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Lynn Hunnicutt
Utah State University

David Aadland
Utah State University

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INVENTORY DYNAMICS: MARKET POWER MEASURES WHEN INPUTS ARE CAPITAL GOODS

by

LYNN HUNNICUTT

and

DAVID AADLAND

Department of Economics
Utah State University
3530 Old Main Hill
Logan, UT 84322-3530

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Lynn Hunnicutt, Assistant Professor

David Aadland, Assistant Professor

Department of Economics
Utah State University
3530 Old Main Hill
Logan, UT 84322-3530

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INVENTORY DYNAMICS: MARKET POWER MEASURES WHEN INPUTS ARE CAPITAL GOODS

Lynn Hunnicutt and David Aadland

ABSTRACT

This paper incorporates inventory dynamics into an analysis of market power. A Cournot duopoly model of competition is presented in which firms account for the effects of current choices on their competitors' current actions on future actions (both their own and their competitors'). We show that measures of market power which ignore inventory dynamics produce biased estimates of true market power, although the direction of the bias cannot be theoretically determined. We then apply the model to the beef packing industry using data on cattle stocks and slaughter from 1948-1999. Our estimates suggest that static measures underestimate true market power levels.

INVENTORY DYNAMICS: MARKET POWER MEASURES WHEN INPUTS ARE CAPITAL GOODS*

1 Introduction

Many studies of market power are based on measures derived from a static model of competition. In examining market power, the Department of Justice relies on the Lerner index and the Hirschman-Herfindahl index, both of which are derived from a model of competition that assumes that firms maximize a separate profit function each period. The possibility of inter-period (dynamic) effects is not easily accounted for in these standard measures. yet we know that current period output choices may affect future period possibilities, through inventory dynamics. If there is a lag in input production, decisions regarding how much input to use in one period may affect how much is available in the future. Market power measures that account for these inventory dynamics will thus more accurately describe competition in a given industry. Using a duopoly model of competition, we provide an exact characterization of how inventory dynamics affect market power measures. We then apply our model to the beef packing industry and demonstrate that ignoring inventory dynamics does indeed lead to biased estimates of market power.

There is a large literature concerning market power in beef packing. The proliferation of research on this issue is understandable, given that the four-firm concentration ratio in beef packing has increased from about 36% to over 80% since 1980 (Capps Jr., Love, Williams and Adams 1999). Most investigations assume that packing firms make production decisions to maximize the profits that they earn in each production period. (See, for example, Schroeter (1987), Schroeter and Azzam (1990), Bhuyan and Lopez (1997), Muth and Wohlgenant (1998), Koontz, Garcia, and Hudson (1993), Azzam and Park (1993), and Weliwita and Azzam (1996) for exceptions.) Beef packing firms are assumed not to consider the effect of current period choices on future profitability. Given the large literature that treats cattle stocks as capital goods (Jarvis 1974; Nerlove and Fornari 1998; Paarsch 1985; Rosen, Murphy, and Scheinkman 1994; Rucker, Burt, and LaFrance 1984; and Trapp 1986), such an omission is surprising. This paper demonstrates that ignoring intertemporal considerations likely leads to inaccurate descriptions of competition in beef packing, and may lead to erroneous conclusions regarding the presence or absence of market power.

Schroeter (1987) is a clear example of the type of model commonly used to estimate market power in beef packing. He uses a standard model of Cournot competition in which the first-order necessary conditions can be used to derive measures of market power in the input and output market. These measures are then estimated using price and output

*We thank DeeVon Bailey for helpful conversations regarding this work.

(input) data, and inferences regarding market power are made. Because the approach is based on the classic Cournot model, it implicitly assumes that the firm's maximization problem is solved each period, using current period information only. We will define market power measures which ignore cattle growth and stock dynamics "myopic".

(Rosen et al. 1994) provide a model that helps to explain the regular cycle in U.S. cattle stocks. They suggest that forward-looking, rational cattle producers when faced with lengthy cattle production lags (due to relatively slow reproduction times) and changes in demand and supply conditions act in such a way as to produce one of "...the most periodic [of all] economic time series." In their model, it is recognized that the future stock of cattle depends on the number of head culled from the herd this period, and that these stock effects should influence current decisions. We believe that it is only reasonable that packers are also aware of this intertemporal link between current culling decisions and future stocks, and thus will account for this relationship in their decision-making process.

Even in the short run, when stock growth through births may be ignored, dynamic considerations may matter to packers. Since cattle that are kept on feed continue to grow, packers may decide to keep a particular pen of cattle on feed for another few days because the additional weight gain more than offsets the cost of feed. Thus, even given a fixed number of cattle available for slaughter, stock growth rates may affect packer decisions.

Such intertemporal constraints are ignored in models of competition which posit simple profit maximization each period. It turns out that incorporating stock growth into the packers' decisions has important theoretical implications for measuring market power. Most notably, studies that ignore cattle stock dynamics may conclude that market power exists (or does not exist), when stock growth considerations are actually driving firm behavior.

There have been a few papers which consider the appropriateness of using the standard Cournot framework to model dynamic competition. (Dockner 1992) demonstrates that static conjectural variations models (such as that used by (Schroeter 1987)) are equivalent to "open-loop" solutions to a dynamic game.[1] "Closed-loop" solutions, on the other hand, lead to conclusions about market power that are different from those derived using a static model of competition. This is true even in the steady state. (Corts 1999) points out that estimates of market power from a Cournot-type model (static or dynamic) will not

[1] An "open-loop" solution assumes that a firm's current period choice may affect its rival's current period choice and its own future choices, but *not* its rival's future choices. A "closed-loop" solution allows all three effects to be non-zero.

accurately describe conduct unless firms behave as Cournot competitors. If firm behavior is not as the Cournot model postulates, then conclusions derived from estimating a model of Cournot competition may not be accurate.

The weaknesses of the Cournot model are well known, yet analyses based on Cournot assumptions continue to be used by many academic economists and policymakers because of the relatively straightforward implications and limited data requirements. Given that firms do behave as Cournot competitors, our model suggests an extension which can be estimated and which will lead to a more accurate assessment of market power.

