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Regime Switching in US Livestock Cycles

Hui-Ping Chao ¹

North Carolina State University

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¹Address for correspondence: Department of Economics, North Carolina State University, PO Box 8110, Raleigh, NC 27511; email: hpchao@unity.ncsu.edu. ©1998 by Huiping Chao. All rights reserved. Readers may make verbatim copies of this document for non-commercial purposes by any means, provided that this ©notice appears on all such copies.

Abstract

This paper applies Hamilton regime-switching model on the US data of quarterly changes cattle and hog breeding stocks. The empirical results suggest that the dynamics of livestock cycles can be captured better through a nonlinear model, and enforce the evidence of an asymmetric property in a livestock cycle.

1 Introduction

It is well known that a livestock market displays persistent cycles in stock and prices. Many studies have shown and tried to explain the existence of livestock cycles. As far back as the 1930's livestock cycles were perceived as an expectation problem (Coase and Fowles; Ezekiel). Recent studies still find that some revisions of rational expectations hypothesis, such as heterogeneous expectations, bounded rational expectations, and quasi-rational expectations, well explain the disturbing fact of continuous cycles in livestock markets (Chavas; Baak; Nerlove and Fornari). It is Jarvis first pointing out that animals in livestock production constitute as both a capital good and consumption good. This study leads research on livestock cycles into the more comprehensive dynamic model in which emphasizes the role of stock and animal population dynamics. The fruitful empirical studies include Nerlove, Grether, and Carvalho; Rucker, Burt, and LaFrance; Chavas and Klemme; Rosen; Foster and Burt; Rosen, Murphy, and Scheinkman; and Anerson, Hansen, McGrattan, and Sargent.

In addition to linear dynamic analysis listed above, an interesting alternative explanation for the existence of a livestock cycle is that the cycle itself may be not perfectly predictable because some possible nonlinear dynamic process. Chavas and Holt found nonlinear dynamics in hog prices and dairy quantities. Results of tests in Kohzadi and Boyd indicate the dynamics of cattle price behavior is nonlinear. Based on these evidences, a nonlinear dynamic model is considered in this study to analyze some stylized facts of a livestock cycle.

The livestock cycle is a clear example of a business cycle noted in Chavas and Holt. For instance, a livestock cycle can be described as a combination of two stages: expansion and liquidation (Lesser) ¹. A strand of literature on measuring business cycles based on the celebrated Hamilton regime-switching model, also known as Markov switching model, sheds light on this study. The regime-switching model can be used to examine the questions this

¹Lesser noted that there were other descriptions of livestock cycles. For instance, three segments including rapid growth, deceleration and turnaround; and four phases consisting of rising, high-constant, falling, and low-constant.

study is interested in. Are there distinct regimes in a livestock cycle? How regime differs? When do switches occur?

As the first experiment applying the regime-switching model to explore a possible non-linear process in a livestock cycle, the present study applies Hamilton's classical two state Markov switching model to the US data on changes of cattle reproductive herd and hog breeding stock. The empirical results on both data show that a positive growth in breeding or reproductive stock is associated with normal times and a negative growth rate associated with livestock liquidation. The estimates, especially results on the data of cattle reproductive herd, support for the stylized fact that the dynamics of liquidation are different from those of expansion times, and suggest evidence on the asymmetry of US livestock cycles.

The paper proceeds as follows. Section 2 of the paper explains the Markov switching model as well as the estimation method. Section 3 discusses the estimation results for changes of cattle and hog breeding herd, emphasizing their implications in terms of the possibility of asymmetric property in production cycles. Concluding remarks are presented in Section 4.

