Cattle Cycles, Expectations and the Age Distribution of Capital

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May 2002

Abstract

This paper builds a dynamic forward-looking model describing the approximate ten-year cattle cycle. The theoretical model improves on existing models by (1) allowing cow-calf operators to make investment decisions on both the cow and calf margins, (2) formally recognizing the age distribution of the capital stock, and (3) considering a mixed scheme of rational and naive expectations. The model is then calibrated and used to simulate artificial data that endogenously generates ten-year cycles in the total stock of cattle.

JEL Codes: C61, Q11 and Q12.

[W] To be presented at the 2002 AAEA Annual Meetings. This paper has benefited from the comments of Kevin Huang, DeeVon Bailey, Sherwin Rosen, Lynn Hunnicutt, Russell Tronstad as well as the participants of the 2001 Western Agricultural Economic Association Annual Meetings, 2000 Society for Computational Economics Annual Meetings, and the 2000 American Agricultural Economics Association Annual Meetings. The author is an Assistant Professor in the Department of Economics, Utah State University. Please send correspondence to David Aadland, Department of Economics, Utah State University, 3530 Old Main Hill, Logan, UT, 84322-3530, or email: aadland@econ.usu.edu.

1 Introduction

When people speak of the business cycle, they are generally referring to the sporadic recessions and booms that occur in developed economies. In this sense, the term business cycle is really a misnomer because it misleads one into thinking of regular cyclical variations in economic activity (for example, something that could be fit along a sine wave). The cattle cycle, on the other hand, is anything but a misnomer. Aggregate cattle stocks are unique in that they are one of the few, if not only, economic time series to display such amazingly regular cycles over such long periods of time — approximately ten years from peak to peak (Mundlak and Huang, 1996). Figure 1 displays the (detrended) total stock of cattle in the United States from 1930 through 1999.[1] The remarkable regularity of the cattle cycle is clearly evident.

These cycles present an intriguing economic puzzle. Exactly what is the mechanism that causes cattle producers to collectively take actions that create such a regular cycle? And why is it spread out over such long time horizons? A substantial amount of research has already been devoted to these questions and other issues related to cattle dynamics (see, for example, Jarvis (1974); Rucker, Burt and LaFrance (1984); Paarsch (1985); Trapp (1986); Rosen (1987); Rosen, Murphy and Scheinkman (1994); Mundlak and Huang (1996); Nerlove and Fornari (1998); and Aadland and Bailey (2001)). While much has been learned about cattle cycles as a result of this research, the basic forces behind the cattle cycle have been understood for some time. An especially clear description is given by DeGraff (1960):

> A number of circumstances might trigger the swings of a cattle cycle....While such influences as a change in demand or in feed supplies may initiate a cycle, they do not explain the sequence of events which follow. The reason why a cycle follows its standardized pattern is found, not in economics, but in biology.... The lifespan of cattle is long. They reproduce and grow slowly. If a beef heifer is kept for breeding instead of being sent to slaughter, her first calf does not reach the market until nearly three years later. This is indeed a long delay in economic response. To say that cycles in cattle originate largely within the industry itself is not to say that producers are either ignorant or indifferent to the consequences of their decisions. The slow-moving biology

[1] The data are detrended using the Hodrick-Prescott filter with smoothing parameter set at $\lambda = 1000$. See Mundlak and Huang (1996) for more details on the use of the HP filter in this context.

of the species is the factor that extends the period between decision and consequence and leads to the patterned nature of the cattle cycle.

The leading modern paradigm for understanding cattle cycles appears to be that of Rosen, Murphy and Scheinkman (1994), RMS hereafter. Their article was a major contribution to the research on cattle cycles[2]. They formalized the concepts described in DeGraff's quotation by showing that regular cycles in the aggregate cattle stocks are consistent with rational, profit-maximizing ranchers who operate in a dynamic, competitive environment with uncertainty. Based in part on their work, it now appears to be fairly well accepted that the cattle cycle is the result of producers' responses to exogenous shocks in their environment, coupled with lengthy biological and maturation lags. The problem with their explanation, however, is that it fails to produce the defining feature of cattle stocks — the regular ten-year cycle. Rather, they produce cycles with periods somewhere in the neighborhood of three to four years. In fact, in their conclusion RMS state that "some longer [approximate ten-year] cycles in consumption and stocks not explained by this model are found in the data."

