A Theoretical and Empirical Investigation of the Supply Response in the U.S. Beef-Cattle Industry

David Aadland, DeeVon Bailey and Shelly Feng[¤]

March 2000

Abstract

This paper investigates the response of beef cattle producers to changes in the price of cattle. Previous research has suggested that there may be a negative short-run supply response to a permanent increase in the price of cattle. We build a dynamic, rational expectations model that predicts that the supply response is generally positive, even for permanent shocks in the short run, and nests the negative supply response as a special case for appropriately restricted demand shocks. Using annual US time series data (1930-1997) and a simultaneous-equations econometric approach, we ...nd a positive short-run supply response in the cow market and mixed evidence in the heifer market.

---

1 Introduction

The possibility of a negative or perverse supply response in agricultural markets is an intriguing concept. As the story goes, for animal industries (such as cattle or hogs) where females are valued both as a capital and a consumption good, an increase in the market price may actually induce producers to reduce the supply of the animal going to market. If the price increase is su¢ciently permanent, then producers may optimally retain a larger than average number of females to add to the breeding stock to take advantage of higher prices in the future. The result, at least in the short-run, is that we may observe a negative relationship between price and quantity supplied (i.e., a downward-sloping supply curve). In the long-run, the supply relationship will eventually turn positive as the larger breeding stocks produce more animals destined for the market.

A seminal article in this area is Jarvis (1974). Jarvis modeled the microeconomics of cattle supply where each cattle producer maximizes a discounted stream of future pro…ts. He showed, among other things, that theoretically there is an opportunity for a negative short-run supply response by producers. Moreover, when applied to the Argentinian beef cattle industry, he found evidence of a negative short-run supply response. Paarsch (1985) extended Jarvis' work by modifying some behavioral assumptions and showed that the short-run supply response to an increase in the relative price of beef is instead positive when the rancher manages a succession of herds. Rosen (1987), using a dynamic rational expectations equilibrium model, also found theoretical evidence for a negative short-run supply response and emphasized how its existence depends on whether the demand shock is transitory or permanent.

The empirical literature on the short-run supply response in the US cattle industry also provides mixed results. Structural changes and low cattle prices during the mid and late 1980s generated concern that the US cattle cycle had fundamentally changed (Successful Farming, 1985). Prior to that time it was generally accepted that increasing cattle prices resulted in ranchers simultaneously instigating short-run reductions in cow culling rates while increasing heifer retention (Beale et al., 1983). Many analysts continue to believe that this type of negative supply response continues to exist (e.g., Anderson, Robb, and Mintert (1997)). Trapp (1986) suggests that it is optimal for producers to build up younger, larger breeding herds by culling more old cows and retaining more heifers in response to increasing prices. A perverse supply response in US female cattle markets is also suggested by Mundlak and Huang (1996) who found a negative relationship between cow slaughter and current and lagged prices in a supply model. Conversely, Matthews et al. (1999), using data from 1935-96, found a negative correlation between changes in cattle inventories and changes in cattle prices. Rucker et al. (1984) in an econometric analysis found that inventories were not particularly responsive to changes in cattle prices. Thus, whether a short-run negative supply response is either theoretically or empirically plausible is still an open question. Our paper attempts to clarify both of these issues.

In doing so, we present a dynamic, rational expectations model that makes clear predictions regarding the nature of the short-run supply response. The model is similar in spirit to that of Rosen, Murphy and Scheinkman (1996), RMS hereafter, but is richer in the

sense that it explicitly considers a wider array of exogenous shocks (such as international trade, price of substitutes, etc.) and allows ranchers to make decisions on two margins. A representative rancher is assumed to make period-by-period culling decisions for both adult cows and heifer calves, which end up in two separate markets – one for cull cows (unfed beef) and one for slaughter heifers (fed beef).[1] This distinction turns out to be important for predicting the optimal supply response to changes in the price for heifers or adult cows. Several different calibrated versions of the model indicate that in response to a permanent demand shock that alters the relative price of heifes and cows, the short-run supply response by cattle producers is positive. This result is robust to alternative parameterizations of the model and is in contrast to the theoretical prediction of Jarvis (1974) and Rosen (1987). It is, however, possible to nest the negative supply response as a special case of our model by appropriately restricting the relationship between the two demand shocks.

We then proceed by testing this hypothesis using annual US cattle data dating back to 1930. Our econometric analysis incorporates the simultaneity of the fed and unfed cattle markets, as well as, the simultaneity of demand and supply. The econometric results provide evidence of a positive short-run supply response in the market for commercial cows, but only mixed evidence with respect to the supply response for heifers.

The paper is organized as follows. In section 2 we present the theoretical model, calibrate the model, generate impulse response functions, and discuss various predictions of the model. In section 3 we describe the data, econometric model, and the estimation results. Finally, in section 4 we conclude by summarizing the paper's most important findings and suggest avenues for further research.

2   Theoretical Model

We begin by briefly outlining the environment being modeled. In Western and Midwestern states, beef calves are typically born in the Spring.[2] In the first six months of life ranchers face few management options. If the calf is male, it is likely to be castrated. Because a mature bull can breed up to 50 cows, the number of males that need to be retained for breeding is small. Calves are then weaned from their mothers in the fall, at which time, they are typically between six to ten months old. At this point, ranchers face an important management decision for female calves since females are both a consumption and a capital good. Producers decide whether to retain the female calf for addition to the breeding stock

---

[1]We refer to beef produced by cull cows as "unfed" beef since typically cull cows are not placed in feedlots on grain concentrates prior to slaughter. We also refer to unfed and fed beef to differentiate between markets for generally high quality beef (fed) and lower quality beef (unfed).

[2]The timing of the cattle operations in regions other than the West and Midwest vary, although the basic economic problem for the ranchers is the same. For instance, in the South, a substantial number of the cattle operators calve in November and December rather than in the Spring. However, for the US as a whole, the majority of the cattle operations follow the seasonal timing used in the West and Midwest (Gilliam, 1984).

(capital good) or sell them (consumption good). The decision for weaned steers is much simpler as they are only a consumption good and are consequently destined for slaughter.

Weaned calves that are sold are not slaughtered immediately. Most go through a process called ...nishing. Finishing typically involves a four to six month period when a weaned calf is maintained on pasture or harvested forage before entering a feedlot. Once this stage is complete, the animal is transferred to a feedlot where it will be fed high-concentrate grains for approximately six months to be fattened for slaughter. By this time, 18 to 24 months have typically passed since the birth of the calf. The ...nishing of young animals is a relatively recent phenomenon. Prior to the 1930s, feeding of high-concentrate grains was atypical. Since then, the practice of ...nishing young animals with grains has become commonplace and in more recent times (beginning in the 1960s), ...nishing has been increasingly completed in organized feedlots.

As mentioned above, heifers that are not sold after weaning typically become part of the rancher's breeding stock. Breeding cows usually produce at most a single calf per year, have a gestation period of nine months, and are typically bred for the ...rst time when they are approximately 15 months old. A breeding cow may then be retained and bred in subsequent years until approximately her tenth year. At this point, her reproductive abilities usually begin to deteriorate. Cows may be culled at any age and are typically culled after pregnancy testing in the fall when the calves are sold. Culled cows usually go directly to slaughter as their beef is of lower grade and ordinarily is not ...nished.

Our theoretical model is created to capture the essential components of the beef cattle industry described above. A more detailed version of the model can be found in a manuscript written by one of the authors. The version presented below removes features that are not central to the issue of the short-run supply response. The model is set in discrete time with decision intervals one year in length. It is assumed that once a year, cow-calf operators make decisions regarding how many heifer calves to retain and adult cows to cull. Similar to RMS (1994), we minimize the role that males play in the model. All males are destined to become either steers, which subsequently go through a one-year ...nishing process, or are kept as bulls for breeding purposes. Operators are assumed to be forward-looking, rational agents that maximize a discounted expected future stream of pro...ts subject to biological and market constraints. All operators are assumed identical and make decisions in competitive input and output markets.

2.1 Biological Constraints

In this section, the laws governing stock dynamics are modeled. Begin with the stock of retained yearling heifers at time t, $k_t^{(1)}$, which depends on last period's stock of female calves, $k_{t-1}^{(0)}$, the fraction of female calves sent to market in period t (i.e., the cull rate for heifer calves), $\circledR_t^{(0)}$, and the death rate for calves, $\pm_0$: Using these items, we can write the law of motion for the stock of yearling heifers as

$$k_{t+1}^{(1)} = (1 - \pm_0)(1 - \circledR_t^{(0)})k_t^{(0)}. \tag{1}$$

4

In other words, the stock of retained yearling heifers available in period $t + 1$ is equal to the number of heifer calves in period t which did not either die or get sent to market (i.e., culled from the stock). Once a female calf becomes a yearling heifer, her fate for the next year is entirely predetermined. If she was culled from the calf stock, she then enters the ...nishing process for the next period on her way to slaughter. If she was retained for addition to the breeding stock, she will be bred approximately three months after her ...rst birthday and will produce her ...rst calf at age two.

