COMMODITY MARKET DYNAMICS

A SYSTEM ANALYSIS OF FUNDAMENTAL RELATIONSHIPS

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Introduction

The agricultural environment encompasses an important segment of production and distribution operations in the American economy. Many agriculturally related enterprises experience large fluctuations in their inventories, production activities, sales, capacity, and earnings. Cyclic, seasonal, and irregular patterns of behavior in such large-scale agricultural systems have persisted over the years.

The Problem

Hog market patterns of behavior have affected everyone concerned with the pork production-consumption system--hog producers, meat packers, distributors, and consumers. Cyclical market patterns with an average duration of 48 months and amplitude variations of from ± 25 per cent to ± 60 per cent characterize the long-term behavior. Large fluctuations in hog supplies create problems of resource allocation, capacity utilization, and product availability throughout the system. Hog producers' income can change radically from one year to the next. Meat packers must build inventories of frozen pork while hog prices are high and rising. Furthermore, consumers are usually forced to pay higher prices for a lower quality grade of pork products as distributors attempt to equalize supply and demand conditions.

The dynamic behavior of the pork system receives considerable thought and effort by many interested parties. Each seeks understanding of the institutional, technological, and behavioral complex in which the market system functions. The economist's goal is to understand market behavior with respect to price and quantity. He chooses to de-emphasize the broad range of decision-making processes in the pork system. Statistical regression studies meanwhile aim toward explaining the formulation of price and determining the events resulting from a change in market conditions. While many such studies have contributed to a higher level of market knowledge, they appear to have one shortcoming relative to broad understanding of the pork system. The studies do not penetrate into the systems' nature of the fundamental decision-making processes and the way in which these processes effectuate the pork system's dynamic behavior.

This paper illustrates, with an application to the United States hog market, the use of industrial dynamics for the analysis of decision-making processes in a large-scale system. The central focus of this study is to explain how the long-term, widely varying pork cycle is dependent on the organizational structures, operational policies and information flows within the pork system.

The system structure consists of (a) numerous independent hog producers who (b) sell to a substantially smaller number of meat packers who, in turn, (c) sell pork products to a relative few large distribution outlets. Various sources of information, including governmental, market, and private are used by the system participants in the breeding, shipping, inventory control, pricing, retailing, and consumption decisions. Knowledge about the nature of the fundamental decision-making processes and the way in which those processes bring about the cyclical pattern is needed to understand better the economic forces which influence price and quantities produced and consumed at various levels in the system. It is needed for improved policy formulation and decision-making by those people interested in the hog market's performance.

The Problem Approach

The philosophy and methods of industrial dynamics provide an effective systems analysis tool for studying large-scale systems.

> Industrial dynamics is the study of the information feedback characteristics of an industrial activity to show how organizational structure, amplification (in policies), and time delays (in decisions and actions) interact to influence the success of the enterprise.[1]

The first phase in any industrial dynamics study calls for the identification of the dynamic behavioral patterns which are symptomatic to the research problem. Data are gathered and studied and ideas are formulated as to how the various activities in the system might be related structurally to produce the patterns observed. Once the patterns have been analyzed, the second phase involves an in-depth study of the influential system activities. This phase demands that considerable effort be exerted in defining (a) the system boundaries, (b) the information feedback relationships in the system, (c) the important system variables and parameters, and (d) the couplings which associate the feedback relationships. This detailed information is used in the third phase to construct the research hypothesis of the structural mechanisms believed to be causing the behavior observed in the first phase. In the fourth phase the research hypothesis is translated into an industrial dynamics model. The resulting model is then tested using computer simulation to determine if the hypothesized model structure of the system produces the behavior of interest. Once the model produces the symptomatic behavior, simulation experiments are performed in the final phase to aid in developing the needed understanding of the real world system dynamics, and in creating new structures to improve system performance.

Specific Objectives of the Study

Related to the central problem of this study are a set of specific objectives which served as a guide in the research effort and the analysis of its results. Those specific objectives are:

1. To identify some of the controlling feedback structures and couplings (between feedback structures) which determine the pork system's cyclic behavior.
2. To illustrate the feedback structures and couplings in a quantitative model.
3. To demonstrate that the amplitudes, phasing, and periods of observable market variables arise from the hypothesized information feedback structure.
4. To show that the system's response is controlled by certain feedback structures.