2 Model

2.1 The basics

We generalize a model developed by (Kamien, Levhari and Mirman 1985) to include the possibility that firms account for stock growth in their current period maximization problem. In order to generate closed form solutions, we model two packers ($i = 1, 2$), each choosing how many cattle x^i to purchase and process in each production period.[2] Without loss of generality, we assume that live cattle are transformed pound for pound into output (boxed beef). Let $X = x^1 + x^2$ denote the aggregate live cattle purchases and the output that is supplied in the period. The price of boxed beef is given by the inverse demand function $p_b = p(X)$. Processing costs incurred by each packer in transforming the raw input into output are $c(x^i)$. Live cattle are purchased from ranchers following the supply function $w_m = w(X)$. The growth characteristics of cattle stocks (S) are represented by the function $f(S, X)$, so that $S_t = f(S_{t-1} - X_{t-1})$. This function is general enough to allow for both stock growth through weight gain (Same number of cattle, each larger in size), and through births (larger number of cattle).[3] Following the literature on cattle growth in feedlots, we assume $f'(\cdot) > 0$, and $f''(\cdot) < 0$.

The objective for firm i is to choose x^i each period to maximize the present value of the sum of per-period operating profits, $\pi_t(p_b, w_m) = p(X_t)x^i - w(X_t)x^i - c(x^i)$, subject to the growth characteristics of the live cattle stock, and the actions of rival firm j. This value

[2]The results generalize to competition between more than two packers, but create additional complexity without additional insight.

[3]There is a three-year lag between the decision to retain a cow and the sale (or retention) of her offspring. In the theoretical section, we account for this by defining a "period" to be three years. In our estimating equation, the stock dynamic equation will be modified to capture this lag structure.

function is

$$V(S_t) = \sum_{t=1}^{\infty} \beta^t \pi_t(p_b, w_m) \qquad (1)$$
$$\text{s.t. } S_{t+1} = f(S_t - X_t),\ S_0,\ X_0 \text{ given}$$

where $\beta = 1/(1+r)$ and r is the market rate of interest.

There are three effects to consider in this model. The first is the competition effect - the quantity choice made by firm i in the current period affects the current period profits of firm j ($i \neq j$) and therefore firm j's current period production choice. This is the standard Cournot effect. The next two effects arise because the quantity chosen by firm i affects live cattle supplies available in future periods. We call these "dynamic" externalities. The direct dynamic externality (DDE) arises because the choice of x^i in the current period affects the next period's stock and therefore firm i's own discounted profit stream. The indirect dynamic externality (IDE) occurs because the choice of x^i in the current period affects next period's stock and therefore affects firm j's discounted profit stream. Furthermore, firm i assumes that firm j will react to this intertemporal stock effect on its profits.

As is standard in oligopoly models, we assume that firm i believes that its rival's quantity is given by $x^j = x^j(x^i, S)$. To ease notation, let $r^j \equiv \frac{dx^j(x^i,S)}{dx^i}$ denote the rate at which firm j's quantity adjusts with x^i, and let $R^i \equiv dX/dx^i = 1 + r^j$ denote the rate at which market output adjusts with x^i. Finally, let ε and η denote the price elasticity of demand $(-p(X)/Xp'(X))$ and the input cost elasticity of supply $(w(X)/Xw'(X))$ respectively. It is common to express the rate at which market output adjusts with x^i in elasticity form, $\theta^i = \frac{x^i dX}{X dx^i} = \frac{x^i}{X} R^i$; thus θ^i is the conjectural elasticity parameter for firm i.

2.2 Deriving the dynamic market power measures

Following (Kamien et al. 1985), we study the equilibrium market outcome under a "closed-loop" solution to equation 1. In a closed-loop solution, both firms consider the impact of their actions on rival behavior (i.e. the competitive effect) and on the future stocks available for production (i.e. the dynamic externalities).[4] The derivation of the forward-looking market equilibrium condition follows directly from (Kamien et al. 1985) and is presented

[4]In contrast, an "open-loop" equilibrium solution does not include the IDE - the effect of i's current period choice on j's future choices.

in an appendix. Here, we interpret the equilibrium solution and discuss its implications for measuring market power in the beef packing industry.

The closed-loop output policy will identify each firm's optimal quantity as a function of the cattle stock, $x^i = x^i(S)$.[5] Because firm i understands that j's quantity decision is also conditional on S, the closed loop conjecture (firm i's belief about what firm j considers in its choice) is $x^j(x^i(S), S)$ at the optimum. Aggregate quantity in the market, according to firm i, is thus $X(S) = x^i(S) + x^j(x^i(S), S)$. In the appendix, we derive the following equilibrium condition

$$A_t = \beta f'(S - X_t)\frac{R_t^i}{R_{t+1}^i}[A_{t+1} - N_{t+1}] \tag{2}$$

for $i = 1, 2$, where the functional dependence on S is implied, $A_t = p(X_t) - w(X_t) - c'(x_t^i) + [p'(X_t) - w'(X_t)]\, x_t^i R_t^i$, A_{t+1} is similarly defined, and $N_{t+1} = [p(X_{t+1}) - w(X_{t+1}) - c'(x_{t+1}^i)]\left(\frac{dx_{t+1}^j}{dS}\right)$.

Equation 2 is the analog to a standard investment rule. In effect, this equation says that firm i equates marginal profits across periods. The left-hand side is the marginal value from slaughtering the last unit of the stock in the current period. Notice that it includes the Cournot effect, R_t^i. The right-hand side is the marginal value of foregone slaughter, that is of the marginal investment in the cattle stock, which is given on the right-hand side of equation 2. This term includes the discounted growth in the stock $\beta f'(\cdot)$ and the future profits earned from slaughtering the animal next period.[6] Both dynamic externalities are included in this model, as firm i accounts for the direct effect that its current quantity choice has on the future stock of cattle and thus its own future profitability (A_{t+1}), as well as the indirect effect of its choice on the future quantity of cattle firm j slaughters (N_{t+1}).