To address this shortcoming, I make three substantial changes to the RMS environment. First, and most importantly, I explicitly model the age distribution of the breeding stock.[3] RMS assume that the cows die out exponentially. In reality, breeding cows have a finite productive life that begins to deteriorate somewhere in the neighborhood of ten years (Jarvis, 1974; Trapp, 1986). The fact that cattle cycles are also approximately ten years in length is no coincidence. Second, in response to recent research questioning the validity of full rational expectations in the cattle industry (Nerlove and Fornari, 1998; Baak, 1999; and Chavas, 2000), I allow some portion of expectations to be formed naively rather than rationally. Coupled with the age distribution, this mixed expectations regime is an important ingredient in the model's ability to propagate shocks to produce regular ten-year cycles. Third, and finally, while RMS assume that only two-year old adult animals are culled from the stock, I allow producers to make culling decision on both the calf

[2] Early research attempting to understand cycles in agriculture typically relied on the cobweb theorem (Ezekiel, 1938), or more generally on a Nerlovian supply specification (Nerlove, 1958). Although the cattle industry is faced with production lags as required by the cobweb model, it has never been successfully applied to the issue of cattle cycles largely because of the unrealistically long production periods necessary to generate the observed cycles (Muth, 1961).

[3] Other authors have explicitly modeled the age distribution of animal herds (e.g., Jarvis, 1982; Trapp, 1986; Chavas and Klemme, 1986; and Foster and Burt, 1992), however none have done so within a model of individual optimizing behavior explicitly intended to explain the cattle cycle.

and cow margins. This distinction relates to the trend over the better part of the twentieth century to feed young animals high concentrate grains prior to slaughtering. In essence, this modification reflects the reality that there are actually two separate markets for beef — one associated with higher quality fed meat (such as steaks and roasts) and one associated with lower quality non-fed meat products (such as hamburger and canned meat).

The paper is organized as follows. Section 2 presents some descriptive facts regarding the U.S. cattle industry and introduces the data. Section 3 presents the theoretical model and highlights some of its implications using impulse response functions. Section 4 presents an attempt to fit the U.S. cycle in cattle stocks using the theoretical model and major economic disturbances that have occurred over the last 70 years. Finally, section 5 concludes by summarizing the paper's most important findings.

2 Cattle Facts and Data

2.1 A Brief Description of the Cow-Calf Operation

Since the details of the cattle industry are not universally understood, I will briefly outline the environment that is being modeled. In Western and Midwestern states, beef calves are typically born in the spring.[4] In the first six months of the calf's 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 approximately six 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 (capital good) or send them to slaughter (consumption good). The decision for weaned steers is simpler as they are only a consumption good and are consequently destined for slaughter.

Weaned calves that are sent to slaughter do not go there immediately. Most will go through a process called *finishing*. Finishing typically involves a four to six month period when a weaned calf is

[4] 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).

maintained on pasture or harvested forage before entering the feedlot. Once this stage is complete, the animal is transferred to a feedlot where it will be fed high-concentrate grains for another four to six months to be fattened for slaughter. The finishing of young animals is a relatively recent phenomenon. Prior to the 1930s, feeding of high-concentrate grains was atypical. Since then, the practice of finishing young animals with grains has become increasingly more common and in more recent times (beginning in the 1960s) the finishing has been completed primarily in organized feedlots.

Heifers that are not sold after weaning typically become part of the producer's breeding stock. Breeding cows can produce at most a single calf per year, have a gestation period of nine months, and can be bred for the first 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 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. The culled cows will go directly to slaughter as their beef is of lower grade and is not suitable for finishing.

2.2 The Data

The primary source for data on the cattle industry is *Agricultural Statistics*, an annual publication of the United States Department of Agriculture. 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 important limitations of the data as well. First, at various times during the twentieth century, there were abrupt changes both in the accounting procedures (e.g., move from an age-based to a weight-based accounting system in 1972) and structure of the industry (e.g., finishing did not become significant until the 1930's). Second, several key series are not recorded prior to 1930 and many of those that are recorded prior to 1930 are heavily aggregated across different classifications of animals. In response to these limitations, I begin the sample period in 1930 and focus attention exclusively on three types of female animals: calves, heifers and adult cows. These three series are given, respectively, by (1) a proportion of the total annual beef calf crop, (2) the total January 1 stock of beef heifers that have not calved, and (3) the total January 1 stock of cows and heifers

operator (i.e., $E_t^N x_{t+1} = x_t$), and $0 \leq a \leq 1$. In the impulse response functions to follow, I use two different parameterizations, $a = 0.70$ and $a = 1.00$. This type of mixed expectations scheme is similar to the analysis in Brock and Hommes (1997) and Baak (1999), although it differs in that I assume that agents are homogeneous and the fraction of naively formed expectations is exogenously given.

