Cattle

1979



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# THE SUB-OPTIMALITY OF THE BEEF CYCLE

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Presented at the annual meetings of the American Agricultural Economics Association, Pullman, Washington, July 29-August ], ]979.

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## Abstract

The supply of beef is investigated using spectral analysis. The 2-1/2 year lag from herd build up until production is realized requires decisions based on future prices. Producers react instead to past prices, and the cycle results. Optimal control applied to an investment model shows the cycle to be sub-optimal.

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## Description of the Cycle

The last five cycles in the beef industry have been 10 or 11 years in length (figure 1). Currently, the price of beef is climbing in the supermarket because massive herd liquidations beginning in 1974-1975 have resulted in a short supply of beef. Typically, the way to describe a cycle is through the cobweb theorem (Ezekial, Nerlove, Talpaz). However, in a cobweb analysis it is assumed that producers react to high prices by immediately increasing production. In the beef industry, the initial reaction is to withdraw heifers and cows from the market to build up herds for future production so that there is a negative short-run supply response (Reutlinger). Thus the cycle is twice as long as the cobweb theorem predicts.

The best description of cycles in livestock production dates back to Lorie in 1947 (see also Larson). Lorie gives the reasons for the persistence of cycles as follows (p. 82):

> For those classes of livestock which do not require a substantial time lag between the decision to increase production and the marketings resulting from that decision, no cycles are evident. Milk cows exhibit very slight cyclical variation; poultry none.

This statement correctly focuses attention on biological factors but it is somewhat misleading. The length of the cycle is very dependent upon lags in herd reproduction, but the magnitude of the cycle is not. The milk cow herd can be expanded and liquidated at about the same rate as the beef cow herd, so that if a milk cycle existed it would be the same length as the beef cycle. Administered marketing programs may have dampened any oscillations in milk production and indicate that the beef cycle might be controlled or moderated.

An adaptation of Lorie's approach shows how the inventory, marketings and price of beef interact (figure 2). Exogenous shocks such as depression or drought can force liquidation which in turn increase beef marketings, causing price to be depressed. In stage II, the depressed price causes producers to cut back further on the cow herd. Even though liquidations continue, the declining herd yields fewer and fewer steers and heifers causing marketings to turn down and price to turn up. At the beginning of stage III, marketings and price are at more "normal" levels, but cow inventory has been declining so that marketings continue to decline and price to rise. The rising price causes producers to build up the cow herd. An additional impact on marketings is the withholding of heifers as replacements. The cycle is completed in stage IV when beef inventory reaches its peak. An increase in marketings occurs through the slaughter of steers and heifers and a decrease in price. At the end of stage IV there is an excess of cows which must be liquidated and the next cycle starts.

A true picture of investment and liquidation in the beef herds requires data on the number of replacement heifers and on the number of cows slaughtered. These numbers have been collected only since 1965. Kendell and Purcell discuss the problem and make assumptions to synthesize the data. Different assumptions will be made here.

To check the validity of Lorie's description (figure 2) aggregate series for total cattle inventory less milk cows, total cattle disappearance, and the price of choice steers deflated by the price of corn (beef-corn price ratio) were taken as proxies for the inventory of beef cows, marketings, and the price level. Both inventory and marketings exhibit growth trends. In order to isolate just the cyclical effects, exponential trends were fit and subtracted from the two series. The residuals are deviations from "normal".

In figure 2, the beef-corn price ratio is plotted along with the deviations from growth of inventory and marketings. Spectral analysis techniques were used to find the length of the cycle and the lead-lag relationships of the three series.

Before 1958, the length of the cycle is estimated to be 10.1 years. Subsequent to 1958, the cycle lengthened to around 10.4 years. The following lead-lag estimates quantify the relationships between the beef-corn price ratio and the deviations from growth of inventory and marketings:

1) inventory leads marketings by 2.4 years
2) price leads inventory by 3.6 years
3) price leads marketings by 5.8 years

These results are very similar to Lorie's description in that inventory leads marketings giving a production lag of close to 2-1/2 years. The important difference is that inventory and marketing deviations lag price by close to one extra year. Producers are making future production decisions based not even on current prices, but on expectations formed from past prices.