Equation 2 can be expressed in a more familiar way as the dynamic closed-loop Lerner index (derived in the appendix),

$$\mathcal{L}^c = -\frac{\theta_t^i}{\varepsilon_t} + \Gamma \tag{3}$$

[5]This function is not to be confused with firm i's belief about firm j's quantity, $x^j(x^i, s)$.

[6]Recall that in this section, the time from birth to maturity is defined as one "period". In estimating this model, we will have to account for the additional years between birth and maturity.

Where $\Gamma = \frac{\beta f'(S_t - X_t)}{p(X_t)} \left(\frac{R_t^i}{R_{t+1}^i}\right) [A_{t+1} - N_{t+1}]$.

The first right-hand term $-\theta_t^i/\varepsilon_t$ is the Lerner index that is commonly estimated in non-forward looking models of market power. The second term, Γ represents the consideration firm i gives to the effect of its current period choices on the stock available for slaughter in future periods. Assuming that the second term is not zero, the myopic measure of market power $(-\theta_t^i/\varepsilon_t)$ does not accurately describe the amount by which firms are able to raise price above marginal cost.

The myopic index accurately describes market power in a few special cases. If firms do not care about future returns, $\beta = 0$, or when the number of calves born just replaces the number of head culled from the herd, $f'(\cdot) = 0$, equation 3 collapses to the myopic Lerner index. As noted in (Dockner 1992), the term $[A_{t+1} - N_{t+1}]$ is extremely unlikely to be zero, since it includes the Cournot effect, the DDE and the IDE. Note also that the Lerner index is equal to zero in a competitive market, which occurs when $R^i = \theta^i = 0$, i.e. when individual firm output decisions do not affect market quantity X and the firm recognizes this. Under perfect competition the forward-looking Lerner index is equivalent to the myopic index (both are zero) because firms cannot be assured that they will be the claimants of the returns from investing in the stock.

We argue that these conditions are not likely to arise in beef packing, with its small number of firms and well-understood (and cyclical) cattle supply conditions. Because of this, estimates of market power based on current period data will probably be biased. Of course, an empirical test of this model is needed to verify or disprove this conjecture.

Equation 2 can also be manipulated to measure market power in the input market. Let $\mathcal{M}^c$ denote the difference between marginal revenue product of live-cattle input and the input price, normalized by the input price. Then, as we derive in the appendix;

$$\mathcal{M}^c = \frac{\theta_t^i}{\eta_t} + \Delta \tag{4}$$

Where $\Delta = \frac{\beta f'(S_t - X_t)}{w(X_t)} \left(\frac{R_t^i}{R_{t+1}^i}\right) [A_{t+1} - N_{t+1}]$.

As with the Lerner index, $\mathcal{M}^c$ is equal to the myopic measure θ_t^i/η_t plus an adjustment which accounts for the value of investing in the stock. The adjustment includes the discounted value of next period cattle stock $\frac{\beta f'(S - X_t) R_t^i}{w(X_t) R_{t+1}^i}$, the direct dynamic externality (the effect firm i's current period choice has on future stock levels) A_{t+1}, and the indi-

rect dynamic externality, N_{t+1}, the effect of firm i's current period choice on future stocks and therefore on firm j's future production choices. Also as with the Lerner index, this adjustment term is unlikely to be zero in the beef packing industry. Models that do not include the discounted profit stream in the firm's maximization problem will not include this adjustment, and may therefore draw inaccurate conclusions regarding market power.

2.3 Determining the bias in myopic market power measures

The forward looking market power measures given in equations 3 and 4 indicate that single-period models are likely to produce biased estimates of market power. Unfortunately, the direction of the bias cannot be determined theoretically. We see that the forward-looking Lerner index ($\mathcal{L}^c$) is larger (smaller) than the corresponding myopic measure ($\mathcal{L}^S$) if and only if the adjustment term (Γ) is positive (negative). Recall that $\Gamma = \frac{\beta f'(S_t - X_t)}{p(X_t)} \left(\frac{R_t^i}{R_{t+1}^i}\right) [A_{t+1} - N_{t+1}]$. The first term in this equation, $\beta f'(\cdot)/p(X_t)$ is positive. R_t^i/R_{t+1}^i is also positive if when market output rises (falls) with firm i's output in the current period, it will continue to rise (fall) with firm i's output in the future.

Thus, the myopic Lerner index is biased downward (upward) if and only if

$$A_{t+1} - N_{t+1} \equiv V'(f(S_t - X_t)) \left(\frac{p(X_t)}{p(X_{t+1})}\right) \left(\frac{R_{t+1}^i}{R_t^i}\right) > (<) 0 \tag{5}$$

Using basic (but somewhat tedious) algebra, we see that the left-hand side of this inequality can be rearranged to

$$\left(\frac{p(X_{t+1}) - w(X_{t+1}) - c'(x_{t+1}^i)}{p(X_{t+1})}\right) \left(1 - \frac{dx_{t+1}^j}{dS_{t+1}}\right) + \frac{[p'(X_{t+1}) - w'(X_{t+1})]x_{t+1}^i R_{t+1}^i}{p(X_{t+1})} \tag{6}$$

From the second-order conditions for profit maximization, which are assumed to hold, the second term in this sum is negative. The sign of the first term is ambiguous, although likely to be positive. The ambiguity arises at two points. First, it is possible that $p(X_{t+1}) - w(X_{t+1}) - c'(x_{t+1}^i)$ is negative. Assuming that $V'(\cdot)$ is not too negative, it can be shown that $p(X) - w(X) - c'(x^i)$ is positive (using the first order necessary condition, equation A.2 from the appendix).[7] Second, the size of firm j's reaction to a change in stock levels ($\frac{dx_{t+1}^j}{dS_{t+1}}$) cannot be theoretically predicted. If firm j does not overcompensate for changes in stock

[7] In particular, when $V'(\cdot) > \frac{(p'(X) - w'(X))x^i}{\beta f'(\cdot)}$, $p(X) - w(X) - c'(x^i)$ is positive.

levels, $\frac{dx^j_{t+1}}{dS_{t+1}}$ will be smaller than one, and (given that $V'(\cdot)$ is large enough) the first term is positive.[8] Since, under reasonable assumptions, we have a positive and a negative term in the bias, both its size and direction are ambiguous.

