 55(May 1993):352–56.

Congress of the U.S., Council of Economic Advisors. *Economic Report of the President.* Washington DC: U.S. Government Printing Office, 1995.

Gallant, A. R., and D. W. Jorgenson. "Statistical Inference for a System of Simultaneous, Non-Linear, Implicit Equations in the Context of Instrumental Variable Estimation." *J. Econometrics* 11(1979): 275–302.

Goodwin, B. K., and G. W. Brester. "Structural Change in Factor Demand Relationships in the U.S. Food and Kindred Industry." *Amer. J. Agr. Econ.* 77(February 1995):69–79.

Just, R. E., and W. S. Chern. "Tomatoes, Technology, and Oligopsony." *Bell J. Econ.* 11(1980):584–602.

Koontz, S. R., P. Garcia, and M. A. Hudson. "Meatpacker Conduct in Fed Cattle Pricing: An Investigation of Oligopsony Power." *Amer. J. Agr. Econ.* 75(1993):537–48.

Lau, L. J. "On Identifying the Degree of Competitiveness from Industry Price and Output Data." *Econ. Letters* 10(1982):93–99.

Ljung, G. M., and G. E. P. Box. "On a Measure of Lack of Fit in Time-Series Models." *Biometrika* 65(1978):297–303.

Marsh, J. M. "Estimating Intertemporal Supply Response in the Fed Beef Market." *Amer. J. Agr. Econ.* 76(August 1994):444–53.

Morrison, C. J. "Structural Change, Capital Investment, and Productivity in the Food Processing Industry." *Amer. J. Agr. Econ.* 79(February 1997):110–25.

Murray, B. C. "Measuring Oligopsony Power with Shadow Prices: U.S. Markets for Pulpwood and Sawlogs." *Rev. Econ. and Statis.* 77(August 1995):486–98.

Muth, M. K., and M. K. Wohlgenant. "Identifying the Degree of Oligopsony Power in the Beef Packing Industry with Variable Proportions Technology." Selected paper presented at annual meetings of the AAEA, Toronto, Canada, July 1997.

———. "A Test for Market Power Using Marginal Input and Output Prices with Application to the U.S. Beef Processing Industry." *Amer. J. Agr. Econ.* 81(August 1999):638–43.

Ospina, E., and C. R. Shumway. "Disaggregated Analysis of Short-Run Beef Supply Response." *West. J. Agr. Econ.* 4(December 1979):43–59.

Rosen, S. "Dynamic Animal Economics." *Amer. J. Agr. Econ.* 69(August 1987):547–57.

Schroeter, J. R. "Estimating the Degree of Market Power in the Beef Packing Industry." *Rev. Econ. and Statis.* 70(1988):158–62.

Schroeter, J. R., and A. M. Azzam. "Measuring Market Power in Multi-Product Oligopolies: The U.S. Meat Industry." *Appl. Econ.* 22(1990):1365–76.

U.S. Department of Agriculture, Economic Research Service. *Feed Situation and Outlook Report.* USDA/ERS, Washington DC. Various issues, 1972–94.

———. *Food Consumption, Prices, and Expenditures.* USDA/ERS, Washington DC. Various issues, 1990–94.

———. *Food Cost Review.* USDA/ERS, Washington DC, 1996.

———. *Livestock and Meat Statistics.* USDA/ERS, Washington DC. Various issues, 1971–78.

———. *Red Meats Yearbook.* USDA/ERS, Washington DC, 1993 and 1994.

U.S. Department of Agriculture, Grain Inspection, Packers and Stockyards Administration. "Packers and Stockyards Statistical Report, 1991–94 Reporting Years." Pub. No. GIPSA-SR-96-1, USDA/GIPSA, Washington DC, October 1996a.

———. "Price Determination in Slaughter Cattle Procurement." Pub. No. GIPSA-RR-96-2. Prepared by the Texas Agricultural Market Research Center, Slaughter Cattle Procurement and Pricing Study Team, Texas A&M University, for USDA/GIPSA, Washington DC, September 1996b.

U.S. Department of Labor, Bureau of Labor Statistics. *Employment, Hours, and Earnings, United States, 1909–1994.* USDL/BLS, Washington DC, 1995.

Wohlgenant, M. K. "Demand for Farm Output in a Complete System of Demand Functions." *Amer. J. Agr. Econ.* 72(May 1989):241–52.