A closer examination of how producers make decisions to invest in replacement heifers or liquidate cows requires less aggregated data that does not exist prior to 1965. Kendell and Purcell assumed that replacement heifers were matched evenly by cows slaughtered for each time period prior to 1965. Such as assumption seems unreasonable since investment and liquidation occur at different points in the cycle. However, data does exist for one complete 10-year cycle following 1965. The assumption is made here that replacement heifers and cows make up the same proportions of the population at a given point in previous cycles as they did in the cycle after 1965. Disaggregated series for beef cow inventory, slaughter of steers and heifers, the beef-corn ratio replacement heifers, and cow slaughter were prepared.

Figure 3 shows the deviations from growth for replacement heifers and cow slaughter. Investment in replacement heifers undergoes very sharp increases, followed by even sharper decreases. Beef cow slaughter increases dramatically and subsides more gradually.

The following timing relationships were determined: (a) beef cow inventory leads steer and heifer slaughter by 2.3 years; (b) price leads beef cow inventory by 3.4 years; (c) price leads steer and heifer slaughter by 5.8 years; (d) price leads replacement heifers by 3.0 years; and (e) price leads beef cow slaughter by 5.6 years.

The first three timing relationships compare favorably with those obtained earlier with aggregate data.

The interesting point is that cow slaughter reacts in a timely fashion to price signals while investment in replacements does not. For producers reacting to present prices, beef cow slaughter should be lowest when price is highest and vice versa, implying a lag of 5 years for the 10-year cycle. The true lag is 5.6 years, showing that liquidation reacts quickly to price. Similarly, investment and price should move together; however investment trails price by three years.

This explanation simplifies by assuming all beef is sold on the same market. At the beginning of stage III of the cycle the cow herd is increasing, but the increased number of steers and heifers to be produced are not marketed until the beginning of stage IV. This is due to the biological lag in the production process. For a 10-year cycle, the production lag would be about 2-1/2 years.

Also implicit in this explanation is a strong assumption about the behavior of producers to price. Specifically, producers must use present and past price levels when making production decisions and be unable to react to the price they will actually receive when the steers and heifers are ready for marketing 2-1/2 years in the future. Finally, there must be many small producers, each unable to affect the price through his decisions. All of these assumptions are consistent with past and present industry behavior.

## The Sub-optimality of the Beef Cycle

The inability of producers to react to future prices results in a market failure. It might be expected that this market failure is sub-optimal for the industry as a whole. Sub-optimality is verified using optimal control techniques.

The optimal decision rules for the industry as a whole will be derived in a capital investment framework. Beef investment has some aspects which make it unique. Beef cattle are self-replicating. In other words, it is not possible to infuse outside capital as you might build a hydroelectric dam. Production from existing stock must be diverted from its flow toward the marketplace back into next year's stock.

A second distinguishing feature is that stock can be liquidated at any time. A well-developed market exists whose price follows the ups and downs of the market for the primary production. There is no market for used hydroelectric dams, on the other hand.

In discrete time, the central decision-maker's problem is characterized as:

$$\max_{S} \sum_{t=0}^{T-1} \left(1/(1+\rho^{t+k} P_{t+k}(\alpha S_t) - 1/(1+\rho)^{t} P_t I_{t-1} + 1/(1+\rho)^{t+d} P_t L_{t-1} \right)$$

subject to:

$$S_t - S_{t-1} = I_{t-1} - L_{t-1}$$

where

$$I_{t-1} \leq \beta S_{t-k}$$

$$L_{t-1} \leq S_{t-1}$$

$$S_t \geq 0$$

$$I_t \geq 0$$

$$D_t \geq 0$$

$S_t$ is the stock

$I_{t-1}$ is last year's production diverted to investment

$L_{t-1}$ is liquidation of stock last year

$P_t$ is the net price received for a unit of production

$\rho$ is the discount rate

k is the production lag between the decision to produce and realized production

$\alpha$ is the reproduction rate of stock

d is a factor denoting the value of stock is reduced by being used over time

$\beta$ is the proportion of reproduced stock useful for reinvestment

In words, the objective is to maximize the discounted value of future production minus the value of lost production diverted to investment plus the value gained from liquidation. The change in stock over time is governed by the equation of motion which states that present stock is last year's stock plus investment minus the stock liquidated. Investment is physically constrained to be some fraction of the stock in k periods previous, where k is the time required for production to reach maturity. Liquidation is constrained to be no greater than the stock. Additional constraints require positive stocks, irreversible investment, and irreversible liquidation.