Similar calculations can be performed on the myopic input measure of market power. Using the same techniques as for the Lerner index, we can show that

$$\mathcal{M}^c > (<)\mathcal{M}^S \Leftrightarrow A_{t+1} - N_{t+1} > (<)0 \tag{7}$$

Notice that since both $p(\cdot)$ and $w(\cdot)$ are positive, the bias in the input market power measure will have the same sign as the bias in the Lerner index. As before, signing this bias in $\mathcal{M}^S$ is an empirical matter, since $A_{t+1} - N_{t+1}$ contains a negative term and a (likely) positive term.

3 Estimating the model

3.1 Deriving the Empirical Specification

The results presented above suggest that investigation of market power based on myopic conjectural variations models are biased.[9] This section applies the forward-looking model of competition to data from the U.S. beef-packing industry.

Our first task is to derive econometric equations based on the theoretical conditions provided above. As noted, a single "period" as defined above represents three years. Since we employ annual data, we specify the following three-period lag structure for stock dynamics

$$S_t = \gamma_1 S_{t-1} + \gamma_3 S_{t-3} \tag{8}$$

where $\gamma_1 = (1-\delta)(1-\alpha_S)$, $\gamma_3 = (1-\delta)^2(1-\alpha_0)0.5g$, δ is the death rate, g is the birthing rate, α_S is the cull rate for cows (i.e., fraction of the cow stock sent to market), and α_0 is the cull rate for calves. The intuition behind (8) is clear and follows closely the laws of

[8] It is not possible to determine the size of dx^j/dS, even in the steady state. It is possible to derive an expression for dx^j/dS, but this expression may take on values greater than or less than one.

[9] This simple model of Cournot duopoly has provided an exact characterization of the bias in estimates based on a myopic model. If there are more than two firms in the industry, and depending on the particular way that cattle stocks evolve, this exact characterization will change, although the main result will continue to hold.

motion for cattle inventories in (Rosen 1987) and (Chavas 2000). The total stock of cows can change for two reasons: (1) some cows from period $t-1$ may die or get sent to slaughter (i.e., culled from the stock) and (2) calves born from cows bred in period $t-3$ that do not die can be retained for addition to the breeding stock in period t.[10]

Given (8), the packer's equilibrium first-order condition is

$$\begin{aligned} A_t &= \frac{\beta\gamma_1 R_t^i}{R_{t+1}^i}\left[A_{t+1}\frac{dX_{t+1}}{dS_{t+1}} - N_{t+1}\right] \\ &+\frac{\beta^2\gamma_1^2 R_t^i}{R_{t+2}^i}\left[A_{t+2}\frac{dX_{t+2}}{dS_{t+2}} - N_{t+2}\right] \\ &+\frac{\beta^3(\gamma_1^3+\gamma_3)R_t^i}{R_{t+3}^i}\left[A_{t+3}\frac{dX_{t+3}}{dS_{t+3}} - N_{t+3}\right] \end{aligned} \tag{9}$$

where A and N are as defined in the theoretical section. The intuition behind this equation is the same as for (2), but it is slightly more complex given the three-period lag nature of the stock dynamics. As before, if packers are forward looking, β will not be equal to zero, and static market-power estimates (which rely on estimates from the equation $A_t = 0$) will be biased. Our ultimate goal is to compare estimates of equation 9 with and without β set equal to zero to determine the size and direction of the bias.

Toward this end, we estimate five equations: the slaughter-stock relationship, the wholesale demand for nonfed beef, the input supply of cows, the packer's equilibrium first-order condition with β set to zero ($A_t = 0$) and with β allowed to be greater than zero (equation 9). We begin by specifying the amount purchased by packers as a given proportion of available stocks:

$$X_t = a_0 + a_1 S_t + \varepsilon_{1,t} \tag{10}$$

This equation will be used later in estimating the packer's equilibrium first-order condition.

Next, we assume that the demand for beef can be represented by a log-linear inverse

[10]This specicfication for (8) simplifies the rancher's problem by assuming that the cull rates for cows and calves are constant over time. Clearly this is an abstraction from reality, but one that greatly simplifies our analysis. The more complicated problem of solving the entire rancher's dynamic optimization problem is beyond the scope of this paper.

demand function:

$$\ln(p_t) = b_0 + b_1 \ln(X_t) + b_2 \ln(di_t) + b_3 \ln(pc_t) + b_4 \ln(pp_t) + b_5 t + \varepsilon_{2,t}. \tag{11}$$

In order to avoid modeling feedlot behavior, we use data on "non-fed" beef only. Cows culled from the herd some years after they have been in the breeding stock do not go through the "finishing" process, which involves approximately 9 months in a feedlot on concentrated feed. Thus, these cows are defined as non-fed.

We hypothesize that the demand curve for (11) is downward-sloping ($b_1 < 0$), nonfed beef is a normal good ($b_2 < 0$), chicken and pork are substitutes for nonfed beef ($b_3 > 0$ and $b_4 > 0$), and there has been a gradual downward trend in the price of nonfed beef over time ($b_5 < 0$).

The (inverse) input supply of cows is also assumed to be log-linear:

$$\ln(w_t) = c_0 + c_1 \ln(X_t) + c_2 \ln(ph_t) + c_3 t + \varepsilon_{3,t} \tag{12}$$

The literature on cattle supply is mixed regarding the nature of the short-run supply response in the cattle industry. Some theoretical studies suggest that the supply curve may be negatively sloped if the shock to demand is sufficiently permanent ((Jarvis 1974), (Rosen 1987)). Others, however, have found evidence that the supply response may instead be positive ((Paarsch 1985), (Mundlak and Huang 1996)). (Aadland and Bailey 2000) in a recent study found that the short-run supply response for cows is generally positive for shocks (transitory or permanent) that impact the relative price of cows (non-fed) to heifers (fed). Therefore, we include the price of heifers to isolate shocks that impact the relative price of cows. We then hypothesize that the supply curve for cows (conditional on heifer prices) is upward sloping ($c_1 > 0$), cows are substitutes for heifers ($c_2 > 0$), and there has been a gradual downward trend in the price of cows over time ($c_3 < 0$).