Rather than keep track of the entire age distribution of adult females, all ages of adult females are aggregated into a single measure, b_t. Net investment into the stock of breeding cows can take one of two forms. First, positive investment into the breeding stock occurs as last period's retained yearling heifers mature into animals of breeding age. Negative investment or disinvestment into the breeding stock occurs as mature cows die or are culled from the herd. The law of motion for the stock of adult breeding cows is thus

$$b_{t+1} = (1 - \pm_1)k_t^{(1)} + (1 - \circledR_t^{(b)})(1 - \pm_b)b_t, \tag{2}$$

where $\pm_1$ and $\pm_b$ are the death rates for yearling heifers and adult cows and $\circledR_t^{(b)}$ is the cull rate for adult cows. We abstract from the possibility of purchasing heifers and adult cows to add to the breeding stock because nearly all increases in the adult cow stock takes the form of heifer retention (Gilliam, 1984).

The number of females calves in any period is taken to be proportional to the number of breeding cows in the previous period. The factor of proportionality is 0.5μ, where 0.5 indicates that half the calves born in each period are female and μ is the successful birthing rate. Therefore, the stock of female calves evolves according to

$$k_t^{(0)} = 0.5\mu b_{t-1}. \tag{3}$$

2.2 Markets

The sequence of markets involved in the process of supplying beef to consumers is complex. Rather than explicitly modeling the relationship between all these distinct markets, we instead specify ad hoc demand and markup equations which attempt to capture in a crude fashion the interaction between these di¤erent markets.

Begin by assuming that the input market is perfectly competitive so that individual ranchers treat the price of inputs as given. Each individual operator considers herself to be too small to in‡uence the market price, but when forecasting future input prices, recognizes that shifts in the industry-wide demand and supply will in‡uence future prices. There are numerous operating expenses for a cattle producer – feed, labor, vaccines, vehicles, corrals, etc. For simplicity, we take these costs to be given by single term, $!_t$, which represents per animal costs. The unit cost function for the industry is assumed to follow

$$!_t = \tilde{A}_0 q_t^{\tilde{A}_1} \exp(\grave{A}_{!;t}) \tag{4}$$

where $q_t = k_t^{(1)} + b_t$ and $\lambda_{I,t}$ follows the first-order autoregressive, AR(1), process $\lambda_{I,t} = \rho_I \lambda_{I,t-1} + \varepsilon_{I,t}$ with $0 \le \rho_I \le 1$ and $\varepsilon_{I,t} \sim iid(0; \sigma_I^2)$.

After a rancher sells his animal and the animal completes the finishing process, it is typically purchased by a packing plant, slaughtered, and then processed for retail sale. Each of these steps adds value to the final product. To capture the added value, we specify the following linear markup equations that relate the live cattle price to the retail price of beef:

$$p_t^{(k)} = \lambda_k E_t rp_{t+1}^{(k)} \tag{5}$$

$$p_t^{(b)} = \lambda_b rp_t^{(b)} \tag{6}$$

where $p_t^{(j)}$ is the live price the rancher receives for an animal of type $j \in (b, k)$ at time t, $rp_t^{(j)}$ is the retail price of beef for an animal of type $j \in (b, k)$ at time t, and E_t is the mathematical expectation operator conditional on all information dated t and earlier. Equation (5) states that the price a rancher receives for his calves in period t, $p_t^{(k)}$, is proportional to the conditional expectation of the retail price consumers are willing to pay for fed beef one period hence, $E_t rp_{t+1}^{(k)}$. Since adult cows do not go through the finishing process, (6) is a contemporaneous markup equation, such that the live price of cows is simply proportional to retail price of unfed beef in the same period.

Following RMS (1994) and Nerlove and Fornari (1995), we assume that the demand for retail beef is (log) linear and depends upon the price of chicken (pc) and pork (pp), national income (I), and an unobserved stochastic term (ω). Inverse demand for retail beef is given by

$$rp_t^{(k)} = \gamma_0 (c_t^{(k)})^{\gamma_1} I_t^{\gamma_2} pc_t^{\gamma_3} pp_t^{\gamma_4} \exp(\omega_{k,t}) \tag{7}$$

$$rp_t^{(b)} = \gamma_0 (c_t^{(b)})^{\gamma_1} I_t^{\gamma_2} pc_t^{\gamma_3} pp_t^{\gamma_4} \exp(\omega_{b,t}) \tag{8}$$

where $c_t^{(k)}$ and $c_t^{(b)}$ are defined below and the disturbances follow mean-zero AR(1) processes:

$$\omega_{j,t} = \rho_j \omega_{j,t-1} + \varepsilon_{j,t},$$

$0 \le \rho_j \le 1$ and $\varepsilon_{j,t} \sim iid(0; \sigma_j^2)$ for $j \in (k, b)$.

Total domestic consumption or slaughter in the respective markets for fed and unfed beef is given by

$$c_t^{(k)} = \beta_{t-1}^{(0)}(1 - \delta_0)(1 - \delta_1)k_{t-1}^{(0)} - NX_t^{(k)} \tag{9}$$

$$c_t^{(b)} = \beta_t^{(b)}(1 - \delta_b)b_t - NX_t^{(b)} \tag{10}$$

where $NX_t^{(k)}$ and $NX_t^{(b)}$ are net exports of fed and unfed beef respectively. In other words, total domestic consumption of fed beef at time t, $c_t^{(k)}$, is given by the total number of calves that were sent to market in period $t-1$ less the net exports of fed beef in period t. Likewise,

6

total domestic consumption of unfed beef, $c_t^{(b)}$, is given as the total number of cows sent to slaughter less net exports of unfed beef.

2.3   The Rancher's Problem

All ranchers are assumed to maximizes the discounted lifetime value of their operation subject to (1) - (10) and the initial stocks, $k_0^{(1)}$ and b_0. The objective function is

$$E_t \sum_{s=0}^{\infty} {}^{-s}\frac{1}{4}_{t+s} \tag{11}$$

where

$$\frac{1}{4}_t = p_t^{(k)} \circledR_t^{(0)}(1 \; \text{¡} \; \pm_0)k_t^{(0)} + p_t^{(b)} \circledR_t^{(b)}(1 \; \text{¡} \; \pm_b)b_t \; \text{¡} \; !_t(k_t^{(1)} + b_t):$$

The rancher then chooses a sequence of cull rates $\left\{ \circledR_t^{(0)}; \circledR_t^{(b)} \right\}_{t=0}^{1}$ to maximize (11) subject to the relevant constraints.

The necessary ...rst-order conditions (assuming an interior solution) are

$$p_t^{(k)} = {}^- E_t \left[(1 \; \text{¡} \; \pm_1)p_{t+1}^{(b)} \; \text{¡} \; !_{t+1} \right] \tag{12}$$

and

$$p_t^{(b)} = {}^- E_t \left[p_{t+1}^{(b)}(1 \; \text{¡} \; \pm_b) \; \text{¡} \; !_{t+1} \right] + {}^{-2} E_t \left[p_{t+2}^{(k)}(1 \; \text{¡} \; \pm_0)0:5\mu \right]: \tag{13}$$

The intuition behind (12) and (13) is clear. Pro...t maximization requires that the returns from either culling or retaining an animal are equivalent at the margin. Beginning with equation (13), it states that the market value of an adult female in the current period must equal the expected discounted net market value of the same animal in the next period plus the expected discounted market value of her calf two periods from now. Equation (12) states that the market of value of a female calf must be equal to the discounted, expected net value of a cow next period. Moving (13) forward one period and substituting it into the right-hand side of (12) then states that the market value of this female calf must equal the discounted, expected net value when she becomes a cow two periods hence plus the discounted, expected value of her calf three periods hence. Notice also that by iterating (13) into the future and using the law of iterated expectations, we can express the present market value of a cow as a discounted expected future stream of her calves plus her expected salvage value.

2.4   Equilibrium and Solution Technique

An equilibrium for this problem is a sequence of prices, cull rates, and stocks which solve the rancher's problem and clear the respective markets in each period. Since all ranchers are

identical and there are constant returns to scale in the production function, the equilibrium values of the variables will be the same for all ranchers and it is notationally simpler to treat the problem as if there is only a single representative rancher.

The system of equations to be solved is (1) - (10), (12), (13) and the initial values $k_0^{(1)}$ and b_0. This is a second-order system of nonlinear equations under rational expectations. To solve the model, we ...rst calculate the steady-state values for the variables, write the variables in terms of percentage deviations from their respective steady-state values, linearize around that steady state, and solve for the unique equilibrium paths of the variables using the Blanchard-Kahn (1970) method. A similar solution technique was employed in King, Plosser and Rebelo (1988).

2.5 Calibration

In order to generate arti...cial data from the system, it is ...rst necessary to assign values for the parameters. To begin, the discount factor is assigned the same value used by RMS (1994), $\bar{} = 0:909$. Next, consider the death rates and birth rates, which are set to the following values:

$$(\pm_0 \quad \pm_1 \quad \pm_b \quad \mu) = (0:07 \quad 0:01 \quad 0:04 \quad 0:88): \tag{14}$$

The death rates (i.e., $\pm_0$, $\pm_1$ and $\pm_b$) are calculated using the death loss ...gures from Agricultural Statistics. Death loss ...gures are published for two categories: cattle and calves. To obtain the natural death rate for calves, we use the historical (1930-1997) average of the ratio of calf death losses to the total calf crop. The death rates for yearling heifers and adult cows are more di₵cult to obtain because the death loss ...gures for the cattle series include both yearlings and adults. Although historical data are not available, the "average loss rates of weaned calves and yearlings from all causes on beef cow-calf farms and ranches" for 1980 is reported in Gilliam (1984). The reported rates were slightly less than 1%. The rates for adult cows contains an additional problem in that the measured natural death rate is certainly an underestimate of the true natural death rate because older, less healthy cows are typically culled rather than allowed to die of natural causes. Notwithstanding this point, the measured "average losses of cows and replacement heifers from all causes on beef cow-calf farms and ranches" in 1980 was approximately 2%. To account for the measurement problem discussed above, we double this ...gure and use a natural death rate of 4% for adult cows.[3] The birthing rate is set at 88%, which is calculated using the 1930-1997 historical average of the ratio of the calf crop to the total number of cows (USDA). This is near to the 85% value used in RMS.