Identification of System Characteristics

The pork system displays two types of time-history behavior in its major flows and accumulations. Oscillations occur at two frequencies in the monthly data of Figures 1 and 2. The low frequency variation has a period of approximately 48 months. Superimposed on this low frequency variation is the higher frequency variation with a period of approximately twelve months. Certain features of the time-history behavior are of particular interest in this study.[2]

Dynamic Behavior

The data in Figure 1 reveal that frozen and cured inventory holdings are small compared to monthly production and consumption activities. An average of ten to twelve days' supply of pork products comprises the normal safety stock. Since consumers demand fresh pork, the packers attempt to clear the market of available supplies leaving only a small carryover as frozen or cured products.

Cyclical price fluctuations do not occur with exactly the same 48 month period over the years of plotted data, and the price amplitudes of the recurring cycles are not identical. During the cyclic swing from December 1955 to December 1959, hog prices rose from 11.5 cents/pound for a time period of 29 months and then fell for 19 months back to 11.5 cents/pound. During the previous hog cycle, prices rose and fell over a period of only 45 months. This 45 month cycle ended at a price below its beginning value in March 1952. The price cycle from December 1959 to November 1963 experienced only a small change in amplitude. Conversely, the subsequent cycle—December 1963 to December 1967—experienced a significant price variation over its 48 months period of fluctuation.

The time-history behavior in Figure 2 reveals certain interesting hog production characteristics. Hog slaughter tends to fluctuate over a period of years regardless of outside factors. As was noted in the previous section, price cycles are not exactly regular in amplitude or in their period of oscillation. Extraordinary conditions such as a sharp reduction in feed supplies may extend a contraction or stifle an expansion in the number of hogs that are in production.

Hog production activities show a marked tendency to follow changes in the level of hog prices. After a short delay for the producer to react to an average price level, the producer will begin to alter the number of sows bred. For example, this activity can be traced starting in 1960 after the price has passed from above an equilibrium value, where it had been for approximately two years, to below an equilibrium value. Correspondingly, several months later the number of sow farrowings turn downward. That downturn is again reflected in the reduction of hog slaughter activity. Furthermore, the buildup and liquidation of breeding herds alters the flow of market supplies. Herd capacity changes occur with the greatest impact during those times when prices have been rising or falling at the greatest rate. During such times the holding of gilts or shipping of sows reenforces the rate of change in price. Although no data are available on gilts retained for herd build-up or for sow replacement, the available data on sow slaughter indicate that producers tend to reduce their herds after prices begin the cyclic decline.

Feedback Model

A feedback structure (model) was developed which reproduced the characteristic behavior of interest. The model consisted of various loop configurations, parameters, and couplings which were relevant to the symptomatic behavior. Numerous model structures had to be examined before arriving at the end product shown in Figure 3.

The following sequence of events describes how the feedback system functions. The meat packing industry experiences an increase in the pork input rate (hogs are shipped at heavier weights), and the packers are placed under heavy pressure to clear the added pork from their inventory. As such, the meat packers attempt to increase the sales to their regular retail customers (Loop B). As the retailers observe a new level of pork supplies on the market, they begin to adjust their normal purchase orders. The retailers' inventories grow and promotional pork sales are offered to pork consumers. Then, in turn the consumers adjust their normal purchases of pork to the increased available supplies offered for sale by the retail outlets (Loop G). In Loop E retailers attempt to maintain a desired inventory level. Since the retailers do not respond immediately to increased availability, the packers' inventories grow. That growth creates a change in the value which the packers place on future hog receipts (Loop C).

The value of pork changes as a result of the net difference between forecasted pork receipts and average retail demand. Value increases when pork sales increase or when the forecast decreases and vice-versa. Since the meat packers maintain a poor bargaining position relative to the retailers, the packers must act to reduce their live hog costs and thus lower prices are bid for live hogs. Attempts are made to increase sales to retail outlets, get packer sales are largely unaffected by sales pressures from the meat packers.

Increased consumer buying is reflected to the retail industry through the coupling Loop F. Retailers respond to a growing consumer demand by increasing their normal orders to the meat packers.

If the increase in the pork input rate sustains itself, the meat packers will change their forecasted pork production (Loop A). Based on the amount of pork expected and the level of pork in inventory, the meat packers formulate their expected pork availability. Using expected pork availability in conjunction with the average retail sales, the packers determine the bidding strength for live hogs (Loop C). An increase in the forecast without a corresponding increase in average sales reduces the value of pork supplies; consequently, lower prices are offered for live hogs. As the level of sales increase through the retailers' and consumers' adjustments, pork supplies again become valuable and the packers bid up the prices of hogs.