The last econometric equation is the equilibrium first-order condition for packers (9). With some substitution and assuming symmetry across packers, equation 9 can be written more simply as

$$(p_t - w_t) = d_0 + \theta(c_1 w_t - b_1 p_t) + \theta \Gamma_t + \varepsilon_{4,t} \tag{13}$$

where θ is the conjectural elasticity parameter defined above and

$$\Gamma_t = \beta\gamma_1 a_1[b_1 p_{t+1} - c_1 w_{t+1}] + (\beta\gamma_1)^2 a_1[b_1 p_{t+2} - c_1 w_{t+2}] + \beta^3(\gamma_1^3 + \gamma_3)^2 a_1[b_1 p_{t+3} - c_1 w_{t+3}]$$

Exclusion of Γ_t from (13) produces what we refer to as the "myopic" conjectural variations estimate. The primary goal of this paper is to establish that estimates of θ from models that exclude the Γ_t term, or equivalently assume that $\beta = 0$, are biased.

We use aggregate time series data from 1948 to 1999 to estimate the model. Our sample begins in 1948 because (i) heifer and cow slaughter were not reported separately until 1944 and (ii) in 1947, the spread between farm prices for cull cows and wholesale prices for nonfed beef was abnormally high. The data are taken from *Agricultural Statistics*, an annual publication of the Economic Research Serivce branch of the United States Department of Agriculture. As mentioned above, we focus our attention on the stock of cows (S), which is measured by the number of cows and heifers that have calved as of January 1. Total cow slaughter (X) is given by the total number of federally inspected slaughtered cows over the year. At the farm level, we use the market price for commercial cows (w) at two different markets. Prior to 1968, the USDA reports the market price at Chicago. After 1968, the USDA reports the market price paid to farmers at Omaha. For the years 1964 through 1968, both series are reported and produce very similar prices, as the law of one price would predict. For heifers (ph), we use the average price received by farmers for calves, which is an average price paid to farmers across the states in a given year. We are unaware of any historical data on retail prices for nonfed beef (p). However, we were able to obtain average wholesale prices of commercial dressed steer beef from 1944 through 1988. After 1988 the USDA stopped reporting wholesale prices for dressed carcasses because packing technology had changed, and beef was no longer sold in this way.[11] For the post 1988 period, we obtained (through the USDA) the wholesale canner-cutter dressed, non-fed, boxed-beef price out of Omaha, NE. When spliced together, these two series serve as our measure for the price of nonfed beef. The final three series are the price of broiler chickens (pc), the average price received by farmers for hogs (pp), and U.S. disposable income (di). All nominal series are deflated using the US consumer price index for all goods and services

[11] In the early 1970s, packing firms began producing "boxed beef". Rather than selling whole carcasses, packers processed the carcass into primal cuts and sold boxes of a given cut. For example, wholesalers now purchase a box of hindquarters, rather than the entire carcass.

(1967 = 100).

3.2 Results

Our estimation is completed in two stages. In stage one, we estimate equations 10, 11 and 12. Then in stage two, conditional on these estimated elasticities and the estimated slaughter-stock slope parameter, we estimate the conjectural variations elasticity θ in (9) for two cases: (i) with myopic packer behavior and (ii) with forward-looking packer behavior.[12]

First, we generate estimates from equation 10 using the Cochrane-Orcutt iterated procedure to correct for first-order autocorrelated errors. Endogeneity of period t cow stocks is not an issue because the stock of cows in period t is predetermined by decisions made in the previous period. Equations 11 and 12, on the other hand, are estimated using instrumental variables (also with an autocorrelation correction) because of the endogeneity associated with $\ln(X)$. The set of instruments for (12) are the remaining exogenous variables, the stock of heifers and cows in period t, and once-lagged $\ln(X)$. The set of instruments for (11) are the remaining exogenous variables, the stock of calves, heifers and cows in period t, and once-lagged $\ln(X)$. Lastly, the estimates for (13) are also generated with autocorrelation-corrected instrumental variables technique. The set of instruments for (13) include the linear time trend, box-beef dummy, the stock of heifers and cows in period t, and the once- and twice-lagged values of $(c_1 w_t - b_1 p_t)$. The results are presented in Table 1.

[Insert Table 1 approximately here]

Begin by focusing on the results in the first three columns of Table 1.[13] All the signs of the estimated coefficients agree with our initial hypotheses and all but the box-beef

[12]Ideally, these equations would be estimated as a system of equations with the appropriate cross-equation restrictions imposed. However, given the nature of the optimizing equation for the packers, we found that full maximum likelihood and generalized method of moments estimation tend to choose $\theta = 1$, $b_1 = 1$ and $c_1 = 1$, generating a perfect fit for the packer's first order-condition. We consider these unreasonable demand and supply elasticities that result simply because of the nature of the first-order condition. We therefore instead rely on estimates from the two-stage procedure. Furthermore, given that we are only interested in showing that models based on myopic conjectural variations produce biased estimates, we are willing to suffer the loss in efficiency caused by using this two-stage procedure. The loss in efficiency from single-equation estimation and generated regressors would be a concern, however, when performing hypothesis tests.