The remaining parameters (i.e., the markup parameter and the price, income and cost

---

[3] We also used values of 2% and 10% for the death rates of cows. The results do not appear to be sensitive to moderate changes in the death rates.

elasticities) are set equal to the following values:[4]

$$(\gamma_1 \quad \gamma_2 \quad \gamma_3 \quad \gamma_4 \quad \frac{1}{4}_1 \quad \frac{1}{4}_2 \quad \frac{1}{4}_3 \quad \frac{1}{4}_4 \quad \tilde{A}_1 \quad \acute{A}) =$$
$$(-1.0 \quad 0.8 \quad 0.0 \quad 0.1 \quad -1.0 \quad -0.1 \quad 0.4 \quad 0.1 \quad 1.0 \quad 0.6): \qquad (15)$$

Obtaining accurate estimates of the above parameters, particularly the elasticities, is an important step in properly calibrating the cattle model. Fortunately, there is a wealth of empirical information on retail market responses for fed (i.e., prime, choice and select) beef and unfed (i.e., hamburger and canned) beef. Several sources report estimated elasticities for either the fed and unfed retail beef markets. The sources include, but are not limited to, Capps et al. (1994), Lesser (1993), Marsh (1991), Smallwood et al. (1989), and Wholgenant (1989). The ...rst eight parameters in (15) were selected as approximate midpoints to the estimated elasticities in these studies. Although, the reported elasticities vary from study to study depending on di¤erences in the sample period, data employed, functional forms, control factors, etc., the numbers in (15) appear to be a reasonable set of baseline values. In particular, there is strong evidence that retail demand for beef is downward sloping, nonfed beef is an inferior good, fed beef is a normal good, and pork and chicken are substitutes for beef at the retail level.

Next consider the elasticity of the cost of feed with respect to the total stock of heifers and cows, $\tilde{A}_1$. As far as we know, there are no studies that directly estimate the e¤ect of the total stock of cattle on feed prices. Presumably, an increase in the total stock of cattle should, all else equal, raise the demand for feed and therefore its price. Since we could not ...nd any reported estimates of the elasticity, $\tilde{A}_1$, we set the value equal to one. This turns out to be almost the exact estimated elasticity when estimating (4) with an autocorrelation correction.

We also do not know of any empirical evidence for the individual markup parameters, $\acute{A}_k$ and $\acute{A}_b$. This is largely due to the lack of a reliable retail price index for unfed beef. In response, we assume that there is but a single markup parameter $\acute{A} = \acute{A}_k = \acute{A}_b$. Mathews et al. (1999) provide time series evidence for the spread between farm level and retail level beef, including a weighted average of both choice beef and hamburger. The spread between the two has been growing in recent decades (a trend that has prompted a large amount of literature regarding the competitiveness of the beef-packing industry), however for simplicity we abstract from the time-varying nature of this parameter and use the historical average which is approximately $\acute{A} = 0.6$.

2.6   Impulse Response Functions

---

[4] Actually, since the retail demand functions are in their inverse forms with price as the dependent variable, the γ's and $\frac{1}{4}$'s are often labeled as own-price and income ‡exibilities rather than elasticities. I continue to use the term elasticities rather than ‡exibilities, but the inverse form of the demand functions needs to be kept in mind.

Next, we graph the responses of prices, cull rates and slaughter to one-time unit shocks in the respective retail demands. These graphs are useful in helping to understand the economics behind demand and supply dynamics. They are especially useful for understanding the supply responses because we can visually observe the current and future culling decisions for heifers and cows in response to a one-time exogenous shock.

Begin by considering a one-time unit shock to the demand for fed beef under two different scenarios: $\frac{1}{2}_k$ equal to 0.5 and 1.0. The responses are shown in Figures 1 and 2. In Figure 1, the transitory ($\frac{1}{2}_k = 0.5$) impulse to the price of fed beef causes an immediate increase in the price of calves because agents rationally anticipate a higher retail price for fed beef in the following period.[5] The increase in the price of calves induces the rancher to contemporaneously cull more heifer calves and fewer adult cows. Thus, we observe a positive supply response to an own-price increase in the heifer market and a negative cross-price response in the cow market. This optimal response on the part of the producers is intuitive as the higher relative price for heifer calves increases their return and to insure that future demand is met, the producer culls fewer cows. Of course, since fewer cows are now being sent to slaughter, the price of cows also increases as we move up the demand curve for unfed beef (8).

Figure 2 presents the impulse response functions for a permanent ($\frac{1}{2}_k = 1.0$) increase in the price of fed beef. Notice that even in response to a permanent increase in the price of fed beef, the quantity of heifers sent to slaughter increases. And as in the transitory case, in response to the higher price of fed beef, the producer begins to hold back more cows to meet future demand. As shown in Figure 2, the primary difference between the transitory and permanent shocks is that in the case of the permanent shock, the heifer cull rate and fed beef consumption display permanent increases rather than returning to their previous steady-state values. The impulse responses for shocks to the demand for unfed beef are mirror images of the responses to the fed beef price shock. In other words, the rancher sends more cows and fewer calves to market in response to a relative (transitory or permanent) increase in the price of cows. We omit these ...gures to conserve on space.[6]

The above results are robust to the parameter values and the varying types of demand disturbances. We performed a sensitivity analysis to a change in all the parameter values, increasing and decreasing each by reasonably large increments and found the qualitative nature of the optimal supply responses did not change. Also, we considered other demand disturbances (such as international trade, price of substitutes, income, etc.) and likewise found the supply-response predictions to be robust.

As a ...nal exercise, consider a simultaneous one-time unit shock to both fed and unfed

---

[5] It is interesting to note that if the fed beef demand shock is purely transitory (i.e., $\frac{1}{2}_k = 0$), then the shock has no e¤ect on cull rates, calf prices or slaughter numbers. This is because agents rationally anticipate that fed beef prices will not be any higher in the next period and thus will not deviate from their steady-state behavior.

[6] We examined price and slaughter margins for the study period and found that the ratios of heifer-to-cow prices and heifer-to-cow slaughter have been increasing over time. This is consistent with the predictions shown in Figures 1 and 2 and provides suggestive evidence that producers have sent more relatively more heifers to slaughter in response to demand shocks that have generated higher heifer-to-cow price spreads.

beef. As in the previous …gures, Figures 3 and 4 depict the responses of the prices, cull rates and consumption for a transitory case ($\frac{1}{2}_b = \frac{1}{2}_k = 0:5$) and a permanent case ($\frac{1}{2}_b = \frac{1}{2}_k = 1:0$). In the case of the transitory shocks, the short-run supply response to the positive price shocks is to increase the supply of heifers and cows sent to market. Notice that since both cull rates increase in the period of the shock, the cull rates then fall below their steady-state levels in order to compensate for the implied reduction in the future breeding sotck. This positive supply response is consistent with the analysis in Jarvis (1974) and Rosen (1987) since the shock is known by producers to be temporary in nature. For the permanent shocks in Figure 4, the short-run supply response becomes negative. Since the relative price of heifers to cows is unchanged, instead of increasing the supply of the animal with the relatively larger price increase, the producer chooses to optimally retain a higher proportion of both animals to take advantage of higher future prices. This is consistent with Jarvis' and Rosen's prediction of a negative short-run supply response and shows that their well-known result is nested as a special case of our model for appropriately restricted demand shocks.

In sum, the theoretical evidence provided by the impulse response functions is unambiguous. Producers respond positively in the short run to relative price changes in each market and compensate for the implied lower breeding stocks by retaining females on the other margin. Moreover, the result is robust to the nature of the shock and the assumed parameter values.

3 Econometric Analysis

In the following section, we describe the data used in the econometric analysis, the econometric model, estimation techniques, and lastly, discuss the results from the estimation.

3.1 The Data

The primary source for data on the cattle industry is collected by the Livestock and Economics Branch of the National Agricultural Statistical Service of the United States Department of Agriculture (USDA). Most of these statistics are reported in their annual publication, Agricultural Statistics. The cattle data in Agricultural Statistics are impressive in their detail and coverage (e.g., the total stock of cattle dates back to 1867). However, there are also several important limitations of the data as well. First, there were abrupt changes in the accounting procedures at various times during the century, and second, several key series do not stretch back to the earlier part of the century. In response to the latter limitation, we begin the sample period in 1930. The sample period ends in 1997, the most recent date for which all the relevant series have been collected and recorded. In the rest of this section, we provide the source and de…nitions for the time series used in this

paper, as well as, discuss some of their shortcomings. Unless otherwise stated, the data are taken from Agricultural Statistics.