3.5 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 $x_0^{(j)}$ for $j = 0, ..., m$. This is a second-order system of nonlinear difference equations under rational expectations ($a > 0$). To solve the model, I first calibrate the model, calculate the steady-state values for the variables, linearize the equations around the stationary steady state, write the variables in terms of percentage deviations from their respective steady-state values, and solve for the unique equilibrium paths of the variables using a method developed by Blanchard and Kahn (1980). Similar methods for solving linear dynamic rational expectations models have been extensively used in the macroeconomic business-cycle literature (see, for example, Cooley and Prescott (1995) and Farmer (1999)).

3.6 Calibration

Before discussing the calibration, it is necessary to address the relationship between culling decisions and the age of the cow. Given a homogenous breeding stock and a single demand for non-fed beef, ranchers will optimally choose to cull the oldest cows first. As a result, the equilibrium path for cull rates will involve a critical age τ_t (possibly varying over time) at which cows would have equal consumption and capital values. All cows younger than τ_t will be retained and cows older than τ_t will be culled (Jarvis, 1974). The implied boundary solution associated with varying slaughter ages greatly complicate the analysis. As RMS (page 471) state, "making the slaughter age endogenous

... has proved too difficult to analyze and is omitted." In order to retain the age distribution of the stock, I allow there to be distinct demands for non-fed beef derived from cows of every age (Trapp, 1986). As a result, there will be an interior solution for the cull rates of every age cow so that standard solution techniques can be applied. Then to retain the idea that ranchers cull from oldest to youngest, I fix $\tau_t = 9$, set the steady-state values of $\alpha_t^{(2)}$ through $\alpha_t^{(8)}$ equal to an arbitrarily small number (0.0001), and assume (near) perfectly inelastic demands ($\pi_j = -100$) for non-fed beef of ages $j = 2, ..., 8$. Consequently, variation in the price of beef will have little impact on the already minuscule number of cows slaughtered between 2 and 8 years — all the action in cow slaughter will occur at ages nine and 10.

To facilitate comparison with RMS, I attempt to choose the parameter values to be as close as possible to their values. I begin by setting the productive lifespan of a cow equal to ten years ($m = 10$), the baseline value mentioned in RMS. The discount factor and birth rate parameters are set at $\beta = 0.909$ and $\theta = 0.85$. As in RMS, the death rate parameters of young animals are set at $\delta_0 = \delta_1 = 0$ while the death rate parameters for the breeding stock are set at $\delta_2 = ... = \delta_{10} = 0$ and $\delta_{11} = 1$, implying an average natural death rate for the breeding stock in the neighborhood of 0.1. Lastly, the persistence parameters for the demand and cost shocks are set equal to 0.6 as in RMS ($\rho_j = \psi_1 = 0.6$) for $j = 0, ..., m$.[6]

As for the price elasticities, there is a wealth of empirical information on retail market responses for fed and non-fed beef (e.g., Wohlgenant (1989), Smallwood, Haidacher and Blaylock (1989), and Capps et al. (1994)).[7] Although, the reported elasticities vary from study to study depending on differences in the sample period, data employed, functional forms, control factors, etc., most studies estimate that beef is inelastic with respect to its own price. The approximate midpoint estimates for the own-price elasticity of demand from these studies is -0.5 (i.e., $\lambda_1 = \pi_{9,10} = -2$), which are the values used in this study.

Unfortunately, I do not know of any empirical evidence for the individual markup parameters, ϕ_k and ϕ_b. This is largely due to the lack of reliable historical information on the retail prices for

[6] There is also some empirical support for RMS' assumption that the autoregressive parameters equal 0.6. Univariate first-order autoregressive estimates for the sample period 1930 through 1999 using the real price of calves, cows and feed index are 0.587, 0.565 and 0.591 respectively.

[7] Actually, since the retail demand functions are in their inverse forms with price as the dependent variable, the λ's and π's are often labeled as own-price *flexibilities* rather than elasticities. I continue to use the term elasticities rather than flexibilities, but the inverse form of the demand functions needs to be kept in mind.

fed and non-fed beef. Mathews et al. (1999), however, provide time series (1970-1997) evidence on the spread between farm-level and retail-level beef for a weighted average of both choice beef and hamburger. The spread between the two has been growing in recent times (a trend that has prompted a large amount of literature regarding the competitiveness of the beef-packing industry). For simplicity, I abstract from the apparent time-varying nature of this parameter and assume there is a single common markup parameter, which averages approximately $\psi_k = \phi_b = 0.6$ over this period.