[13]The results in the last column of Table 1 are conditioned upon the following parameter values for cattle stock dynamics: $\beta = 0.96$, $g = 0.85$, $\delta = 0.1$, $\alpha_S = 0.2$ and $\alpha_0 = 0.6$. We experimented with different reasonable values for these parameters and found the differences between to the myopic and forward-looking estimates of θ to be robust.

dummy are statistically significant. The primary coefficients of interest are a_1, b_1 and c_1. The estimate for a_1 implies that for an increase in the aggregate stock of cows by 1000, cow slaughter will increase by 396 animals. As we estimated inverse supply and demand functions, the reciprocal of b_1 gives the price elasticity of supply, and the reciprocal of c_1 gives the price elasticity of demand. The supply elasticity suggests the supply of cull cows (holding constant the price of heifers) is quite responsive to changes in the price of cows (i.e., an elasticity of approximately 4.2). The demand elasticity suggests that demand for nonfed beef is slightly elastic with respect to its price (i.e., an elasticity of approximately -1.2).

The final two columns in Table 1 report the conjectural elasticity estimates for myopic and forward-looking packers.[14] The myopic estimate of the conjectural elasticity paramater is $\theta = 0.352$ and is statistically significant at the 1% significance level. The forward-looking estimate is approximately 33% larger ($\theta = 0.467$), is also statistically significant, and shows that (at least using aggregate US time series data) myopic conjectural variation estimates appear to be downwardly biased, implying that packers are exerting more market power than myopic estimates would suggest. According to the work in our theoretical section, the myopic market power measure is biased downward if and only if the direct dynamic externality (captured in A_{t+1}) is larger than the indirect dynamic externality (captured by N_{t+1}). Since our results suggest a downward bias in θ, our findings support the notion that direct dynamic effects outweigh indirect dynamic effects. Once again, note that while the levels of our market power estimates are of interest, the signicant conclusion is that these two estimates, derived from the same data set and estimating techniques, are different. Ignoring stock dynamics appears to lead to inaccurate estimates of market power.

4 Conclusion

Increased concentration in the beef packing industry continues to be a major policy concern in the United States. Previous studies of market power in beef packing ignore the intrinsic growth characteristics of cattle stocks, and thus fail to consider the shadow value of investing

[14]These conjectural variations elasticity estimates are similar to those found by (Bhuyan and Lopez 1997), and (Schroeter and Azzam 1991). They differ from estimates obtained in (Schroeter 1987), and (Azzam and Schroeter 1995). We feel, however, that it is more appropriate to compare the conjectural variations elasticity estimates we generate with each other, rather than with estimates from other studies, because other estimates are generally derived using different data sets and/or estimation techniques.

in this stock. We present a simple forward-looking Cournot duopoly model illustrating the bias introduced into both the "standard" Lerner index and the measure of oligopsony market power. We also show that this bias cannot be theoretically signed, so that determining whether existing measures over- or understate market power is an empirical matter. However, as long as firms do not completely discount the future, and have non-zero conjectures regarding the effect of their choices on market output, myopic measures of market power are expected to be biased. Using data on cattle stocks, sales and prices from 1948-1999, we demonstrate that myopic measures of market power are indeed biased. In our data set, myopic market power measures understate the degree of packer market power.

A Derivation of Forward-Looking Market Power Measures

Firm i's closed loop conjecture of firm j's quantity is $x^j(x^i, S)$. The Bellman equation representation of the firm value function is

$$V(S) = \max_{x^i} \left\{ [p(x^i + x^j(x^i, s)) - w(x^i + x^j(x^i, s))]x^i - c(x^i) + \beta V(f(S - x^i - x^j(x^i, s))) \right\} \tag{A.1}$$

Notice that firm j's choice depends both on x^i (the Cournot externality), and on s (the dynamic externality). We take the derivative of $V(S)$ with respect to x^i to obtain the first-order necessary condition

$$\begin{aligned} &[p(X) - w(X)] + [p'(X) - w'(X)]R^i x^i - c'(x^i) \\ &\quad - \beta V'(f(S - X))f'(S - X)R^i = 0 \end{aligned} \tag{A.2}$$

where $X = x^i + x^j(x^i, s)$. Assuming second-order sufficient conditions are satisfied, there exists a function $x^i(S)$ which solves equation A.2 and maximizes A.1. Inserting this solution into equation A.1, differentiating with respect to s, and using equation A.2 obtains

$$\begin{aligned} V'(S) = &[p'(X(S)) - w'(X(S))]x^i(S)\frac{dx^j}{dS} \\ &+ \beta V'(f(S - X(S)))f'(S - X(S)) \left[1 - \frac{dx^j}{dS}\right] \end{aligned} \tag{A.3}$$

where $X(S) = x^i(S) + x^j(x^i(S), s)$. Solving for $\beta V'(\cdot)f'(\cdot)$ from equation A.2 and simplifying yields

$$\begin{aligned} V'(S) &= \left[p'(X(S)) - w'(X(S))\right] x^i(S) \\ &\quad + \frac{p(X(S)) - w(X(S)) - c'(x^i(S))}{R^i}\left(1 - \frac{dx^j}{dS}\right) \end{aligned} \tag{A.4}$$

To obtain the forward-looking equilibrium condition, evaluate equation A.4 at $f(S - x^1 - x^2)$ instead of s, let $X_{t+1}(S)$, $x^i_{t+1}(S)$, θ^i_{t+1}, and ε_{t+1} denote the values of X, $x^i(S)$, θ^i, and ε evaluated at $s_{t+1} = f(S - x^i - x^j)$, and substitute this value for $V'(S)$ into the necessary condition for an optimum, equation A.2, to obtain

$$\begin{aligned} &p(X_t) - w(X_t) - c'(x^i_t) + \left[p'(X_t) - w'(X_t)\right] x^i_t R^i_t = \beta f'(S - X_t) \\ &\times \left[\left(p(X_{t+1}) - w(X_{t+1}) - c'(x^i_{t+1})\right)\left(1 - \frac{dx^j_{t+1}}{dS}\right) + \left[p'(X_{t+1}) - w'(X_{t+1})\right] x^i_{t+1} R^i_{t+1}\right] \frac{R^i_t}{R^i_{t+1}} \end{aligned} \tag{A.5}$$