Since the role of males in this paper is minimal, we focus solely on the stock of heifers and cows since the culling decisions are made with respect to these two types of animals.[7] The total federally inspected slaughter of heifers and cows was recorded as a single series up to 1944. Since then, it has been recorded as two separate series – one for heifers and one for cows. In order to make use of the entire data set back to 1930, we interpolate the individual heifer and cow data by multiplying the total heifer and cow slaughter series prior to 1944 by 0.21 and 0.79 (the fractions of heifer and cow slaughter in 1944) to form the respective series for heifer and cow slaughter between 1930 and 1944. Figure 5 depicts the time series plots for the slaughter of heifers and adult cows. While cow slaughter displayed only a moderate upward trend over the last six decades, heifer slaughter since the mid 1950's has increased rapidly, corresponding to the rise in active ...nishing of yearling heifers and steers.

Since the cost of feed is the predominant operating cost for cattle operations, we measure the price of feed on the supply side using the average price of hay received by farmers.[8] We do this since hay and pasture are they two principal feed costs incurred maintaining breeding stock. On the demand side, the price of grain is anticipated to be an important factor in the ...nishing of young animals. To capture this notion, we use the average price per bushel of corn in the heifer demand equation. For heifer calf prices, 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. For cows, we use the market price for commercial cows at two di¤erent 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. Finally, we measure the chicken price, pork price and national income using the live-weight price for chicken, the average price received by farmers for hogs and disposable income in current dollars respectively. All price series and disposable income are de‡ated using the US consumer price index for all goods and services (1967 = 100). Figure 6 shows time series plots of the de‡ated calf and cow prices.

Since we are primarily interested in the short-run behavior of cattle producers, we detrend all the data. By considering only detrended data, it allows us to abstract from slow-moving trends such as productivity and population growth. We ...rst take the natural logarithm of all the data and then detrend the data using both a quadratic time trend and

---

[7] For several cattle series, beef and dairy animals are combined. Rather than attempt to separate the two and risk introducing bias, we retain the dairy cattle in the stock and slaughter measures. Retaining dairy cattle also seems reasonable from a theoretical perspective as dairy operators face a similar problem to beef operators. They make period-by-period decisions regarding how many heifer calves to retain for addition to the breeding stock and how many adult cows to send to slaughter. Dairy operators do, however, react to a slightly di¤erent set of variables than beef cattle operators, e.g., the price of milk. When interpreting the empirical results, this needs to be kept in mind.

[8] Gilliam's (1984) survey of the US beef cow-calf industry supports this assumption. Gilliam writes on page 27, "Costs of production or purchasing feedstu¤s frequently comprise more than half of the total direct production cost in cow-calf production."

the Hodrick-Prescott (HP) ...lter. For the quadratic trend, we ...rst regress all series on a constant, time and time squared. The residuals from that regression are taken as the quadratically detrended series. An alternative method for detrending the data is the HP ...lter, which is commonly used in macroeconomic business-cycle studies. The HP ...lter is a ‡exible method for extracting the trend from a non-stationary time series. Let y_t^c be the cyclical component (detrended data) and y_t^g be the growth component of a time series y_t. The HP ...lter is then given by choosing the cyclical and growth components to minimize

$$\sum_{t=1}^{T}(y_t^c)^2 + \lambda \sum_{t=1}^{T}(y_{t+1}^g - 2y_t^g + y_{t-1}^g)^2:$$

As $\lambda \to \infty$, the growth component becomes a linear trend. As $\lambda \to 0$, the growth component becomes the series itself. Lambda is commonly set equal to 1600 in quarterly studies, but using annual data, we set $\lambda = 6.25$ as argued in Ravn and Uhlig (1997), although in a sensitivity analysis, $\lambda = 100$ and $\lambda = 400$ produced similar results.

3.2 Econometric Model and Techniques

A key prediction of the model in Section 2 is that the short-run supply response is positive to its own price and negative to the cross price for both the cow and heifer markets. In order to test this hypothesis, we develop a four-equation system of equations that includes both the demand and supply for heifer and cow markets. The system of equations is

$$xs_t^{(k)} = \beta_{1;0} + \beta_{1;1}p_t^{(k)} + \beta_{1;2}p_t^{(b)} + \beta_{1;3}p_t^{(hay)} + \varepsilon_{1;t} \tag{16}$$

$$xd_t^{(k)} = \beta_{2;0} + \beta_{2;1}p_t^{(k)} + \beta_{2;2}pc_t + \beta_{2;3}pp_t + \beta_{2;4}l_t + \beta_{2;5}p_t^{(corn)} + \varepsilon_{2;t} \tag{17}$$

$$xs_t^{(b)} = \beta_{3;0} + \beta_{3;1}p_t^{(k)} + \beta_{3;2}p_t^{(b)} + \beta_{3;3}p_t^{(hay)} + \varepsilon_{3;t} \tag{18}$$

$$xd_t^{(b)} = \beta_{4;0} + \beta_{4;1}p_t^{(k)} + \beta_{4;2}pc_t + \beta_{4;3}pp_t + \beta_{4;4}l_t + \varepsilon_{4;t} \tag{19}$$

where $xs_t^{(j)}$ is the quantity supplied of heifers ($j = k$) and cows ($j = b$), $xd_t^{(j)}$ is the quantity demanded of heifers ($j = k$) and cows ($j = b$), and $\varepsilon_t = (\varepsilon_{1;t}\ \varepsilon_{2;t}\ \varepsilon_{3;t}\ \varepsilon_{4;t})'$ is the vector of errors at time t with variance-covariance matrix equal to Σ for all t. We do not place any restrictions on the elements of Σ and also allow each error term to follow a second-order autoregressive process $\varepsilon_{j;t} = \phi_{1;j}\varepsilon_{j;t-1} + \phi_{2;j}\varepsilon_{j;t-2} + \eta_{j;t}$, where $\eta_{j;t} \sim iid(0; \sigma_j^2)$ for $j = 1; ::: ; 4.$[9] To close the system, we impose the equilibrium conditions $xs_t^{(j)} = xd_t^{(j)}$ for all t and j.

The equations (16) - (19) represent a simultaneous system of demand and supply equations for heifers and cows at the farm level. As a point of clari...cation, we note that the sellers in each market are the cattle producers while the buyers are the feedlot operators in

---

[9] A second-order autoregressive process was necessary because once a ...rst-order autoregressive correction was incorporated, the correlogram for the residuals displayed a signi...cant cyclical pattern. A second-order process allows for complex roots in the autoregressive polynomial which is able to capture this type of dynamics.

the heifer market and the packers in the cow market. This is consistent with the design of the theoretical model, which focuses on the period-by-period culling decisions made by individual cattle producers at the farm level. Next, we discuss the structure of (16) - (19) and the expected signs for the coefficients.

First, consider equation (16). We assume that the quantity of heifers supplied in period t is a linear function of the price of heifer calves, the price of cull cows and the price of hay. According to our theoretical model, an increase in the price of heifers (everything else equal) will increase the number of heifers sent to market, and an increase in the price of cows will decrease the number of heifers sent to market. Thus the price of heifers and cow in (16) are expected to be positve and negative respectively. The price of hay is included to capture the farm-level cost of holding heifers. The model predicts that as the cost of holding heifers increases, fewer are retained for addition to the breeding stock. Hence, the coefficient on the price hay is expected to be positive.

For equation (17), we assume that the demand for heifers in period t is assumed to be linearly related to the prices of heifer calves, chicken, pork, corn and to income. The law of demand states that the coefficient on the price of heifer calves should be negative. For the chicken price, pork price and income, it is the one-period ahead expected values of the variables that influence the derived demand for heifer calves at time t because heifers will go through a one-period finishing process before being slaughtered. For simplicity, we assume that heifer buyers use a simple adaptive expectations formation rule, $E_t x_{t+1} = x_t$. Therefore, the chicken price, pork price and income show up in (17) with time subscript t. We hypothesize that chicken and pork are substitutes for beef at the retail level so that the coefficients on these variables are expected to be positive. We also hypothesize that fed beef is a normal good such that the coefficient on income should be positive. Finally, the price of corn is included to capture the costs to the feedlot operators. As the price of corn increases, we expect that fewer heifer calves will be demanded by feeders and thus its sign should be negative.

The supply and demand equations for cows are analagous to the heifer equations in all but two ways. First, since cows are not sent through a finishing process, it is not the expected one-period ahead price of substitutes and income at the retail level that influence the derived demand for cows at the farm level. Rather, it is the current period prices and incomes that are relevant, so it is not necessary to make any assumptions regarding expectations. And second, since cows do not go through the finishing process, the price of corn is excluded from (19).

In both markets, we measure quantities (left-hand-side variables) using actual slaughter numbers since data on the sale of cull cows and calves are not available at an aggregate level for our sample period. For cows this does not present a difficulty because cows are generally slaughtered shortly after being culled so that slaughter numbers in a given year provide a good approximation to the number of cull cows sold that year. Heifer calves, however, go through an approximate one year finishing process before being slaughtered. Therefore, we use the one-period ahead slaughter numbers for heifers to proxy for the number of heifer calves sold in the current period.