Hog producers watch the prices being paid for their livestock (Loop K and I). Accordingly, producers alter their past rate of hog production and the time taken for feeding hogs to market weight (Loops J, L, M). A declining price level induces a reduction in the hog production rate (Loop L and M). Correspondingly, price declines cause cutbacks on the available sow breeding capacity (Loop P and S). Capacity reductions flow to the meat packer and add to the packers' pork supplies. As prices fall, producers tend to feed their hogs to a lighter finish weight (Loop J).

Producers rapidly adjust their hog production rate and sow capacity availability, and at times the available sow capacity may limit the desired hog start rate (Loop Q). Loop O monitors the pig production intentions.

Movement continues in the major system variables, and the meat packers' assessed value of pork supplies turns upward. Although the meat packers reach an equilibrium condition in their environment, the other system participants continue to adjust their activities toward equilibrium positions. The system is carried beyond an equilibrium condition by corrections previously made in the system.

The primary overadjustment occurs in the production sector as the producers over-respond to a falling price.

Once the production cutbacks are felt in the market, the pork values increase in the meat packers' operations. Again, the system attempts to correct these circumstances by adjusting the bidding strength for live hogs. The cycle soon reverses itself as the system participants attempt to maintain stable operations.

The entire system reacts to the forces generated from the observation of environmental conditions. For the consumers, the available supply of pork in relation to their normal purchase creates buying adjustments. For the retailers, the pork being offered for sale relative to their normal orders brings forth ordering corrections. For the producers, new price levels give rise to production changes. For the meat packers, forecasted pork receipts relative to their past sales create pork value.

Quantitative Model

The feedback model of Figure 3 was transformed into a system of first order difference equations using the DYNAMO simulation language.[3] Nonlinearity and complexity of the system of equations necessitated model synthesis and experimentation based on computer simulation. The system of equations was solved sequentially over time and the resulting system behavior compared to the actual behavior of interest.

Model Analysis

The simulation experiments selected for the model analysis provide (1) a demonstration that the feedback model generates the desired modes of behavior in a logical and consistent manner and (2) an assessment of each loop's importance in controlling the system's response. Through these experiments insight into the system's cyclic movement and the interrelationships within the system network is developed. A ten per cent step input to the meat packers' operations is used as the basic model test function. The input creates excessive pork supplies and forces the various model sectors to adjust their activities to new system states. Model variables are sequentially calculated every one-tenth of a month and plotted as a function of monthly elapsed time from initial model conditions.

Construct and Response Validity for the Basic Model

With a step input the model generates the pork system's behavior via the structure of the information feedback loops identified in Figure 3. Within the feedback structures, decision-making processes convert information about certain system conditions into sector activities--production, meat packing, retailing and consumption. These activities are governed by policy statements which approximate the dominant response relationships of numerous decision makers. The model's feedback structures were developed using actual system delay times, policy statements, and market structures which exist within the system. System variables were selected and interconnected based on actual system operations.

The model's response to the step input test function provided a test of response validity. The model should ideally generate time patterns of behavior similar to the actual system. The time patterns of behavior shown in Figures 4, 5 and 6 result from a ten per cent input applied to the basic model (Figure 3). Certain behavioral characteristics in the model's performance patterns are pertinent features of response validity. First, long-term cycles in the major variables occur with the following amplitude ranges:

	Basic Model Performance Range	Average Cyclical Range in the Data
Pork Production (lbs/month)x10^9	8.550- 11.45	7.850- 11.40
Pork Consumption (lbs/month)x10^9	8.500- 11.40	7.800- 11.00
Hog Price (cents/lb)	11.500-20.000	12.000-26.000
Frozen and Cured Inventory (lbs)x10^5	1.800- 3.200	1.800- 3.500
Hog Slaughter (hog/month)x10^6	5.588- 7.126	4.450- 6.850

As appears to be true in the actual system, the basic model generates production fluctuations which are larger than the consumption fluctuations. Furthermore, production and consumption fluctuations are noisier than frozen and cured inventory fluctuations, as observed in the actual system. The model behavior displays no tendency to attenuate the fluctuating behavior and hence sustained oscillations result.