Appendix:
Interpretation of the Market Power Parameter

In this appendix, we demonstrate the derivation of each of the two alternative interpretations of the market power parameter, θ. Consider the following profit function of a representative firm i:

$$\Pi_i = p \bullet f_i(x_{1i}, \mathbf{x}_i) - w_1 x_{1i} - \mathbf{w}'\mathbf{x}_i, \tag{A1}$$

where $w_1 = g(x_1, \mathbf{z})$ as before, and each firm has a unique production function. The general form of the first-order condition with respect to the choice of the input level (x_1) for firm i is

$$\text{(A2)} \qquad \frac{\partial \Pi_i}{\partial x_{1i}} = p\frac{\partial f_i(x_{1i}, \mathbf{x}_i)}{\partial x_{1i}} - w_1 - \frac{\partial g(x_1, \mathbf{z})}{\partial x_1}\frac{\partial x_1}{\partial x_{1i}}x_{1i} = 0.$$

Rearranging this expression so that the marginal factor cost terms are on the left-hand side and the value marginal product is on the right-hand side results in the following:

$$\text{(A3)} \qquad w_1 + \frac{\partial x_1}{\partial x_{1i}}\frac{x_{1i}}{x_1}\frac{\partial g(x_1, \mathbf{z})}{\partial x_1}x_1 = p\frac{\partial f_i(x_{1i}, \mathbf{x}_i)}{\partial x_{1i}}.$$

Averaging this expression over all firms in the industry results in

$$\text{(A4)} \qquad w_1 + \frac{1}{n}\sum_{i=1}^{n}\frac{\partial x_1}{\partial x_{1i}}\frac{x_{1i}}{x_1}\frac{\partial g(x_1, \mathbf{z})}{\partial x_1}x_1 = \frac{p}{n}\sum_{i=1}^{n}\frac{\partial f_1(x_{1i}, \mathbf{x}_i)}{\partial x_{1i}},$$

where n is the number of firms in the industry.

If the aggregate marginal product term in equation (4) of the text is interpreted as the average of the marginal product terms over firms in the industry, that is,

$$\frac{\partial f(x_1, \mathbf{x})}{\partial x_1} = \frac{1}{n}\sum_{i=1}^{n}\frac{\partial f(x_{1i}, \mathbf{x}_i)}{\partial x_{1i}},$$

then equation (A4) takes on the same form as text equation (4), except now θ is interpreted as the average of the input conjectural elasticities:

$$\theta = \frac{1}{n}\sum_{i=1}^{n}\frac{\partial x_1}{\partial x_{1i}}\frac{x_{1i}}{x_1}.$$

The input conjectural elasticity measures the percentage increase in total industry input purchases in response to a 1% increase in a particular firm's input purchases. If the industry is perfectly competitive in its input purchases, then the conjectural elasticity is zero. If it is monopsonistic, the conjectural elasticity is one. In an oligopsonistic industry, the conjectural elasticity will fall between zero and one.

The second interpretation of θ is obtained by assuming a Cournot input market, in which each firm in the industry expects no reaction by other firms in the industry to changes in the level of its input purchases. That is, they expect $\partial x_1/\partial x_{1i} = 1$. Then equation (A3) can be written instead as follows:

$$\text{(A5)} \qquad w_1 + s_i\frac{\partial g(x_1, \mathbf{z})}{\partial x_1}x_1 = p\frac{\partial f_i(x_{1i}, \mathbf{x}_i)}{\partial x_{1i}},$$

where s_i is the input market share of firm i (i.e., $s_i = x_{1i}/x_1$). Multiplying through by s_i and summing over the firms in the industry yields the share-weighted industry expression:

$$\text{(A6)} \qquad w_1 + \sum_{i=1}^{n}s_i^2\frac{\partial g(x_1, \mathbf{z})}{\partial x_1}x_1 = p\sum_{i=1}^{n}s_i\frac{\partial f_1(x_{1i}, \mathbf{x}_i)}{\partial x_{1i}}.$$

Now, if the aggregate marginal product term in text equation (4) is interpreted as the share-weighted marginal products of firms in the industry, that is,

$$\frac{\partial f(x_1, \mathbf{x})}{\partial x_1} = \sum_{i=1}^{n}s_i\frac{\partial f(x_{1i}, \mathbf{x}_i)}{\partial x_{1i}},$$

then θ takes on the interpretation of the input market counterpart to the Herfindahl index:

$$\theta = \sum_{i=1}^{n}s_i^2.$$

Thus, θ can be related back to a measure of concentration in the industry.