Given the calibrated parameter values above, Table 1 displays the implied steady-state values for a select set of variables (asterisks denote imposed values). One item worthy of mention is that although calf prices per pound have historically been approximately twice that of cull cows, cull cows weigh about twice as much. Therefore, their gross values are approximately equal and imposing equal steady-state, farm-level prices for calves and cows is justified (see also RMS, footnote 2).

Table 1. Select Steady-State Values

Variables	$k^{(0)}$	$k^{(1)}$	b	$c^{(0)}$	$c^{(9)}$	$c^{(10)}$	$\alpha^{(0)}$	$\alpha^{(9)}$	$p^{(0)}$	$p^{(9)}$	w
Values	10.7	3.0	25.2	7.8	1.5	1.5	0.7	0.5*	0.6*	0.6*	0.23

3.7 Impulse Response Functions

To highlight the dynamics of the model, begin by considering a 1-ve percent persistent ($\rho = 0.6$) negative shock to the demand for retail non-fed beef[8]. The responses of the cow stock, total female stock, cow cull rate and calf cull rate are shown in Figure 2[9]. The dashed lines are the responses of these four variables within the model that incorporates the age distribution of the breeding stock ($m = 10$) and rational expectations ($a = 1$). This model is referred to as the ADRE model. The optimal producer response for the $t = 2$ negative demand shock that temporarily increases the relative price of calves to cows is to immediately send fewer cows and more calves to market[10]. In

[8] Choosing non-fed beef also facilitates later comparisons to RMS who do not explicitly model fed beef.

[9] A single, aggregate cow cull rate is created by taking the ratio of total non-fed beef consumption to the stock of breeding cows.

[10] In contrast to Rosen (1987), this positive supply response holds even for permanent shocks that alter the relative price of calves to cows (Aadland and Bailey, forthcoming). The important distinction between Rosen (1987) and the ADRE model is that the latter separates the markets for fed and nonfed beef.

essence, consumers have "bid away cows from the producers' capital stocks" (Jarvis, 1974). These culling decisions imply an increase in both the cow and total female stocks in period $t = 3$ (recall that culled calves remain in the total female stock while they are being fattened). The cow and total female stock then return back toward their steady-state values, but the total female stock returns more slowly because the additional $t = 3$ cows add to future total stocks by giving birth to calves in period $t = 4$. As the impulse associated with the $t = 3$ additional cows and their $t = 4$ calves pass through time, they eventually approach the end of their productive life. In order to compensate for this impending decrease in the breeding stock, producers respond by sending fewer cows to market (i.e., the dip in the cow cull rate at $t = 12$). These new $t = 13$ cows and their $t = 14$ calves generate an "echo effect" exactly $m = 10$ periods after the initial peak in the cow and total female stock. Similarly, an even smaller third peak (barely visible in Figure 2) appears $m = 10$ periods after the second peak, and so on and so forth. Thus, the ADRE model *endogenously* generates cycles in cattle stocks with a period of 10 years.

One shortcoming of the ADRE model is that subsequent peaks in stocks are substantially smaller than the initial peak. Subsequent peaks are dampened because forward-looking producers anticipate the certain decline in the breeding stock ten years hence and take actions to mitigate future cyclical variation. To address this problem, now let a positive fraction of expectations be backward looking. I refer to this model with the age distribution of the breeding stock ($m = 10$) and mixed rational and naive expectations ($a = 0.7$) as the ADME model.[11] The dynamic responses for the ADME model are depicted by the solid lines in Figure 2. The primary consequence of moving from pure rational expectations to a mixed expectation scheme is to magnify the secondary cycles. Producers also now respond more vigorously along the calf margin because they are not looking forward as much to the impact that the reduction in retained heifers will have on subsequent breeding stocks. As a result, the breeding stock will fall below its steady state path and require a larger amount of investment into the breeding stock when then last of the period $t = 3$ cohort of breeding cows dies at $t = 16$. This effect illustrates the well-known idea that rational expectations models tend to have weaker propagation methods than do boundedly rational models and hence assign more of the volatility to exogenous shocks rather than endogenous responses (Cogley and

[11] The model becomes nonstationary for parameterizations in the neighborhood of $a \leq 0.5$. This type of behavior is also described in Baak (1999).