Secondly, the model variables oscillate with a period characteristic like that of the actual time history patterns. Periods of approximately 48 months exist in the fluctuations of the pork system. Examination of the patterns in Figures 4, 5 and 6 reveals that periods of 52, 48, 49, and 49 months occur over the simulated time horizon. The 48 month interval separating the peaks of the model variables indicates approximately the natural period of the pork system.

Thirdly, the phasing relationships in the basic model's performance patterns are like those of the actual pork system data in Figures 1 and 2. Examination of Figures 4, 5, and 6 shows that the peaks and valleys of production and consumption occur at approximately the same time. Inventory peaks and valleys occur approximately at the crossover points of production and consumption. Hog producers are increasing production at the fastest rate when prices are at a peak, and sow capacity is at its peak when hog prices are decreasing at their fastest rate. Furthermore, sow farrowings lead hog shipping by the variable delay time needed for raising pigs to market weight.

General Behavior. Closer examination of the model behavior provides insight into the pork system's oscillatory nature. The oscillations result from the over and under corrections continually made by the system participants. Referring to Figure 4, 5 and 6 a description of the forces creating the behavior is presented below.

Time 12 to Time 24. Increased pork supplies, brought about by the step input in time 12, immediately sends the system into its characteristic modes of behavior. The packers' expected pork availability and the desired packer pork sales rise due to the increased inventory of frozen and cured pork. Under the pressures of forecasted increases in pork supplies and larger inventory holdings, the packers' value assessment goes down, thereby lowering bid prices. Soon after hog prices decline, producers market hogs faster and decrease hog production. The hog shipping rate amplified the original effects of the step disturbance.

Even though prices continue to decline over a twelve-month period (Time 12 to Time 24), hog production rate reverses its downward movement at time 18. The reversal occurs as two conditions arise. First, the producer attempts to maintain production levels near previous production operations; consequently, rising hog shipments (due to the shorter feeding delay) create a short-termed increasing production order rate. Secondly, increased production operations lose desirability because of lower price expectations. The producers' cutbacks do not change proportionally with the average price level.[4] As the average price level drops, the slope of the percentage change relationship becomes less steep and eventually becomes zero. Consequently, even though price expectations might indicate a reduction in hog operations, the combined effects of maintaining past production levels and reducing production only up to a maximum percentage cause the production rate to turn upward. In effect, a nonlinearity in Loop K of Figure 3 forces the loop dominance to shift from the Mature Hog Inventory Loop (Loop M) to the Shipping Production Loop (Loop L).

During the production cutbacks, capacity adjustments are made on the available breeding levels. Figure 4 illustrates sow shipments rising and sow capacity declining as the producers bred fewer sows.

Time 24 to Time 48. At time 24, the packers' assessment policy dictates higher pork values; hence, hog prices reverse their downward swing. An upward movement of price continues until time 35. At that point, the packers are receiving the hog supplies started in production approximately ten months earlier. Until those supplies can be moved to the consumers, hog prices will reflect the decreased value of additional pork supplies. The upward price movement continues again at time 39 as the sharp drop in hog slaughtering reduces expected pork availability.

Consumer demand for pork products follows the availability of retail supplies. Frozen and cured inventory absorbs the difference between the packers' production activities and the retailers' orders.

Starting at time 41 (relative to the original equilibrium conditions) the producers switch from an overall activity of production cutback to production buildup. A rising price level indicates higher prices to the producers and production operations become expansion oriented. Sow shipping drops to the old-age replacement level and sow capacity conditions indicate gilt retentions.

Time 48 to Time 74. At time 48, hog prices reach a peak value. System conditions indicate increased expected availability due to the sharply rising hog slaughterings at the packers' operations. The hog production rate continues to increase as the average level of hog prices indicates positive production corrections to the past production activity. Correspondingly, sow shipments remain at the normal replacement level.

Production expansion continues until the average hog price level crosses below the equilibrium value (Time 67). Prices keep falling, however, because the packers are receiving hogs from the expansion activity approximately eleven months earlier. Falling hog prices cause the producers to ship faster and amplification occurs in the price movement.

At time 74, the cyclic movement completes itself and similar system conditions exist in the model as it did at time 12.

General Behavior with Noise. Additional insight into the system's characteristics can be obtained by applying noise to the pork input rate. Random noise disturbances contain a broad range of component frequencies. If the system selects certain periodicities to amplify, then the system is said to have a natural period. In Figure 7 model behavior with noise shows the 48-month natural period in the pork system. Throughout the model run, random noise causes the system variables to fluctuate around the initial equilibrium values. Furthermore, because the forecasting process has been made less accurate, the system variables oscillate at greater magnitudes than in the error free behavior of Figures 4, 5, and 6.