We obtain estimates of the parameters in (16) through (19) using three-stage least

squares (3SLS) estimation, with a correction for autocorrelated errors (Greene, 2000, p.688). Once the two-stage least squares estimates are calculated, we use the residuals from each equation in the system to estimate the autocorrelation coefficients $\rho_{1 \cdot j}$ and $\rho_{2 \cdot j}$ for $j = 1; :::; 4$ and then use those estimates to pseudo-difference all the variables in the system (Greene, 2000, p.543). Then, in the last stage, we use our estimate of – to obtain more efficient estimates of the β coefficients.[10]

3.3 Econometric Results

The econometric results from the 3SLS estimation are presented in Table 1. We present two sets of estimates – one set for the quadratically detrended data and one set for the HP-filtered data. The results from the cow market are generally robust to the detrending method, but the results from the heifer market are sensitive to the detrending method. This might be expected after examining the heifer and cow slaughter numbers in Figure 5. Whereas cow slaughter has only a slight upward drift over time, heifer slaughter has increased much more rapidly over time. Moreover, the trend appears to be variable: between 1930 and 1950 heifer slaughter remained relatively constant; between 1950 and 1975 heifer slaughter expanded rapidly; and then since 1975 it has drifted up only slightly. To the extent that the HP filter is a more flexible detrending method, it may be the more appropriate method of removing the apparently time-varying nature of the trend.

Begin by focusing on the HP-filter results in the first four columns of Table 1. First, notice that other than the corn price (which is statistically insignificant) in heifer demand, the signs of the coefficients are reasonable. In particular, the demands for heifer and cow are negatively related to their own price, chickens and hogs are substitutes for cattle at the retail level, beef is a normal good, and the price of hay is positively related to the supply of heifers and cows. In addition most of the coefficients are statistically significant at the 10% level.

The key results in Table 1 are the coefficients on own and cross prices in (16) and (18). For the cow supply equation using HP-filtered data the own supply response is positive and the cross price response is negative. The own-price coefficient is statistically significant at the 1% level and the cross-price coefficient is significant at the 10% level. The signs on the two coefficients conform with the predictions of the theoretical model. That is, all else equal, in response to a positive cow (heifer) price shock, producers cull more (fewer) cows. Stated differently, producers optimally sell more cows when the relative price increases and compensate for the future decrease in the breeding stock by retaining more heifers. The opposite appears to be true for the heifer market. The estimates indicate that in the short run, producers respond to a positive heifer price shock by retaining more heifers and selling more cows. This is consistent with Jarvis' (1974) and Rosen's (1987) theoretical predictions that the short-run supply response to permanent price shocks may be negative.

---

[10] The estimation was performed in Gauss. A copy of the code and data are available from the authors by request.

Now focus on the results using the quadratically detrended data. In this case, the supply-response predictions from both the heifer and cow markets are in line with our theoretical predictions: producers respond positively to changes in the (relative) own-price and make compensating adjustments to the breeding stock along the other margin. Most of the coefficients are statistically significant at the 10% level and only the corn and chicken price in heifer demand have unexpected signs (although both are not statistically different than zero). We conjecture that the unexpected sign on the chicken-price coefficient occurs because the quadratic trend is not flexible enough to remove the effects of structural breaks in the chicken industry throughout our sample period.

We also perform two specification tests on the model: a Q test for randomness of the disturbances (Greene, 2000, p. 762) and a Hausman (1983) test of the overidentifying restrictions. In all eight cases, the Q statistic is smaller than the critical value of 7.81 at the 5% significance level, indicating that the second-order autoregressive process for the disturbances appears to have produced white-noise error terms.[11] The Hausman test checks the appropriateness of the exclusion restrictions in (16) through (19), which overidentify the respective equations. Since heifer demand is exactly identified, we present the test statistics for the other three equations only. A large value for the TR^2 statistic indicates that variables may have been inappropriately excluded from the equations of interest. In all cases except heifer supply using quadratically detrended data, we fail to reject the null at the 10% significance level, and for the heifer supply, we fail to reject at the 5% significance level. Therefore, there is little evidence that the overidentifying restrictions imposed on the system are inappropriate.

4 Conclusions

As alluded to in our introduction, it is still an open question as to whether or not there is a negative short-run supply response in the US beef cattle industry. First, the predictions from theoretical models arrive at different conclusions depending on the manner in which the models are designed (e.g., Jarvis (1974), Paarsch (1985), and Rosen (1987)). And second, the empirical estimates provide mixed evidence for the presence of a negative short-run supply response in the US (e.g., Trapp (1986), Mundlak and Huang (1996) and Matthews et al (1999)).

Our contribution to the literature is to build a model of the cattle industry that separates the markets for fed and unfed cattle and allows producers to make culling decisions on both of these margins. When set witin a dynamic, rational expectations framework, the short-run

---

[11] The Q test is performed for three lagged values of the autocorrelation coefficients. For three (i.e., HP-filtered cow supply, heifer supply and heifer demand) of the eight equations there is some evidence of marginally significant autocorrelations at longer lags. Despite this point, we maintain the second-order autoregressive structure for the errors rather than consider higher-order processes because it appears to do a reasonably good job of removing the persistence in the errors and conserves on degrees of freedom.

supply response predictions are clear: producers will respond positively to relatively higher prices along one margin and will build up stocks along the other margin. Furthermore, we are able to nest the negative short-run supply response in Jarvis (1974) and Rosen (1987) as a special case of our model for appropriately restricted exogenous shocks.

We then test our proposition using annual US time series data from 1930 through 1997. For the cow market, our results are robust and con...rm our hypothesis that the short-run supply response is positive and stocks are built up along the other margin (i.e., retaining heifers). For the heifer market, the evidence is mixed and appears to depend upon the detrending method – for quadratically detrended data, our hypothesis is con...rmed; but for HP-...ltered data, the short-run supply response is negative. When taken as a whole, our results (both theoretically and empirically) cast serious doubt on the proposition of a negative short-run supply response in the US cattle industry.

The model presented in this paper o¤ers additional insights regarding inventory decisions by US ranchers since it examines culling and retention decisions for cows and heifers simultaneously in a dynamic environment. The model could be used to investigate additional research questions regarding cattle market dynamics. For example, it could be used to examine the impact(s) of improving eＣciency (e.g., increasing weaning rates and beef produced per cow) on culling decisions. The model could also be used to determine how increasing margins between the retail and farm level prices have a¤ected the composition of the US cattle inventory or how trade has a¤ected the US cattle inventory.

References

[1] Anderson, David P., James G. Robb, and James Mintert. (1997) "The Cattle Cycle." in Managing for Today's Cattle Market and Beyond, eds. Chris Bastian and DeeVon Bailey, Department of Agricultural Economics, University of Wyoming, Laramie.

[2] Beale, Tommy, Paul R. Hasbargen, John E. Ikerd, Douglas E. Mur...eld, and David C. Petritz. (1983) Cattle Cycles: How to Pro...t From Them. U. S. Department of Agriculture, Washington, DC.

[3] Blanchard, Oliver J. and Charles M. Kahn. (1980) "The Solution of Linear Di¤erence Models under Rational Expectations." Econometrica, 48, 1305-13.

[4] Capps, Oral, Jr., Donald E. Farris, Patrick J. Byrne, Jerry C. Namken, and Charles D. Lambert. (1994) "Determinants of Wholesale Beef-Cut Prices." Journal of Agriculture and Applied Economics, 26(1), 183-99.

[5] Gilliam, Henry C. Jr. (1984) "The U.S. Beef Cow-Calf Industry." Economic Research Service, USDA, Agricultural Economic Report No. 515.

[6] Greene, William H. (2000) Econometric Analysis, 4th edition, (Prentice Hall, Upper Saddle River, NJ).

[7] Hausman, Jerry. (1983) "Speci...cation and Estimation of Simultaneous Equations Models." in Z. Grilliches and M. Intriligator, eds., Handbook of Econometrics, Amsterdam: North Holland.

[8] Jarvis, Lovell S. (1982) "Cattle as Capital Goods and Ranchers as Portfolio Managers: An Application to the Argentine Cattle Sector." Journal of Political Economy, 82(May/June), 489-520.

[9] King, Robert G., Charles I. Plosser and Sergio T. Rebelo. (1988) "Production, Growth, and Business Cycle Models: I. The Basic Neoclassical Model." Journal of Monetary Economics, 21, 195-232.

[10] Lesser, William H. (1993) Marketing Livestock and Meat, Food Products Press, New York.

[11] Marsh, John M. (1991) "Derived Demand Elasticities: Marketing Margin Methods Versus an Inverse Demand Model for Choice Beef." Western Journal of Agricultural Economics, 16(2), 382-91.

[12] Mathews, Kenneth H. Jr., William F. Hahn, Kenneth E. Nelson, Lawrence A. Duewer and Ronald A. Gustafson. (1999) "U.S. Beef Industry: Cattle Cycles, Price Spreads, and Packer Concentration." Technical Bulletin #1874, USDA, Economic Research Service.

18

[13] Mundlak, Yair and He Huang. (1996) "International Comparison of Cattle Cycles." American Journal of Agricultural Economics, 78(November), 855-68.

[14] Nerlove, Marc and Ilaria Fornari. (1995) "Quasi-Rational Expectations, An Alternative to Fully Rational Expectations: An Application to U.S. Beef Cattle Supply." unpublished manuscript.