A word needs to be said about how this capital investment model corresponds to the beef industry. The stocks are the number of beef cows in the herd. Investment is the number of replacement heifers kept. Liquidation is beef cow slaughter. $\alpha$ will be the weaning rate or some measure. $\beta$ will be $1/2\ \alpha$. It is assumed that breeding bulls make up a small proportion, and that all animals are either kept for breeding or slaughtered in their second year, so that k becomes 2.

Form the augmented Hamiltonian:

$$H_t = 1/(1+\rho)^{t+k}P_{t+k}(\alpha S_t) - 1/(1+\rho)^{t}P_t I_{t-1} + 1/(1+\rho)^{t+d}P_t L_{t-1}$$
$$+\lambda_t( I_{t-1} - L_{t-1}) + \mu_1(\beta S_{t-k} - I_{t-1} ) + \mu_2( S_{t-1} - L_{t-1} )$$

or upon rearranging,

$$H_t = 1/(1+\rho)^{t+k}P_{t+k}(\alpha S_t) - ( 1/(1+\rho)^{t}P_t - \lambda_t )I_{t-1}$$
$$+ ( 1/(1+\rho)^{t+d}P_t - \lambda_t )L_{t-1} + \mu_1(\beta S_{t-k} - I_{t-1} ) + \mu_2( S_{t-1} - L_{t-1} )$$

$S_t$ is the state variable, and $I_{t-1}$, $L_{t-1}$ are the controls. A Pontryagin necessary condition is that H be maximized with respect to these controls, yielding the following conditions:

$1/(1+\rho)^{t}P_t > \lambda_t$ then $I_{t-1} = 0$

$1/(1+\rho)^{t}P_t < \lambda_t$ then $I_{t-1} = \beta S_{t-k}$

$1/(1+\rho)^{t+d}P_t > \lambda_t$ then $L_{t-1} = S_{t-1}$

$1/(1+\rho)^{t+d}P_t < \lambda_t$ then $L_{t-1} = 0$

Kuhn-Tucker conditions on the feasibility constraints impose ceilings on the values $I_{t-1}$ and $L_{t-1}$. $\lambda_t$ is the discounted user cost of holding stock for future production. It is compared to the discounted net value of investment, $1/(1+\rho)^{t}P_t$, and the discounted net value of liquidation, $1/(1+\rho)^{t+d}P_t$. The fact that $1/(1+\rho)^{t}P_t > 1/(1+\rho)^{t+d}P_t$ means that $I_{t-1}$ goes to zero before $L_{t-1}$ goes to $S_{t-1}$. The following three ranges result:

1) $\lambda_t < 1/(1+\rho)^{t+d}P_t$ then $I_{t-1} = 0$; $L_{t-1} = S_{t-1}$
2) $1/(1+\rho)^{t+d}P_t < \lambda_t < 1/(1+\rho)^{t}P_t$ then $I_{t-1} = 0$; $L_{t-1} = 0$
3) $1/(1+\rho)^{t}P_t < \lambda_t$ then $I_{t-1} = \beta S_{t-k}$; $L_{t-1} = 0$

Condition 1 states that the value of holding and using stock cannot be less than the present value of liquidating the stock. Condition 3 states that investment should occur if the value of using stock exceeds that foregone by diverting production to investment. Condition 2 holds when it is profitable to keep the existing stock, but net investment is not profitable.