Nason, 1995 and Baak, 1999).

Finally, I contrast the dynamics of the ADME model with those from the RMS model. The RMS model differs from the ADME model in four ways: (1) expectations are rational ($a = 1$); (2) no calves are culled from the stock ($\psi_t^{(0)} = 0$); (3) there is no retail-farm markup ($\phi = 1$); and (4) cows that enter the breeding stock become ageless and subsequently die at an exponential rate. Figure 3 reproduces the dynamics of the ADME model and superimposes the IRFs for the RMS model (essentially the mirror images of those in Figure 4b, page 478 of RMS). The most noticeable difference between the dynamics of the ADME and RMS models is that the RMS model does not endogenously generate cycles in the total stock (although it does produce much shorter cycles in the breeding stock — approximately three to four years from peak to peak). The differences between the ADME and RMS IRFs are primarily due to the differential treatment of the age distribution of the breeding stock, which when coupled with boundedly rational agents, is capable of endogenously generating ten-year cycles in cattle stocks.

4 Explaining the Periodicity of the U.S. Cattle Cycle

The primary motivation for this research is to build a model, consistent with individual producer behavior, which is capable of generating cycles in cattle stocks similar to those observed in the United States.[12] Surprisingly, to my knowledge, there is no existing model which is capable of endogenously generating cattle cycles similar to those in the U.S. without resorting to ad hoc dynamics. Mundlak and Huang (1996, p. 855) state that "there is no empirical model that fully captures the role that it [technology] plays in determining the dynamics of the sector and that can reproduce the cyclicity observed in the data. This is not for lack of trying but due to the complexity of the problem." RMS come the closest. However, their apparent excellent fit to the U.S. cattle cycle is somewhat overstated. RMS document the closest fit by contrasting the coefficients from an empirical ARMA model to the coefficients from a theoretic model of the same order. However, as Nerlove and Fornari (1998, p. 142) state, "...many different ARMA models are consistent with the basic data (not identified by the final-form solutions) so that comparison of the estimated coefficients with theoretical benchmarks for the same orders of processes reveals

[12] Cattle cycles also appear in countries other than the U.S. Mundlak and Huang (1996), for example, note that Argentina and Uruguay display cattle cycles with similar periods to those in the U.S.

little." Moreover, the graphs in Figure 6b of RMS are generated by feeding in the reduced-form ARMA residuals from the U.S. data into the theoretical ARMA process of the same order. Given that the theoretical ARMA process for stocks in RMS do not display long cycles, the excellent fit is essentially an application of the Slutsky (1937) effect.[13] A more compelling comparison would work directly with the structural disturbances and the restrictions imposed by theory on the reduced-form disturbances.

The standard method for evaluating dynamic rational expectations models is to calibrate the model by choosing reasonable parameter values, then replace the structural disturbances with random draws from a distribution (typically Gaussian), simulate artificial data by feeding the realized disturbances into the equations describing the equilibrium time path, and then contrast various statistical properties of the artificial and actual data. The problem with this methodology, within the context of cattle cycles, is that draws from a Gaussian distribution will not generate approximate ten-year cycles in the any of the current structural cattle-cycle models. Once the wheels of the cattle cycle get set in motion by producers' response to the exogenous shock, another shock of similar magnitude is likely to be drawn, blurring the lengthy cyclical responses.

Instead, I argue that the exogenous shocks to the cattle industry have not been Gaussian. Rather, over the last 70 years, my interpretation of the historical literature is that the cattle industry has been disproportionately influenced by four transient macroeconomic shocks. Of course, there have been other major changes in the cattle industry over the last 70 years (e.g., finishing on organized feedlots, advances in cattle feeding practices and genetics, increased beef-packer concentration, etc.). However, these are generally more gradual, structural phenomena that act primarily on the steady-state cattle stock rather than cyclical deviations about this steady state. Since this research is focused on cattle cycles and not secular trends, I do not attempt to model the trends and accordingly remove them from the U.S. data by passing the data through the Hodrick-Prescott filter.

4.1 Four Macroeconomic Episodes

The four big macroeconomic episodes during the past 70 years were: (1) the Great Depression; (2) World War II; (3) the OPEC oil price shock of 1973 and the subsequent 1974-75 recession; and (4)

[13] Confirmed via personal correspondence with one of the authors.

the OPEC oil price shock of 1979 and the subsequent 1981-82 recession. Below I present descriptive evidence to support the hypothesis that these shocks, as well as some simultaneous droughts, had a disproportionately large impact on the cattle industry and provided the impetus for subsequent cattle cycles. Schlebecker (1963) writes "Clearly, depression and prosperity originated in causes far removed from anything that happened on the Plains. And yet nothing is so clear as the effects of the business cycles on the affairs of the cattlemen."