2 Model Specification and Estimation

The Markov switching model assumes that time series may display periodic changes in their observed behavior. Such changes happen through switches in states, where the data generating process and average duration of each state are allowed to differ. The apparent success of the regime-switching model encourages a lot of new developments² on studying business cycles and fluctuations, market volatility, and policy interpretation in macroeconomics. The Hamilton's regim-switching model with r autoregressive term is:

$$\begin{aligned}
 y_t - \mu(S_t) &= \phi_1(y_{t-1} - \mu(S_{t-1})) + \dots \phi_r(y_{t-r} - \mu(S_{t-r})) + \sigma\epsilon_t \\
 (1) \quad \mu(S_t) &= \alpha_0(1 - S_t) + \alpha_1 S_t
 \end{aligned}$$

²The detail list of literature is discussed in Hamilton.

where y_t is the series in which the study is interested, and $\{\epsilon_t\}$ is a sequence of i.i.d. $N(0, 1)$ random variables ³. S_t is a binary state variable taking value of 0 and 1. The state variable S_t follows a two-state, first-order Markov process and its transition probability matrix can be written as:

$$P = \begin{bmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{bmatrix}$$

where $P_{ij} = Pr[S_t = j | S_{t-1} = i]$ with $\sum_{j=0}^1 P_{ij} = 1$ for all i . Thus P_{01} is the probability of going from state 0 to state 1. In constructing the probability structure, transition probabilities are assumed to be constant ⁴ and take the following logit form ⁵:

$$(2) \quad P_{11} = Pr(S_t = 1 | S_{t-1} = 1) = \frac{\exp(\theta_{0p})}{1 + \exp(\theta_{0p})}$$

$$(3) \quad P_{00} = Pr(S_t = 0 | S_{t-1} = 0) = \frac{\exp(\theta_{0q})}{1 + \exp(\theta_{0q})}$$

Since only variable y_t is observed, Hamilton suggested a nonlinear filter to draw probabilistic inference about the unobserved state S_t based on the history of the observed values of y_t . In a recursive fashion similar to the Kalman filter, this algorithm ⁶ gives as a by-product the conditional distribution function of y_t :

$$(4) \quad f(y_t | y_{t-1}, y_{t-2}, \dots, y_{-r+1}) \\ = \sum_{s_t=0}^1 \sum_{s_{t-1}=0}^1 \dots \sum_{s_{t-r}=0}^1 f(y_t, S_t = s_t, \dots, S_{t-r} = s_{t-r} | y_{t-1}, y_{t-2}, \dots, y_{-r+1})$$

Thus the sample log likelihood is:

$$(5) \quad \log f(y_T, y_{T-1}, \dots, y_1 | y_0, y_{-1}, y_{-2}, y_{-r+1}) \\ = \sum_{t=1}^T \log f(y_t | y_{t-1}, y_{t-2}, \dots, y_{-r+1})$$

³This simple assumption can be replaced by the ARCH or GARCH model. On the other hand, it is possible to allow the variance shifts in different regimes. Those alternative models will be discussed in the future research.

⁴Diebold, Lee, and Diebold suggested a model with time-varying transition probabilities.

⁵There are some studies, for example Huntley and van Norden who use the normal distribution function format such that $P_{ii} = Pr(S_t = i | S_{t-1} = i) = \Phi(\theta_i)$ $i = 1, 2$ where Φ denotes the normal distribution function.

⁶The detail procedure of this algorithm is provided in Hamilton.

which can be maximized numerically with respect to the unknown parameters α_1 , α_0 , θ_{0p} , θ_{0q} , σ , and $\phi_i, i = 1, 2, 3, 4$.

Based on Hamilton's algorithm one can obtain a sequence of joint conditional probabilities $Pr(S_t = i, \dots, S_{t-r} = j | \Omega_t)$, where Ω_t is denoted as the information set available at time t . By summing up these joint probabilities, one can get the filter probabilities of S_t shown as follows:

$$(6) \quad Pr(S_t = j | \Omega_t) = \sum_{s_{t-1}=0}^1 \cdots \sum_{s_{t-r}=0}^1 Pr(S_t = j, S_{t-1} = s_{t-1}, \dots, S_{t-r} = s_{t-r} | \Omega_t) \quad j = 0, 1$$

These are the probabilities of being in state 0 or 1 at time t given Ω_t . The filter probabilities are useful to determine the date of switches ⁷