Now suppose that $P_t$ is not an exogenously given factor, but is determined by the supply side of the market,

$$P_t = c - \gamma(\alpha S_{t-k} - I_{t-1}) - \delta L_{t-1}$$

The term $\alpha S_{t-k}$ is total production at time t after a lag of k. From this is subtracted the investment diverted to production to give the production marketed at time t. Marketings and liquidations, $L_{t-1}$ are expected to depress price. It is also assumed that liquidations and investment cannot adjust instantaneously from zero to their upper bounds. If $L_{t-1}$ were ever to hit its maximum of $S_{t-1}$, the industry would cease to exist.

If the system were in the liquidation phase, range 1, price will fall over time. The user cost, $\lambda_t$ is a function of price and will also fall. A Pontryagin necessary condition is:

$$\lambda_{t+1} - \lambda_t = - \partial H_{max} / \partial S_t$$

or

$$\lambda_{t+1} = \lambda_t - 1/(1+\rho)^{t+k} P_{t+k} \ (\alpha)$$

With $P_t$ decreasing over time, less will be subtracted from $\lambda_t$, and it will fall more slowly. If price decreases fast enough, liquidation is stopped and steady-state, range 2 is reached at a lower level of stock.

If the system is in the investment phase, range 3, $P_t$ will rise, $\lambda_t$ will rise more slowly, and steady-state will be resumed at a higher level of stock.

If the system remains in the steady-state for at least k time periods, $P_t$ will be the same as $P_{t-k}$ when production decisions were made, and the system will be stable. The optimal policy requires no net investment or liquidations.

Even for atomistic producers where $P_t$ and $\lambda_t$ are not optimized by a central decision making body, the steady-state should be stable. Price will remain the same k periods hence and expectations of the future value of production can rightly be based upon it. An exogenous physical shock which increases $L_t$, or an economic shock which lowers $P_t$ will move the system into the liquidation phase. An increase in price from excess demand will move the system into the investment phase. Rational producers who can predict the future price will move to a higher or lower steady-state.

However, if the expectations of $\lambda_t$, the value of holding stock for future production, are based upon prices in the present, a decreasing price will cause over liquidation. Producers perceive k periods too late that price has returned to normal levels, and by that time the available stock is too small to support a steady-state. Price will continue to rise. Thus cyclical behavior is perpetuated. Producers confuse the value of holding stock for future production with current price levels. It is this failure of atomistic producers to equate these marginal conditions which can cause suboptimal behavior for the industry as a whole.

A producer who understands the cycle forms expectations of $\lambda_t$ on future prices rather than present prices. When current prices are low his $\lambda_t$ will be large and the producer who predicts the cycle will be investing while others are liquidating.

Why, then, does the cycle persist? Is it lack of knowledge, or are there institutional and liquidity constraints? Who benefits and loses? These are the unanswered questions of the beef cycle.

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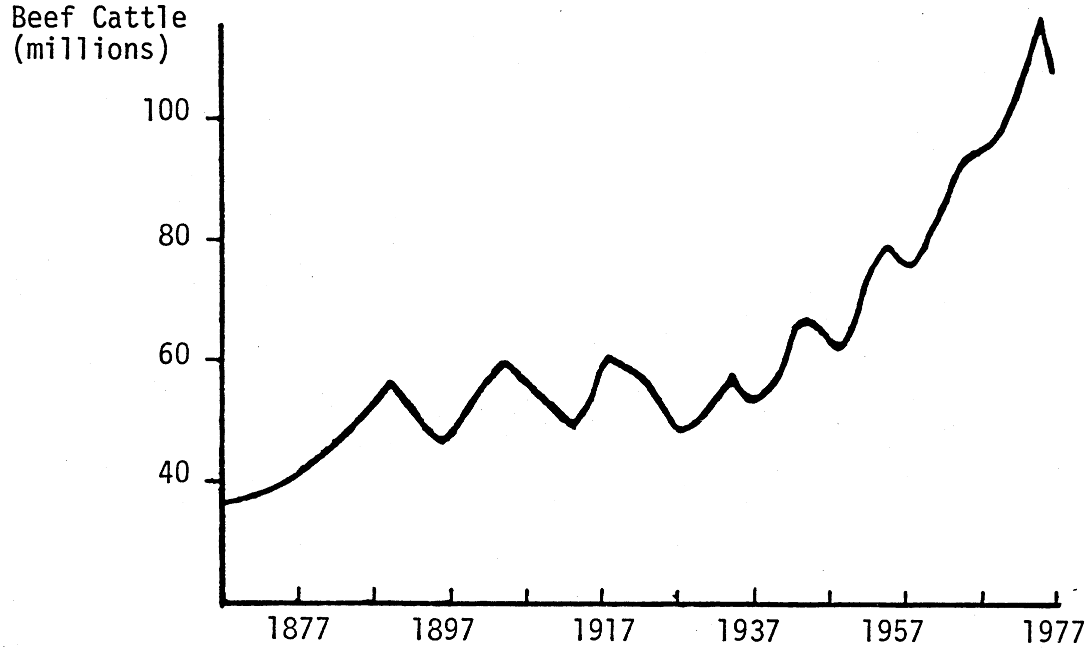