4.1.1 Great Depression

First was the Great Depression — the largest economic downturn in modern U.S. history. The first signs of a downturn began in 1929 after the stock market crash in October. Real GDP fell for the next four years and although real GDP began to rise again in 1934, unemployment was still at 22%. The Great Depression had severe effects on the cattle industry, as in almost all economic sectors. The low point for the cattle industry appeared to be 1933. The U.S. unemployment rate was at 24.5% and four years of declining national income meant consumers could no longer afford to eat beef. To make matters worse, many of the cattle-producing states faced terrible drought conditions. As Schlebecker (1963) writes

> In 1933, each American ate an average of 58.6 pounds of beef and veal. Americans would have eaten even less if the federal government had not furnished beef for people on relief. Cattle prices fell to unbelievably low levels...as much as 25 per cent below the already low levels of 1932. As 1933 began, many cattlemen had already become insolvent, and most of them produced cattle at a loss.

Skaggs (1986) continues regarding conditions in 1933

> Compounding the disaster was a devastating drouth that not only seared the grassy plains but also hurt the usually well-watered Missouri, Mississippi and Ohio valleys. Livestock raisers and feeders alike dumped cattle on an already glutted market, and prices tumbled ... to reach a new twentieth-century low.

As shown in Figure 1, cattle numbers were increasing during the early periods of the Great Depression — 1930 through 1934. After 1934, cattle numbers started to decline, not so much due to

contemporaneous economic factors, but an accumulation of years of low prices and adverse weather that placed ranchers in a position of financial hardship.

4.1.2 World War II

The United States' involvement in World War II spanned the period 1941 to 1946. Higher personal incomes and higher government demand for beef, coupled with price controls that began in 1942 led to a shortage of beef that was felt most acutely beginning in late 1942 (Schlebecker, 1963). In response, the Office of Price Administration began rationing meat in 1943, which continued through late 1945 (Sims, 1951). Under normal market conditions, such a strong, temporary demand for beef would have provided an incentive to cull more animals to take advantages of higher prices. However, in an environment of price ceilings and frequently changing government policies, cattle producers held onto animals in the face of substantial uncertainty about expected future prices. Schlebecker (1963) writes that

> Unquestionably, cattlemen and others intentionally created meat shortages before controls ended. Producers held their cattle off the market as they waited for the end of controls; when controls did cease, they expected prices to shoot up. They were right, and they did not have to wait long. In October, 1946, all meat controls ended, and prices immediately rose. Stimulated by price incentives, producers sold all they could, but they could not market enough beef to satisfy consumers. The postwar inflation had begun.

William Arant (1946) adds

> ...the official belief throughout the war was that producers were missing the bus by failing to liquidate their herds when demand for meat was high. The Department of Agriculture repeatedly urged greater cattle marketings... The holding back of cattle was in part a result of the uncertainty surrounding the government programs. It has been the experience rather consistently under controls that the man who held on a little longer secured a higher price. Also, in many cases, income taxes could be reduced by postponing the realization of profits until the next taxable year.

At the same time, the Southwest and especially Texas was experiencing a major drought. Schlebecker (1963) writes about the drought:

> The southwestern drouth grew worse in 1943. Texas reported the worst weather since 1917. Large parts of Texas, Kansas and Oklahoma were declared disaster areas. The War Food Administration sent in quantities of soybeans and hay to rescue the stricken ranchers.

4.1.3 OPEC Oil Shock I and the 1974-75 Recession

In late 1973, the OPEC oil cartel drastically reduced its production of crude oil and imposed an oil embargo on the United States. This sudden adverse supply-side shock sent the prices of oil in the U.S. up by nearly 70% between 1973 and 1974 (Bureau of Labor Statistics, 2001). Higher oil prices led to substantially higher operating costs for firms across many different sectors, and subsequently, the U.S. economy fell into recession in 1974 and 1975 (Hamilton, 1983). As a result of a relatively energy-intensive feed-crop sector (Hanson, Robinson and Schluter, 1993), a sharp increase in grain exports due to a depreciated dollar and a drought, the price of feedstuffs increased drastically in 1974 (Beale et al., 1983). Exacerbating the problem, the Nixon administration imposed a freeze on the retail price of beef in 1973. Feedlot operators reduced their demand for cattle, and when coupled with an economy-wide recession, this led to a sharp decrease in the demand for beef and the derived demand for cattle (Rucker, Burt and LaFrance, 1984). Consequently, cattle producers postponed sending animals to market and aggregate cattle stocks rose sharply, reaching their highest level of the twentieth century in 1975 (Martin and Haack, 1977).