[15] Paarsch, Harry J. (1985) "Micro-economic Models of Beef Supply." Canadian Journal of Economics, 18(3), 636-51.

[16] Ravn, Morten O. and Harald Uhlig. (1997) "On Adjusting the HP-Filter for the Frequency of Observations." Unpublished Manuscript.

[17] Rosen, Sherwin. (1987) "Dynamic Animal Economics." American Journal of Agricultural Economics, 69 (August), 547-57.

[18] Rosen, Sherwin, Kevin M. Murphy and Jose A. Scheinkman. (1994) "Cattle Cycles." Journal of Political Economy, 102(3), 468-92.

[19] Rucker, Randal R., Oscar R. Burt and Je¤rey T. LaFrance. (1984) "An Econometric Model of Cattle Inventories." American Journal of Agricultural Economics, 66(May), 131-44.

[20] Smallwood, David M., Richard C. Haidacher and James R. Blaylock. (1989) "A Review of the Research Literature on Meat Demand," in The Economics of Meat Demand, Rueben C. Buse, editor.

[21] "What Happened to Cattle Cycles." (1985) In Successful Farming, Des Moines, Iowa, 83(Sept.): B6-B10.

[22] Trapp, James N. (1986) "Investment and Disinvestment Principles with Nonconstant Prices and Varying Farm Size Applied to the Beef-Breeding Herds." American Journal of Agricultural Economics, 68(August), 691-703.

[23] United States Department of Agriculture. Various editions. Agricultural Statistics.

[24] Wohlgenant, Michael K. (1989) "E¤ects of the Changing Composition of Beef Consumption on the Elasticities for Beef and Poultry," in The Economics of Meat Demand, Rueben C. Buse, editor.

Figure 1. Responses to a Unit Increase in Heifer Calf Prices (rhok = 0.5)

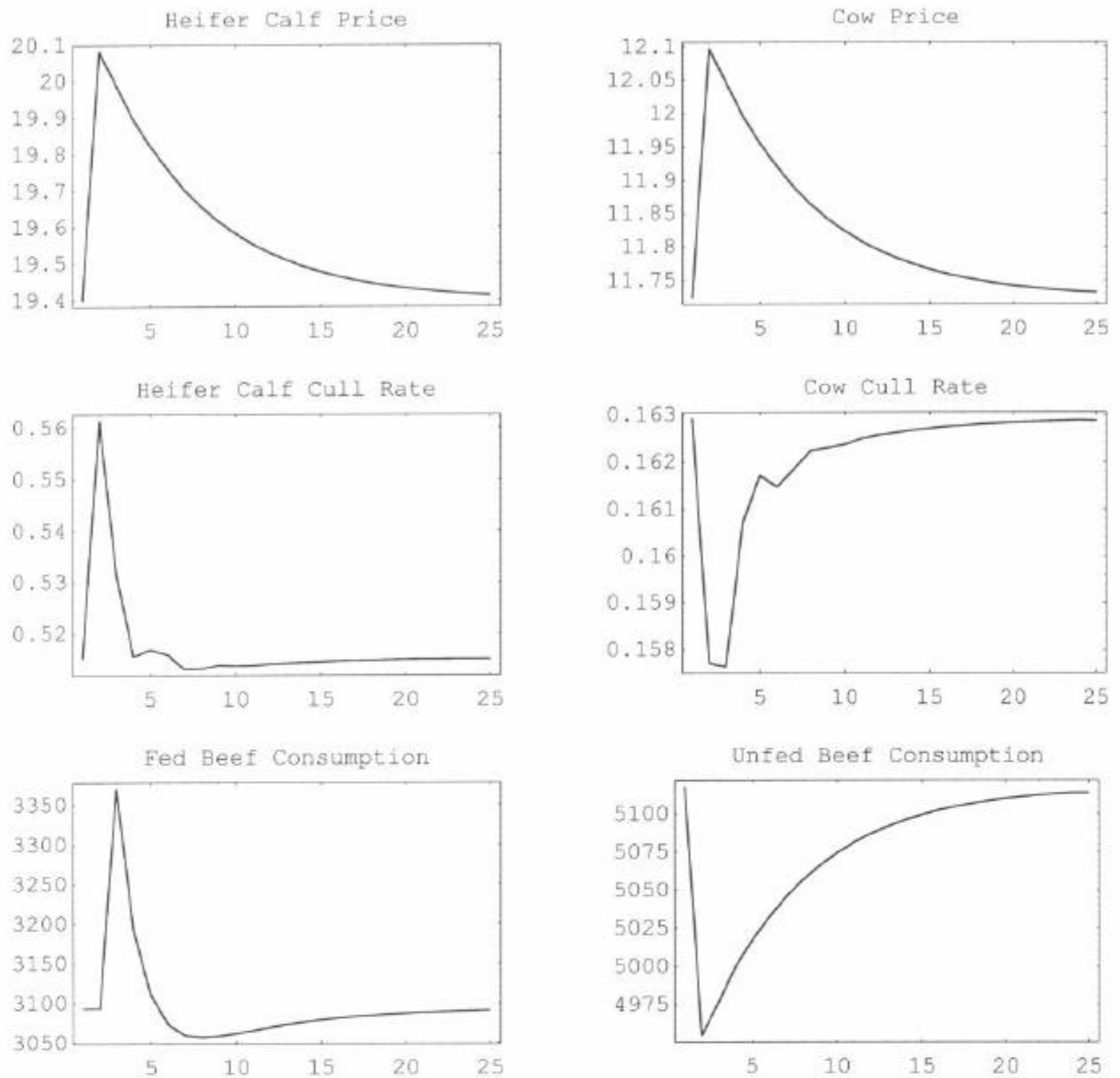Heifer Calf Price

Cow Price

Heifer Calf Cull Rate

Cow Cull Rate

Fed Beef Consumption

Unfed Beef Consumption

Figure 2. Responses to a Unit Increase in Heifer Calf Prices (rhok = 1)

Heifer Calf Price

Cow Price

Heifer Calf Cull Rate

Cow Cull Rate

Fed Beef Consumption

Unfed Beef Consumption

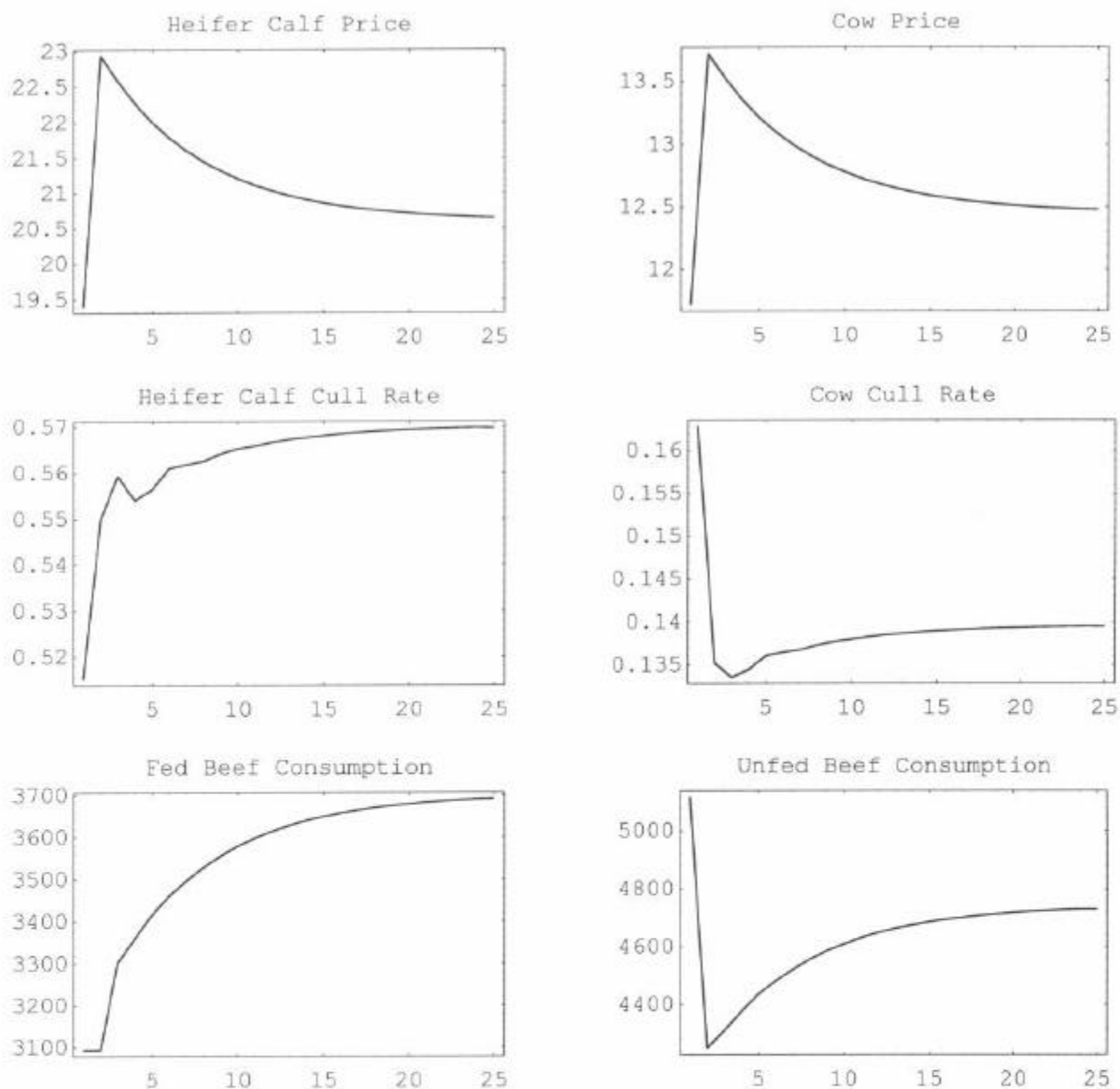Figure 3. Responses to a Unit Increase in Calf and Cow Prices {rho = 0.5}