3 Empirical Results

In reality, a specific livestock production is a series of several interlocking segments. While these various segments are generally connected, they operate quite independently from each other (Taylor). For example segments of the beef industry in the US include seedstock producers, commercial cow-calf producers, yearling or stocker operator, feeders, packers, purveyors, and retailers. It is, obviously, a challenge to understand or even model the whole dynamic structural movements in a livestock market. As the first attempt applying regime-switching model, only the data on breeding stock are examined in the present study. There are reasons to start with changes of breeding size. First, the movements of breeding herd are very similar to total stock in cattle and hog industries. Second, the decision of keeping a certain size of breeding herd is analogous to an inventory decision in manufacturing sectors which plays an important role in the market dynamic changes. In the further development of

⁷In addition to filter probabilities one can compute similar probabilities with information available up to time T . The probabilities are called smoothed probabilities. Hamilton noted that the smoothed probabilities are more accurate since they are based on more information. Since there's no significant difference between two probabilities in the present paper, only the filter probabilities are reported.

this study, other series such as changes in prices, marketing or slaughtered stock, and input prices are going to be examined in a more complete dynamic structural format.

3.1 Data

The data used in this paper are the quarterly changes in size of cattle herd and hog breeding stock from 1955 to 1992 and 1965 to 1994 respectively ⁸. The percentage changes is constructed by simply subtracting two consecutive logarithm of head counts. The quarterly cattle data are same as Nerlove and Fornari. Figure 1 plots the reproductive herd consisting of cows and heifer is that have calved ⁹. Figure 2 is the changes in this herding size. The liquidation phase in cattle production has shown a tendency to shorten. This may due to

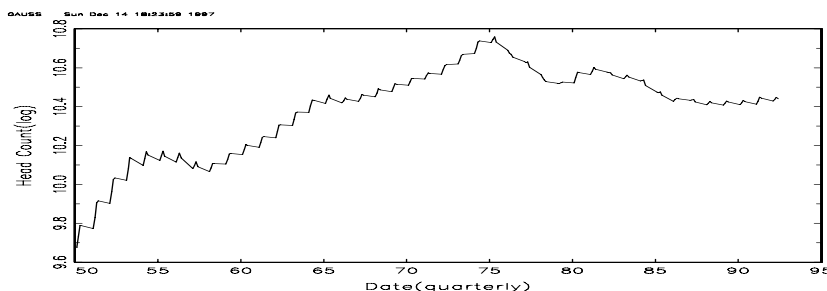


Figure 1: Cattle Cows-Heifer (calved) Stock: 1955:1 - 1992:4

the rapid reduction through slaughter decision.

Since the late 1970s, the “cycle” has not followed traditional patterns. For example, the expansion only lasted three years, 1979-1982, while the drawdown has been prolonged. In

⁸Annual data from 1875 to 1990 is used in Rosen et al. Nerlove and Fornari argued that their model disregards the important structural changes which have occurred in the more than 100 years covered by their analysis. Besides their model deals with annual data is too coarse to capture the changing dynamics of the industry. They pointed out the data before 1920 are not appropriate for analyzing cattle cycles. Thus Nerlove and Fornari’s data is considered to be suitable in the current study.

⁹Following model in Nerlove et al., the reproductive herd is the capital stock consists of all the animals kept for reproductive purpose.

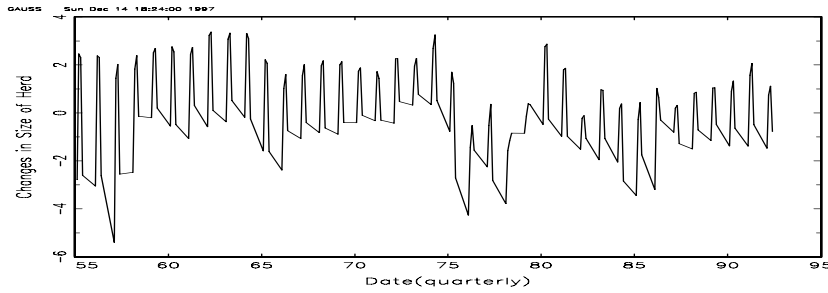


Figure 2: Change in Size of Cattle Cows-Heifer (calved) Stock: 1956:1 - 1992:4

addition the number of breeding herd prolonged downturn for over approximately 15 years.