4.1.4 OPEC Oil Shock II and the 1981-82 Recession

In 1979, only five years after the first oil price shock, OPEC once again cut back drastically on oil production. U.S. inflation returned to double-digit levels and the economy fell to recession again in late 1981 and 1982. The recession and abundant supplies of competing meats reduced consumers' demand for beef (Beale et al., 1983). At the time of the price shock, aggregate cattle numbers were at the bottom of the downside of a cycle initiated by the increased retention from the 1974-75 recession. Cattle numbers then started increasing again with the onset of the 1979 oil price shock and the subsequent recession, reaching their peak again in 1982. The timing of the oil shock and

recession led to the shortest cattle cycle over the last 70 years — seven years from its 1975 peak to its 1982 peak.[14]

4.2 Simulation Results

The four major shocks outlined above provide a natural experiment to test the theoretical cattle model. Certainly, there were other smaller macroeconomic and industry-specific shocks that influenced producers' incentives. The advantage, however, of focusing on these four disturbances is that their macroeconomic impacts and timing are well recognized and they can be treated as exogenous to the cattle industry. In fact DeGraff (1960) notes:

> Some of the influences that bring on the cyclical fluctuations in cattle numbers and prices arise entirely outside the cattle industry. When the nation encounters the upheavals of war followed by a return to peace-time markets, or the disruption of a great depression or a great drought, there is impact on the cattle industry which no one can avoid. These are situations beyond the control of the cattlemen.

To highlight the effects of these four episodes, I simulate artificial data from the ADME model using shocks from only these four time periods. This events-based approach to shock identification and model evaluation is similar in spirit to Romer and Romer (1989) and Ramey and Shapiro (1998). Moreover, since the primary focus of this paper is to explain the observed periodicity of the U.S. cattle cycle, as opposed to its amplitude, the difficult task of identifying the magnitude of the shocks is ignored. Artificial data on cattle stocks are simulated by feeding in four adverse beef (fed and non-fed) demand and operating cost shocks at time periods 1933, 1943, 1974 and 1981.[15]

[14] At the same time, a second negative demand shock hit the cattle industry (Purcell, 1990 and Chavas, 1983). Consumers became increasingly concerned about high cholesterol diets associated with red meat. Purcell writes that "consumer-level ... decreases in demand are hypothesized to be the single most important causal factor in the structural changes of the 1980s." However, the evidence appears to support a fairly gradual decline beginning in the late 1970s and extending through to approximately 1987. No attempt is made here to distinguish the effects of the 1981-82 recession-driven decline in the demand for beef with the decline associated with health concerns.

[15] Unlike the Great Depression and the 1974/1981 recessions, World War II led to an increase in the demand for beef. At a first glance, it would therefore seem more appropriate to simulate data using a positive shock to the demand for beef during World War II. However, cattle and beef markets were not in equilibrium during the war due to price controls. The equilibrium models discussed here, as a result, are incapable of accurately describing the nature of prices and quantities during this time period. Rather than abandon the equilibrium model, I model World War II as resulting in a decline in the demand for beef, which is observationally equivalent (with respect to female stocks) to an increase in the demand for beef under price controls and substantial uncertainty regarding future governmental regulations and controls. Recall that aggregate U.S. cattle stocks were increasing during the beginning of World War II as producers held onto cattle in the midst of this uncertainty.

For simplicity, the shocks are all of equal magnitudes with autocorrelation coefficients set equal to 0.6. The exact timing of these disturbances and their impact on the cattle industry is somewhat open to debate. I choose 1933 because it was the trough of the Great Depression; 1974 and 1981 mark the beginning of the other two major postwar economic downturns (NBER, 2001); and 1943 marked the beginning of meat rationing during World War II.