Figure 4. Responses to a Unit Increase in Calf and Cow Prices (rho = 1)

Heifer Calf Price
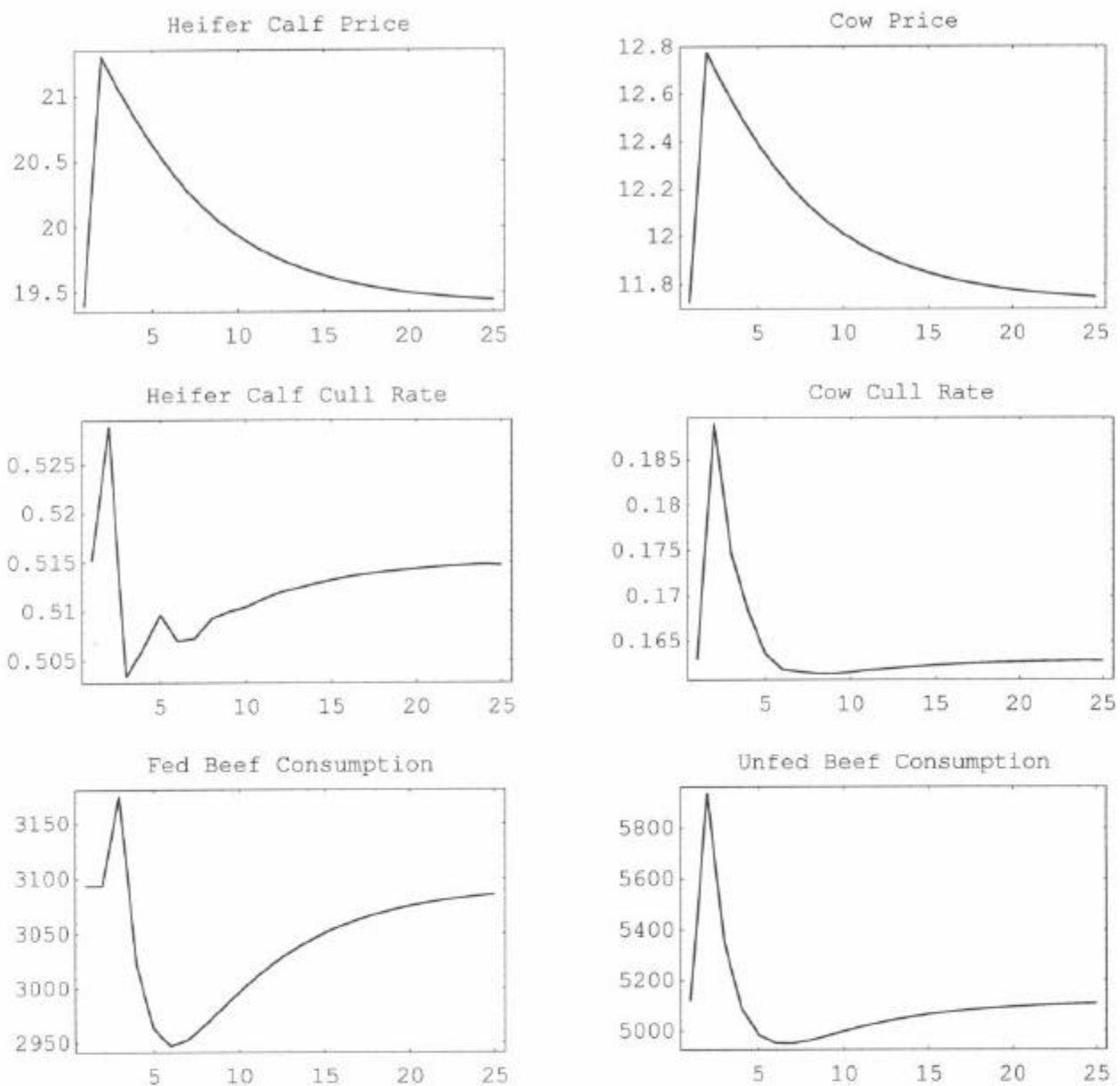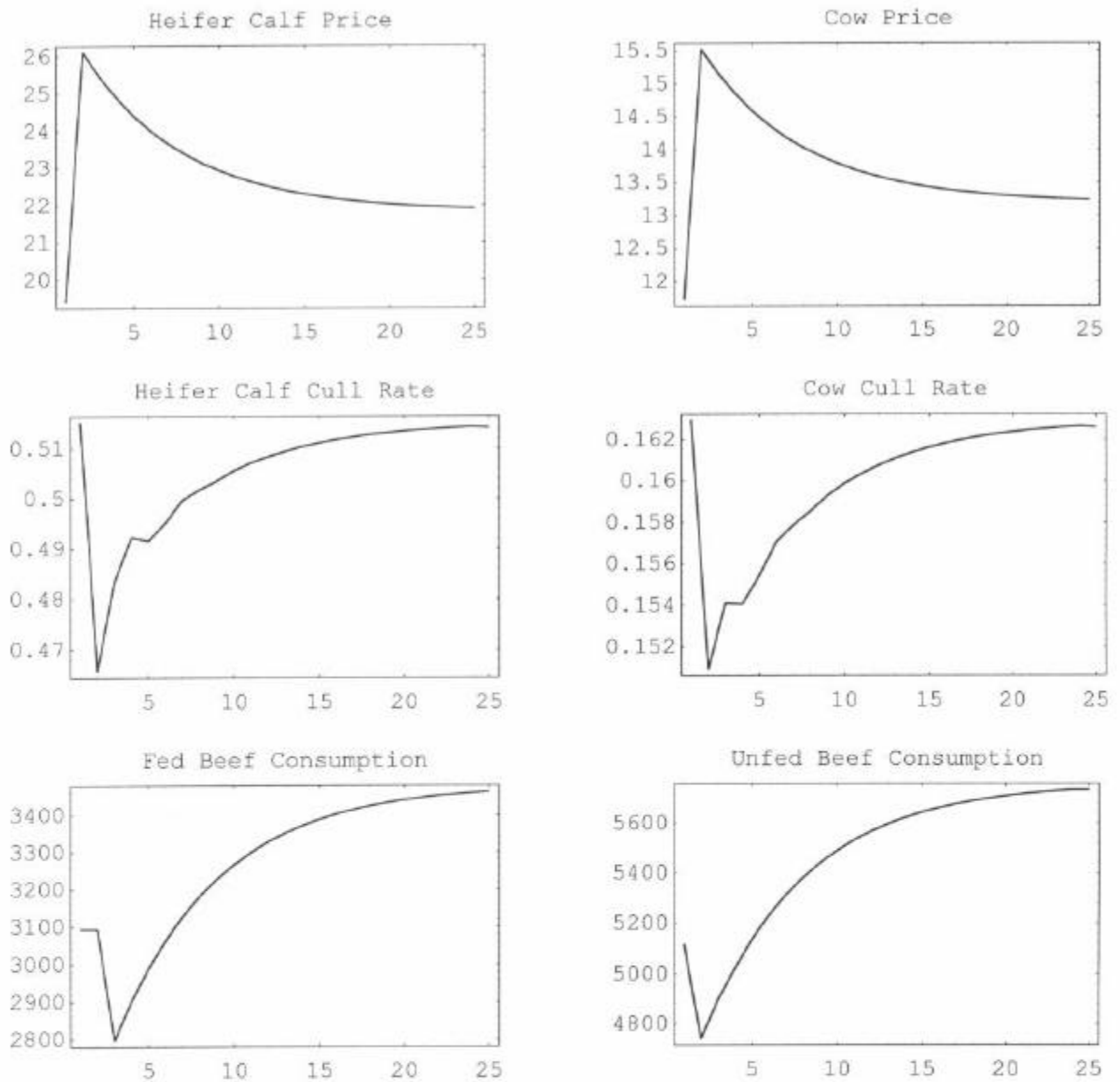

Cow Price

Heifer Calf Cull Rate

Cow Cull Rate

Fed Beef Consumption

Unfed Beef Consumption

Figure 5. U.S. Cattle Slaughter (1930-1997)