Figure 1. Total beef cattle inventory.

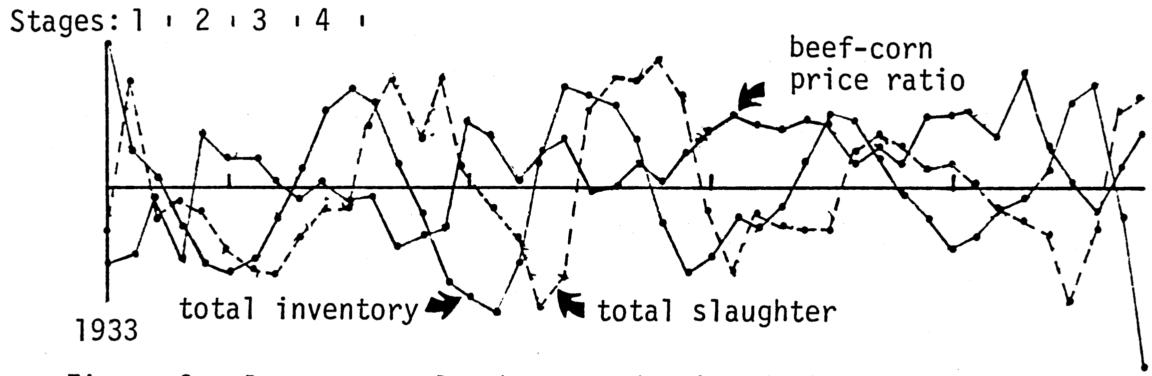


Figure 2. Inventory, slaughter, and price deviations from growth.

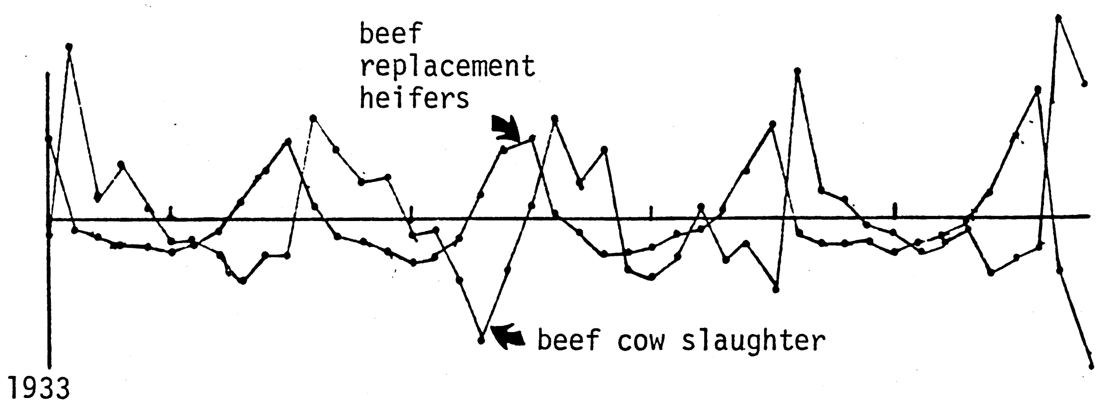


Figure 3. Replacement heifers and cow slaughter deviations from growth.