The results of the simulation exercise are shown in the top panel of Figure 4. The solid line depicts detrended U.S. female cattle stocks from 1930 through 1999, while the dashed line depicts artificial stocks from the ADME model. Vertical lines indicate the timing of the driving shocks. The ADME model, using only the four macro shocks described above, does a remarkable job of matching the periodicity of the U.S. cattle cycle. The model misses some aspects of the cattle cycle (i.e., tends to overstate the peakedness of the cycle and predicts a spurious echo effect in 1985), which is to be expected given the abstract nature of the model and the use of only four driving shocks. However, overall the fit is good with a simple correlation coefficient between ADME cattle stocks and detrended U.S. cattle stocks equal to 0.56. Of particular interest is the fact that the 1954 and 1964 peaks in U.S. cattle stocks, as well as the 1989 trough, are predicted by the ADME model as endogenous "echo effects" that occur ten years or more after the driving shock. These echo effects are caused by producers' responses to the changing age distribution of the breeding stock which result from actions taken during the Great Depression, World War II and the 1974/1981 recessions.

Finally, consider the performance of the RMS model using the same four set of shocks.[16] The bottom panel of Figure 4 shows the U.S. detrended female cattle stocks (solid line) and the predicted response given by the RMS model (dashed line). The most notable feature of the graphical comparison is that unlike the ADME model, the RMS model is not capable of generating ten-year cycles in stocks without the support of driving shocks approximately every ten years. In fact, the contemporaneous correlation between the RMS and U.S. data is only 0.03, as compared to 0.56 in the ADME model. Even if one were to account for the apparent one-year right-shift in the RMS simulations by beginning the impulses one year earlier (i.e., 1932, 1942, 1973 and 1980),

[16] Recall that RMS do not distinguish between fed and non-fed beef so there is but a single shock to the demand for beef in each of the episodes.

the correlation is still only 0.27. The test statistic

$$\frac{(r_{13} - r_{23})\sqrt{(T-3)(1+r_{12})}}{\sqrt{2(1+2r_{13}r_{23}r_{12} - r_{13}^2 - r_{23}^2 - r_{12}^2)}}$$

where r_{xy} indicates the simple correlation coefficients between the (1) ADME, (2) RMS and (3) U.S. data and T is the number of observations used to calculate the correlation, can be used to test the hypothesis that the ADME model provides a superior fit (Weinberg and Goldberg, 1990). The statistic above has a student t distribution with 5% critical value equal to 1.67. The realized value of the test statistic (using the more optimistic RMS shock dates) equals 2.10 and leads to a rejection of the null of equal correlations, indicating that the ADME model provides a better statistical fit of the periodicity of the U.S. cattle cycle than the RMS model.

5 Conclusion

The most prominent feature of the cattle industry is the approximate ten-year cycle in stocks. Very few economic time series display such regular cycles that stretch over such long periods of time. The basic forces that drive cattle producers to act in such a way as to create the cattle cycle are now fairly well understood. For example, Foster and Burt (1992, p.423) state

> It would appear that the combination of price shocks and cycles along with the heifer-replacement and cow-culling decisions, based on a changing age distribution within the mature cow herd, all interacting with a neoclassical demand curve for beef, results in the observed cattle cycle.

Nevertheless, to my knowledge, there does not exist any model of the cattle industry which incorporates (1) exogenous price shocks, (2) investment decisions along both the heifer and cow margins, (3) a changing age distribution of the mature cow herd, and (4) individual optimizing behavior which is capable of endogenously generating approximate ten-year cycles in stocks. The ADME model presented in this paper makes progress in that direction. The model satisfies the four conditions above and is capable of endogenously propagating structural disturbances to generate ten-year cycles in cattle stocks. The ability of the model to generate ten-year cycles in cattle stocks

relies heavily on the realistic assumption that beef cows have a productive lifetime somewhere in the neighborhood of ten years and that ranchers act in a manner consistent with a mixed expectations scheme.

An undesirable property of competing models of the cattle cycle is that since they are not capable of endogenously generating ten-year cattle cycles, they require the unlikely scenario that the economy experiences driving shocks approximately every ten years. To illustrate this point, I simulate artificial data from the ADME model, focusing exclusively on shocks from four major macroeconomic episodes during the 1930-1999 period. These simulations demonstrate that the ADME model is capable of matching the periodicity of the U.S. cattle cycle without relying on major shocks hitting the cattle industry every ten years.

The ADME model appears to be a promising paradigm for understanding cattle cycles. However, more research is necessary to fully understand the interesting phenomena of cattle cycles. Important avenues for future research include more precise identification of the structural disturbances driving cattle cycles, further examination of price dynamics (including the implications for countercyclical production strategies) and the relationship between trends and cycles.

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