The hog data are collected from USDA data information on hog inventory. Figure 3 and Figure 4 plot the level and changes in hog breeding stock respectively. Because of

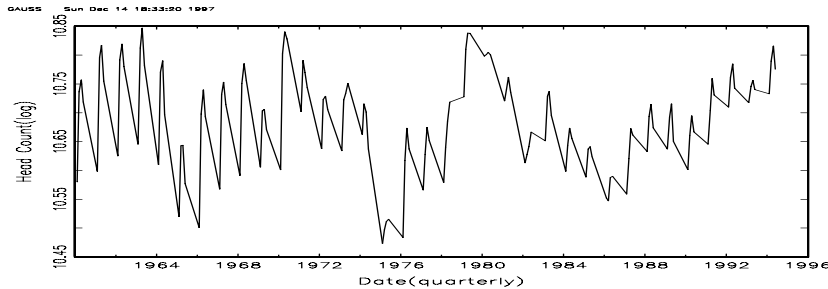


Figure 3: Hog Total Stock: 1965:1 - 4/1994:4

the shorter production life period, the cyclical behavior of this time series is different from cattle reproductive herd. First, hog cycles fluctuate in smaller magnitude from low to high compared to cattle cycles. Second, hog cycles are less pronounced but have stronger seasonal variation because of the shorter gestation period (about four months) and larger litter size. Similar to the cattle industry, the cyclical features of hog cycles become less obvious after

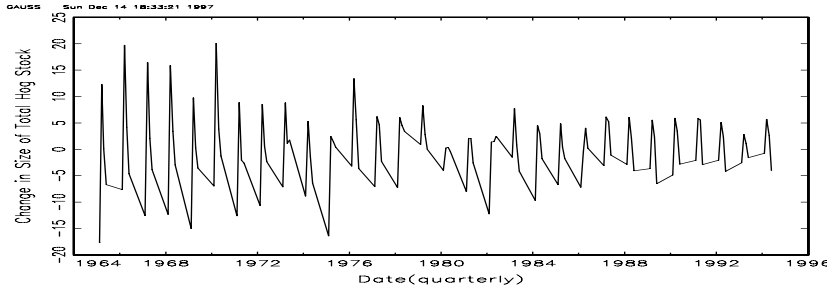


Figure 4: Change in Size of Hog Breeding Stock: 1966:1 - 1994:4

late 1970s.

3.2 $AR(4)$ regime-switching model

The data used in Markov switching models need to be strictly stationary. The various unit root test statistics indicate that both series on percent changes of US cattle reproductive herd and hog breeding hog are stationary¹⁰. Table 1 compares the regime-switching model with a linear $AR(4)$ specification¹¹ of cattle reproductive herd based on sample period 1955:I – 1992:IV, with asymptotic standard errors reported in the next column. The likelihood ratio statistic¹² for the data in the table 1 is 28.26. Compared with the critical values provided in Garcia, it implies strong rejection of the linear model. The sample likelihood is maximized by a negative change rate of $\alpha_0 = -1.53\%$ per quarter during state 0 and a positive change rate of $\alpha_1 = 0.43\%$ during state 1. These values correspond to the dynamics of cattle cycles as opposed to long-term variations in secular change rates. Unlike Hamilton's empirical

¹⁰Various unit root test results, on the other hand, show nonstationarity on the level of these two series.

¹¹The number of regimes and autoregressive parameters is chosen based on Hamilton's empirical study on growth rate of US GNP, which the order of lag 4 is arbitrarily determined in his research. Some model specification tests have been discussed in his recent paper (Hamilton).

¹²The asymptotic distributions of likelihood ratio tests are non-standard because some parameters are not identified under the null hypothesis of no switching. Detailed discussion can be found in Hansen and Garcia.