From A.5, the (closed-loop) price-cost margin can be written as

$$\begin{aligned} \mathcal{L}^c_t &= \frac{p(X_t) - (w(X_t) + w'(X_t)x^i_t R^i_t) - c'(x^i_t)}{p(X_t)} \\ &= -\frac{p'(X_t)}{p(X_t)} x^i_t R^i_t + \frac{H}{p(X_t)} \end{aligned} \tag{A.6}$$

where

$$H = \beta f'(S - X_t)\left[\left(p(X_{t+1}) - w(X_{t+1}) - c'(x^i_{t+1})\right)\left(1 - \frac{dx^j_{t+1}}{dS}\right) + \left[p'(X_{t+1}) - w'(X_{t+1})\right] x^i_{t+1} R^i_{t+1}\right] \frac{R^i_t}{R^i_{t+1}}$$

It is straightforward to show that

$$\begin{aligned} \mathcal{L}^c &= -\frac{\theta^i_t}{\varepsilon_t} + \beta f'(S - X_t)\left(\frac{p(X_{t+1})}{p(X_t)}\right)\left(\frac{R^i_t}{R^i_{t+1}}\right) \\ &\quad \times \left[\frac{\theta^i_{t+1}}{\varepsilon_{t+1}} + \mathcal{L}^c_{t+1} - \frac{p(X_{t+1}) - w(X_{t+1}) - c'(x^i_{t+1})}{p(X_{t+1})} \frac{dx^j_{t+1}}{dS}\right] \end{aligned} \tag{A.7}$$

Let $\mathcal{M}^c$ denote the measure of oligopsony power, which is given by the difference between

marginal revenue product and the input price, normalized by the input price. Manipulating equation A.5 we obtain

$$\begin{aligned}\mathcal{M}_t^c &= \frac{p(X_t) + p'(X_t)x_t^i R_t^i - c'(x_t^i) - w(X_t)}{w(X_t)} \\ &= \frac{w'(X_t)x_t^i R_t^i}{w(X_t)} + \frac{H}{w(X_t)}\end{aligned} \tag{A.8}$$

Manipulating this equation we see that

$$\begin{aligned}\mathcal{M}_t^c = &\frac{\theta_t^i}{\eta_t} + \beta f'(S - X_t)\left(\frac{w(X_{t+1})}{w(X_t)}\right)\left(\frac{R_t^i}{R_{t+1}^i}\right) \\ &\times \left[\mathcal{M}_{t+1}^c - \frac{\theta_{t+1}^i}{\eta_{t+1}} - \frac{p(X_{t+1}) - w(X_{t+1}) - c'(x_{t+1}^i)}{w(X_{t+1})}\frac{dx_{t+1}^j}{ds}\right]\end{aligned} \tag{A.9}$$

B Derivation of the Estimating Equation

Because the firm is forward looking, it accounts for the biological constraint present in the market for fed cattle. In the theory section, we illustrated the problem in using a static framework to estimate an inherently dynamic problem using a simple one-period lag structure for cattle stock dynamics. The Bellman equation approach used in that section gives the most straightforward representation of the firm's problem. Unfortunately, the lag structure in cattle stock dynamics involves at least three periods, which makes the Bellman equation approach quite complex. To generate our estimating equation, we will use the more general approach of substituting the stock dynamic constraints into the firm's problem and solving the firm's problem directly. The results are the same as would be generated by a Bellman equation approach.

A second concern, which we do not address in this paper is the derivation of the rancher's supply function. Solving the rancher's problem and the packer's problem simultaneously could lead to interesting market outcomes, and is the subject of ongoing research. Here, we are simply demonstrating that static measures of market power may be biased, and attempting to determine whether the bias is positive or negative.

As noted, the firm's problem is

$$\max_{x_t^i} \sum_{t=0}^{\infty} \beta^t \left[\{p(X_t) - w(X_t)\} x_t^i - c(x_t^i) \right] \tag{B.1}$$
$$\text{s.t. } S_t = \delta S_{t-1} + \gamma S_{t-3}, \;\; X_0, S_0 \text{ given}$$

There are four terms of interest from this discounted stream of profits:

$$\begin{aligned} &\beta^t \left[\{p(X_t) - w(X_t)\} x_t^i - c(x_t^i) \right] \\ &+\beta^{t+1} \left[\{p(X_{t+1}) - w(X_{t+1})\} x_{t+1}^i - c(x_{t+1}^i) \right] \\ &+\beta^{t+2} \left[\{p(X_{t+2}) - w(X_{t+2})\} x_{t+2}^i - c(x_{t+2}^i) \right] \\ &+\beta^{t+3} \left[\{p(X_{t+3}) - w(X_{t+3})\} x_{t+3}^i - c(x_{t+3}^i) \right] \end{aligned}$$

Dividing through by β^t and taking the derivative with respect to x_t^i gives

$$\sum_{k=0}^{3} \beta^k \left[\{p_{t+k} - w_{t+k} - c'(x_{t+k}^i)\} \frac{dx_{t+k}^i}{dx_t^i} + \{p'_{t+k} - w'_{t+k}\} x_{t+k}^i \frac{dX_{t+k}}{dx_t^i} \right] \tag{B.2}$$

Where $p_{t+k} \equiv p(X_{t+k})$ and $p'_{t+k} \equiv p'(X_{t+k})$ and similarly for w. To estimate this equation, we need to know how future market input usage changes with firm i's current period input usage ($\frac{dX_{t+k}}{dx_t^i}$), and how firm i's own future input usage depends on its current period input usage ($\frac{dx_{t+k}^i}{dx_t^i}$). We can expand the second derivative as follows:

$$\begin{aligned} \frac{dx_{t+k}^i}{dx_t^i} &= \frac{dx_{t+k}^i}{ds_{t+k}} \frac{ds_{t+k}}{ds_t} \frac{ds_t}{dX_t} \frac{dX_t}{dx_t^i} \\ &= -\frac{dx_{t+k}^i}{ds_{t+k}} \frac{ds_{t+k}}{ds_t} R_t^i \end{aligned} \tag{B.3}$$