Controlling Features of the Model

The feedback model shown in Figure 3 had numerous loops and parameters which were tested for sensitivity. Throughout the model synthesis process certain model features were found to be relatively unimportant in controlling system behavior. Some features, however, were found to be critical to the system performance.

Simulation experiments were made in accordance with the following procedure:

a. For a feedback control loop:
   (1) Examine the effects of a change in a flow path delay time.
   (2) Examine the effects of a change in the adjustment time or the nonlinear decision component within the loop.
   (3) Examine the effects when the control is made inoperative.
b. For a coupling delay:
   (1) Examine the effects of a change in the information smoothing constant within the loop.

The simulation runs obtained from the research experiments were evaluated to find those parameters and loops which have the most dramatic effect on system behavior. By contrasting the individual runs with the basic model behavior of Figures 4, 5, and 6 the system effects could be assessed. The details of the various simulation experiments are too numerous to include in this paper; however the results will be presented in the following section.[5]

Conclusions and Recommendations

The conclusions reached as a result of this investigation are broad in scope since the decision processes under study represent aggregate activities of numerous participants. Nevertheless, the broad conclusions and recommendations are germane to the level of study.

The overall objective of this study was to explain how the long-term dynamics are created in the pork system. To fulfill that objective a feedback structure has been synthesized, tested, and analyzed. The tests and analyses show that the structure has both construct validity and response amplitude and phasing validity. Thus, it can be concluded that relative to the purpose and objectives of this study, the model structure is representative of the actual pork system.

Specific Conclusion

1. The pork system gives rise to its own unstable behavior. A disturbance in pork receipts at the meat packers' level creates the undamped behavioral patterns observed in actual data of the pork system.
2. The activities of the meat packers and hog producers are the primary determinants of system bevaior. Loop analysis in the producers' sector indicated both short and long-term effect of producer responsiveness. In the short run price changes alter hog feeding delays, and hog price changes are subsequently amplified by abnormal hog slaughtering. In the long run producers over-respond to hog price changes. The over-response is manifested through future hog marketing being greater or less than needed to maintain equilibrium price conditions. Loop analysis in the hog inventory control loop (Loop M) indicated the sensitive nature of the producer adjustment time and the information link from hog inventory. Long adjustment times create a more stable production-price relationship and, conversely, short adjustment times produce more system instability. Furthermore, the cycle's period was found to be sensitive to the inventory adjustment values. The controlling aspects of the hog inventory information link was found to be important in constraining the unstable tendencies of the producers. Loop analysis in the meat packers' sector indicated that the value assessment loop (Loop C) was sensitive to parameter changes. Loop analysis also indicated system sensitivity when the inventory control information link was cut and more stable behavior was produced.
3. Amplitude characteristics of the model's behavior were found to be sensitive to the meat packers' adjustment parameter, and to the hog producers' adjustment parameter.
4. The model analysis demonstrated that in the pork system consumer response, retailer inventory control and ordering, and producer capacity adjustments had little influence on the cyclical patterns.
5. Loop interaction between the meat packers' sector and producers' sector depends upon the value assigned to the coupling delay parameter. Shortening the delay coupled the packers' sector and producers' sector more tightly and vice versa. Tighter coupling led to greater instability and responsiveness, whereas looser coupling led to a more stable but less responsive system. The cycle's period was found to be sensitive to this coupling delay.
6. Forecasting error in the meat packers' sector causes instability and sustained oscillations in the model behavior. The inability to forecast accurately drove the system variables to larger amplitudes of fluctuation; nevertheless, the basic frequency characteristics of the system were present.

Recommendations

Several recommendations for further research and analysis can be made relative to the feedback model, system parameters, and loop analysis. For example, seasonal production habits could be used as a forcing function and shorter-term characteristics could be studied. Additional time could be spent collecting information on the activities of the retail sector. The retail sector will probably grow more dominant as the producers and meat packers become more responsive to the retailers' pressures and incentives. Substantial work could be undertaken in the area of producer price expectations. Past hog prices are the factors considered in this research; however, other factors such as feeding costs and alternative profit opportunities may be important.