Table 1: Estimation of Markov Switching Specifications for Cattle
Period of Estimation: 1955:1 to 1992:4 (Quarterly)

	Linear AR(4)		Markov Switching	
	Coefficient Estimate	Standard Error	Coefficient Estimate	Standard Error
θ_{0p}	—	—	3.01203	0.01918
θ_{0q}	—	—	0.45788	0.12682
ϕ_1	0.66320	0.08018	0.69150	0.10409
ϕ_2	-0.66958	0.08311	-0.69813	0.10722
ϕ_3	0.58330	0.08275	0.63635	0.10494
ϕ_4	0.25420	0.07886	0.24114	0.10347
σ	0.85580	—	0.57780	0.03612
α_0	0.13483	0.37594	-1.52722	0.40548
α_1	—	—	0.42765	0.37024
log likelihood	-191.58161		-163.32378	

results for $AR(4)$ model of US GNP growth rate, the two estimated leading autoregressive coefficients are significant from zero. These coefficients suggest that investigating other Markov switching models such as ARCH or GARCH effects or the time-varying probabilistic transition matrix will be interesting topics for future research. The estimated P_{11} and P_{00} are 0.95311 and 0.61251, thus the average durations of state 0 and state 1 are $(1 - P_{00})^{-1} = 2.58$ quarters and $(1 - P_{11})^{-1} = 21.32$ quarters, respectively. Indeed, $5\frac{1}{2}$ years is about the time required if the breeding herd is first expanded (Lesser).

A plot of the filtered probabilities results is shown in figure 5, which graphs the probability that a given quarter is in the negative growth (liquidation) state, based on Markov switching model described above. The probability of being in state 0, associated with negative growth in herding size, is close to zero in most of the sample period. When the probability being in state 1 deviates from state 0, it typically does for a short period of time. This is reflected to the spike-looking intervals in figure 5, except a small blip in the mid 60s. The estimates and the graph of filter probabilities seem capture the nature of regimes in cattle cycles.

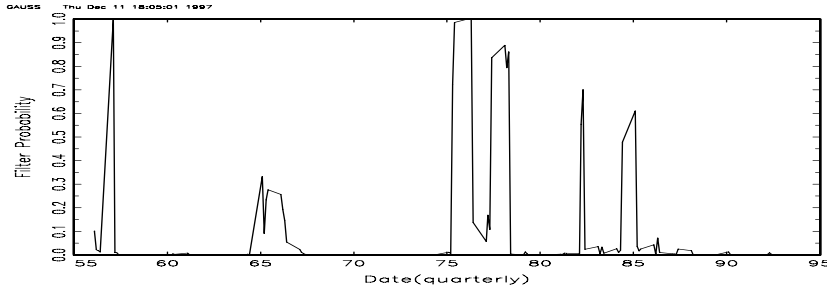


Figure 5: Probability of the Cattle Liquidation State Based on the Markov Switching Model

Furthermore, let the cattle production is in liquidation if $Pr(S_t = 0|y_T, y_{t-1}, \dots, y_{-r+1}) > 0.005$. Dates for US cattle cycles based on this measure¹³ are compared with Lesser's dating of cattle cycle indicator in table 2. Based on the particular decision rule, the dating of cattle

Table 2: Alterantive Dating of US Cattle Cycle Peaks and Through

Lesser		Markov Switching	
Peak	Through	Peak	Through
1949	1955	—	—
1958	1965	1957:4	1965:1
1967	1975	1967:3	1975:2
1979	1982	1978:4	1982:3
1989		1988:2	

cycles is remarkably similar to Lesser's.

Similarly, the same model is applied to analyze the hog cycle. The estimation results are in table 3. The likelihood ratio statistic on hog data in table 3 is about 30 which also implies strong rejection of no switching hypothesis. In state 0, the estimated mean indicates

¹³Although this measure is arbitrarily chosen to make up the liquidation dating closer to Lesser's, Hamilton noted that the criteria choosing the threshold is determined by the econometrician.