Since $\frac{ds_t}{dX_t} = -1$, because cattle are either slaughtered or not in period t, and every head not slaughtered ($dX_t = -1$) increases the stock by exactly one head ($ds_t = 1$). We have defined $\frac{dX_t}{dx_t^i}$ to be R_t^i. To get $\frac{dx_{t+k}^i}{ds_{t+k}}$, we use the following definition (which holds at firm i's

equilibrium input choice)

$$
\begin{aligned}
X_{t+k} &\equiv x^i_{t+k}(S_{t+k}) + x^j_{t+k}(x^i_{t+k}(S_{t+k}), s_{t+k}) \\
\Leftrightarrow & \frac{dx^i_{t+k}}{ds_{t+k}}(1 + \frac{\partial x^j}{\partial x^i_{t+k}}) = \frac{dX_{t+k}}{ds_{t+k}} - \frac{\partial x^j}{\partial s_{t+k}} \\
\Leftrightarrow & \frac{dx^i_{t+k}}{ds_{t+k}} = \frac{1}{R^i_{t+k}} \left[\frac{dX_{t+k}}{ds_{t+k}} - \frac{\partial x^j}{\partial s_{t+k}} \right]
\end{aligned}
\tag{B.4}
$$

Using the constraint to derive $\frac{ds_{t+k}}{ds_t}$, and equation B.4, we obtain the following derivatives:

$$
\begin{aligned}
\frac{dx^i_{t+1}}{dx^i_t} &= \frac{-\delta R^i_t}{R^i_{t+1}} \left(\frac{dX_{t+1}}{ds_{t+1}} - \frac{\partial x^j}{\partial s_{t+1}} \right) \\
\frac{dx^i_{t+2}}{dx^i_t} &= \frac{-\delta^2 R^i_t}{R^i_{t+2}} \left(\frac{dX_{t+2}}{ds_{t+2}} - \frac{\partial x^j}{\partial s_{t+2}} \right) \\
\frac{dx^i_{t+3}}{dx^i_t} &= \frac{-(\delta^3+\gamma) R^i_t}{R^i_{t+3}} \left(\frac{dX_{t+3}}{ds_{t+3}} - \frac{\partial x^j}{\partial s_{t+3}} \right)
\end{aligned}
$$

Next, we derive $\frac{dX_{t+k}}{dx^i_t}$. First, note that at equilibrium, $X_t = x^i_t(S_t) + x^j(x^i_t(S_t), s_t)$. We also know that

$$
\begin{aligned}
\frac{dX_{t+k}}{dx^i_t} &= \frac{dx^i_{t+k}}{dx^i_t} + \frac{dx^j_{t+k}}{dx^i_t} \\
&= \frac{dx^i_{t+k}}{dx^i_t} + \frac{\partial x^j}{\partial x^i_{t+k}} \frac{dx^i_{t+k}}{dx^i_t} + \frac{\partial x^j}{\partial s_{t+k}} \frac{ds_{t+k}}{dx^i_t} \\
&= \frac{dx^i_{t+k}}{dx^i_t} R^i_{t+k} + \frac{\partial x^j}{\partial s_{t+k}} \frac{ds_{t+k}}{ds_t} \frac{ds_t}{dX_t} \frac{dX_t}{dx^i_t} \\
&= -R^i_t \frac{ds_{t+k}}{ds_t} \left[\frac{dX_{t+k}}{ds_{t+k}} - \frac{\partial x^j}{ds_{t+k}} \right] - \frac{\partial x^j}{\partial s_{t+k}} \frac{ds_{t+k}}{ds_t} R^i_t \\
&= -R^i_t \frac{ds_{t+k}}{ds_t} \frac{dX_{t+k}}{ds_{t+k}}
\end{aligned}
\tag{B.5}
$$

Thus, we obtain:

$$\begin{aligned}
\frac{dX_{t+1}}{dx_t^i} &= -\delta R_t^i \frac{dX_{t+1}}{ds_{t+1}} \\
\frac{dX_{t+2}}{dx_t^i} &= -\delta^2 R_t^i \frac{dX_{t+2}}{ds_{t+2}} \\
\frac{dX_{t+3}}{dx_t^i} &= -(\delta^3+\gamma) R_t^i \frac{dX_{t+3}}{ds_{t+3}}
\end{aligned}$$

Finally, we can write the equation we estimate as:

$$\begin{aligned}
&a_t + b_t x_t^i R_t^i = \\
&\frac{\beta\delta R_t^i}{R_{t+1}^i}\left[\left\{p_{t+1} - w_{t+1} - c'(x_{t+1}^i)\right\}\left(\frac{dX_{t+1}}{ds_{t+1}} - \frac{\partial x^j}{ds_{t+1}}\right) + R_{t+1}^i x_{t+1}^i \left\{p'_{t+1} - w'_{t+1}\right\}\frac{dX_{t+1}}{ds_{t+1}}\right] \\
&+ \frac{\beta^2\delta^2 R_t^i}{R_{t+2}^i}\left[\left\{p_{t+2} - w_{t+2} - c'(x_{t+2}^i)\right\}\left(\frac{dX_{t+2}}{ds_{t+2}} - \frac{\partial x^j}{\partial s_{t+2}}\right) + R_{t+2}^i x_{t+2}^i \left\{p'_{t+2} - w'_{t+2}\right\}\frac{dX_{t+2}}{ds_{t+2}}\right] \\
&+ \frac{\beta^3(\delta^3+\gamma) R_t^i}{R_{t+3}^i}\left[\left\{p_{t+3} - w_{t+3} - c'(x_{t+3}^i)\right\}\left(\frac{dX_{t+3}}{ds_{t+3}} - \frac{\partial x^j}{\partial s_{t+3}}\right) + R_{t+3}^i x_{t+3}^i \left\{p'_{t+3} - w'_{t+3}\right\}\frac{dX_{t+3}}{ds_{t+3}}\right]
\end{aligned} \tag{B.6}$$

defining A_t and N_t as in the theoretical section, we can rearrange this equation to the one given in the text above.

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