U.S. Heifer Slaughter

U.S. Cow Slaughter
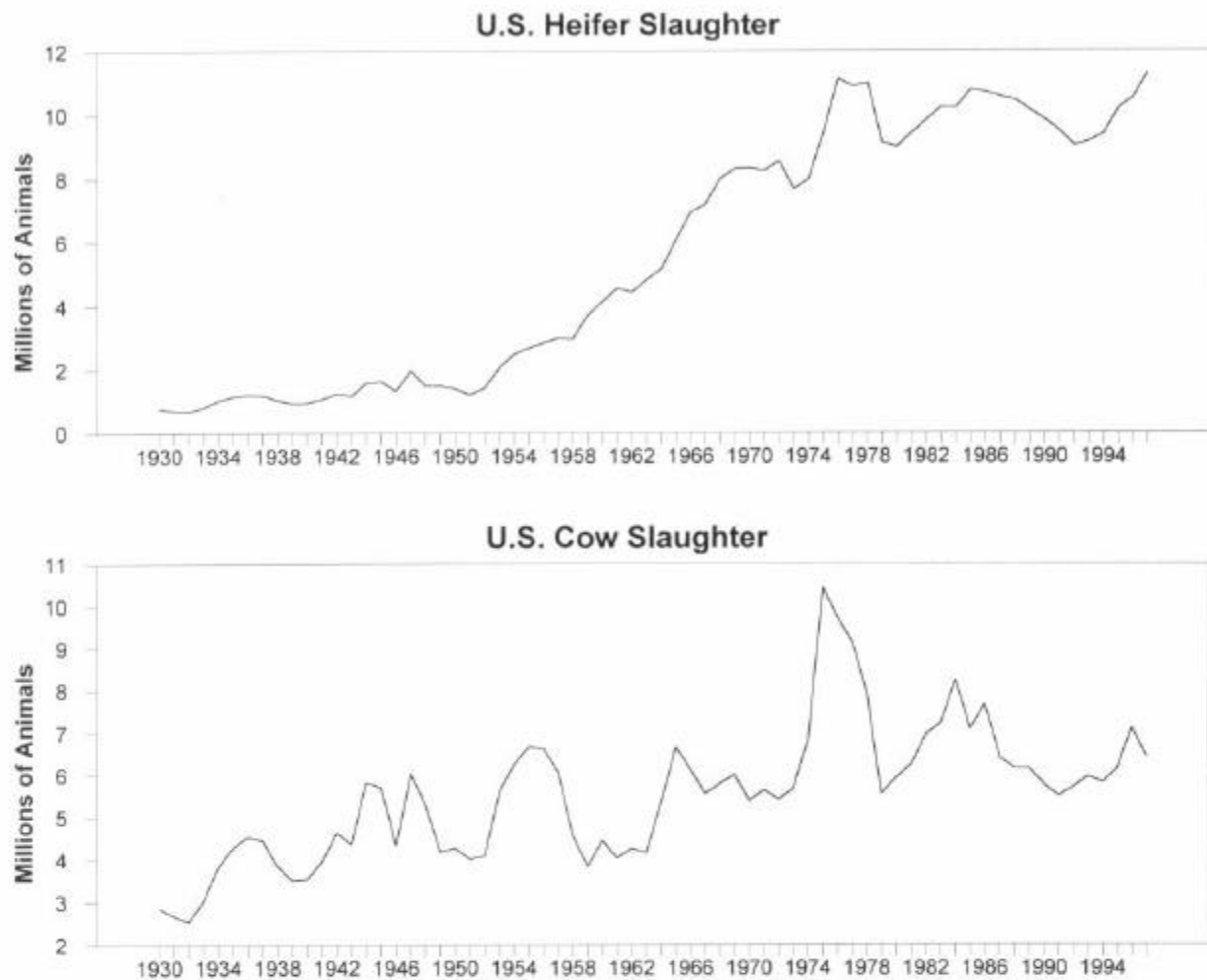
Figure 6. U.S. Beef Prices (1930-1997)

U.S. Real Price of Calves

U.S. Real Price of Cows
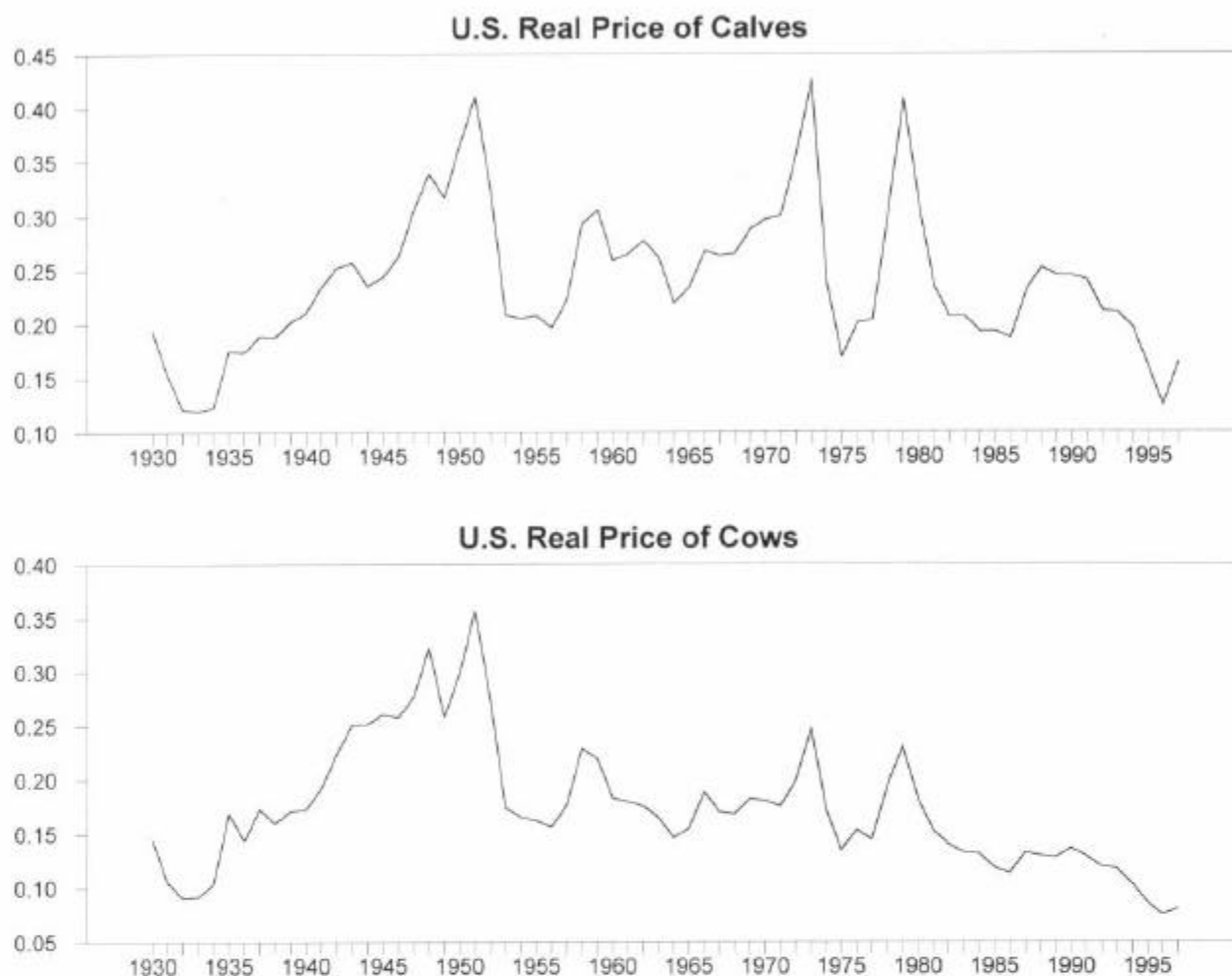
Table 1. 3SLS Estimation Results (1930-1997)

Variables	HP Filter ($\lambda = 6.25$)				Quadratic Trend			
	Heifer Market		Cow Market		Heifer Market		Cow Market	
	Supply	Demand	Supply	Demand	Supply	Demand	Supply	Demand
Heifer Price	-1.072 (0.469)	-1.210* (0.824)	-1.017* (0.703)		1.808** (0.886)	-1.127 (4.127)	-0.419 (0.854)	
Cow Price	0.910 (0.410)		1.431*** (0.613)	-0.480 (0.665)	-1.706*** (0.516)		0.697* (0.494)	-0.765** (0.457)
Hay Price	0.234*** (0.084)		0.121 (0.112)		0.304* (0.191)		0.219* (0.172)	
Corn Price		0.064 (0.119)				0.385 (0.449)		
Chicken Price		0.117 (0.184)		0.203* (0.131)		-0.895 (0.885)		0.523** (0.242)
Hog Price		0.248** (0.144)		0.334** (0.163)		0.348 (0.627)		0.525*** (0.120)
Income		0.806 (0.892)		0.866** (0.588)		1.027 (2.908)		0.169 (0.250)
Q statistic	6.68 (0.08)	4.82 (0.19)	2.76 (0.43)	3.68 (0.30)	1.01 (0.80)	1.20 (0.75)	1.08 (0.78)	3.43 (0.33)
TR^2	1.73 (0.42)	-- --	0.30 (0.86)	1.96 (0.16)	5.19 (0.07)	-- --	2.86 (0.24)	0.71 (0.40)

Notes: The dependent variable in each equation is the quantity in the respective market. Asymptotic standard errors are in parentheses except for the Q and TR^2 statistics, which have the p-value in parentheses. One (*), two (**) and three (***) asterisks refer to significance at the 10, 5 and 1 percent levels respectively. All nominal variables have been divided by the (1967 = 100).