Table 3: Estimation of Markov Switching Specifications for Hog
Period of Estimation: 1966:1 to 1994:4 (Quarterly)

	Linear AR(4)		Markov Switching	
	Coefficient Estimate	Standard Error	Coefficient Estimate	Standard Error
θ_{0p}	—	—	2.09380	0.04192
θ_{0q}	—	—	1.85940	0.05383
ϕ_1	0.13551	0.08525	-0.00765	0.03911
ϕ_2	-0.26437	0.08293	-0.03364	0.04190
ϕ_3	-0.12374	0.08505	-0.02896	0.004117
ϕ_4	0.43346	0.08430	0.86720	0.04146
σ	3.85966	—	2.42714	0.18049
α_0	-0.12446	0.42356	-2.95146	1.22178
α_1	—	—	2.58969	1.20411
log likelihood	-330.47795		-300.53308	

a drop of hog breeding size in 3%. When the state 1 occurs, the size increases by about 2.6 % in a single quarter. The fact that three leading autoregressive coefficients are remarkably close to zero indicates the first- to third-order serial correlation in logarithmic changes of hog breeding herd can be captured by shifts between states. The significant coefficient at lag 4 suggests a possibility of a higher-order Markov process for the trend. P_{11} and P_{00} , are shown to be 0.89 and 0.86. The probability of remaining either state is about the same and persistent. In the same way, one can obtain the average durations of liquidation and expansion state, and are 9.1 and 7.42 quarters respectively.

The filtered probabilities of hog cycles staying in the liquidation state are plotted in figure 6. It is quite different from the results on changes of cattle reproductive herd. The probability of being in state 0 is close to 1 for most of the sample period before 1987. When the probability of being state 0 deviates from state 1, similar to the results on cattle data, it also happens in a small period of time. The switches, however, occur more often in the hog cycles. Because of shorter gestation periods (four months vs. nine months) and larger

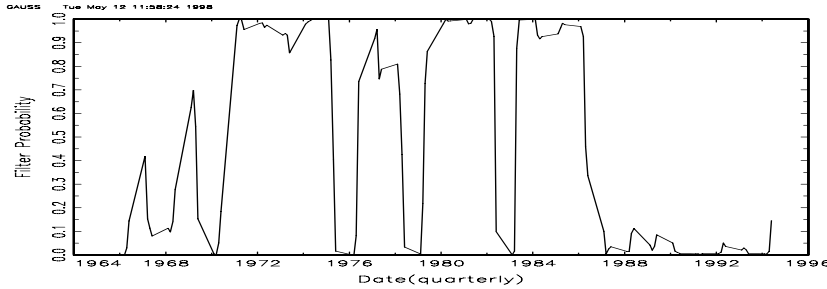


Figure 6: Probability of the Hog Liquidation State Based on the Markov Switching Model

little size, the buildup phase in a hog cycle is much more rapid than a cattle cycle. This may explain the major difference between figures 5 and 6.

4 Summary and Future Research

This paper uses the Hamilton regime-switching model to analyze the cycles of breeding herd in US cattle and hog industries. This approach is motivated by the evidence in Hamilton that the business cycle is characterized by recurrent shifts between a positive- and negative-growth state. Furthermore this method may provide an insight to examine an asymmetric property of cycles in livestock productions which to the best of knowledge has only been discussed and not rigorously tested.

The findings provide support for the view that the dynamics of livestock cycles can be captured better through a nonlinear model. In addition, the evidence suggests an asymmetric property in a livestock cycle. Estimates of the cattle cycle state cohere well with the cattle cycle indicator in Lesser and might be used as an alternative method for assigning cattle cycle dates. Distinguishing features of cycles in cattle and hog industries are found. That is, not only is the average durations of cycles different, the shape of a cycle is particular to each specific industry.

The results of this study suggest a new perspective on the nature of livestock cycles. A number of studies have extended the Markov switching model to consider models with ARCH or GARCH effects, time varying transition probabilities, multivariate regime-switching model, and the combination with dynamic factor models. Consequently, there are many directions for future research. Based upon preliminary model specification test results, models with ARCH or GARCH effects are a necessary extension of Markov switching model. Another promising avenue is to model regime shift with time-varying transition probabilities which incorporate the important structural changes, such as concentration of meat packing industries, changes in consumption behavior of meat demand, and so on. Finally, multivariate regime switching models will further improve understanding of the whole entire dynamic co-movements of livestock markets.

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