Recommendations can also be made relative to implementing the research results. Given the desire to diminish the variability in pork supplies, new policies for system control must be developed. The new policies can be constructed upon the base of systems understanding which has been developed in this research. Improvement criteria will have to be defined and translated into behavioral characteristics. Then new system behavior produced by changes in the model structure or parameters can be evaluated. Some form of vertical integration may be the means by which pork supplied will flow in a more steady stream throughout the system.

Given the desire to study in greater depth the hog pricing mechanism, additional analysis must be made in the meat packers' sector. Analysis in the meat packers' sector should focus on the value assessment policy and forecasting procedure. For example, the packers' desired inventory carryover was formulated to be a constant value; however, a seasonally varying end-of-month carryover may be more representative of the actual operations. Substantial work could be done in determining the accuracy of the packers' hog receipts forecast. The systems effect of an inaccurate forecast was demonstrated in this research to be a destabilizing influence. Substantial work could be undertaken in developing a decision rule for predicting the timing and resulting magnitude of a future turn in hog prices. An understanding of the causal mechanisms of the meat packers' sector should serve as a basis for determining the information components needed in the decision rule. The information components to be included must be ones on which current available data is published. A valid decision rule would be beneficial for planning inventories in the meat packing and retailing sectors, or for developing hedging and speculative positions in the futures market.

Footnotes

[1]Jay W. Forrester, Industrial Dynamics, The M.I.T. Press, Cambridge, Mass., 1961, p. 13.

[2]Data was gathered from the United States Department of Agricultural Reports.

[3]Alexander L. Pugh IV, DYNAMO Users' Manual, The M.I.T. Press, Cambridge, Mass., 1963.

[4]Percentage changes indicating an expansion or contraction in the past hog production rate are modeled using a nonlinear dependency on average hog prices.

[5]Robert D. Landel, Commodity Market Dynamics - A Systems Analysis of Fundamental Relationships, Ph.D. Dissertation, Georgia Institute of Rechnology, 1970.

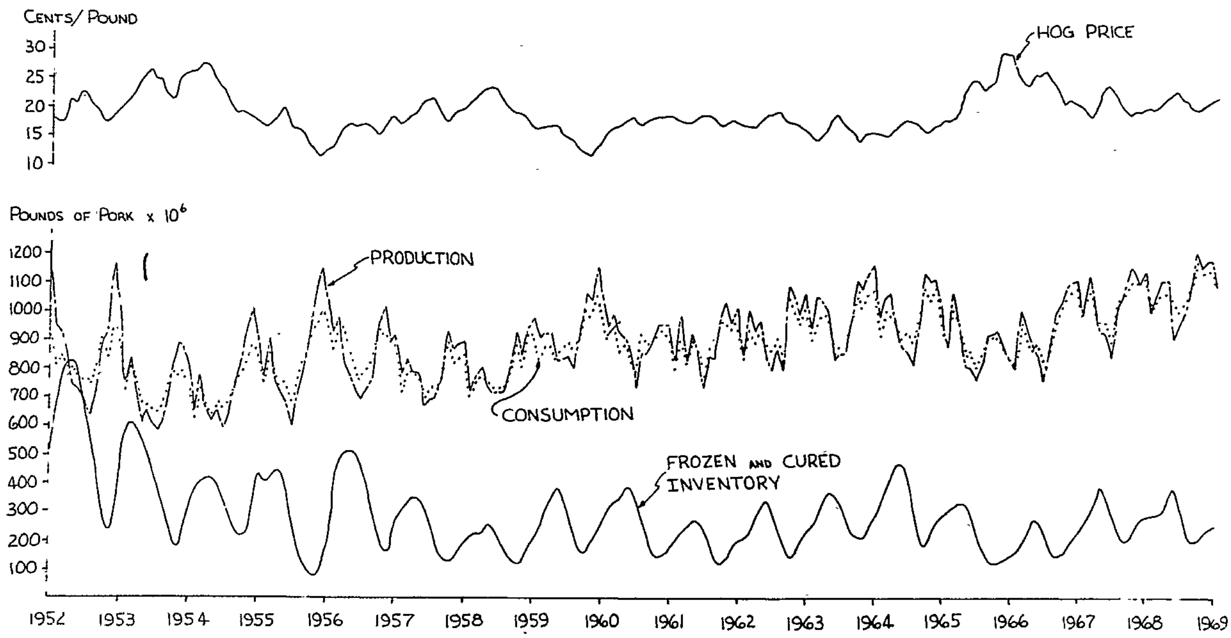

Figure 1. Pork Distribution Data

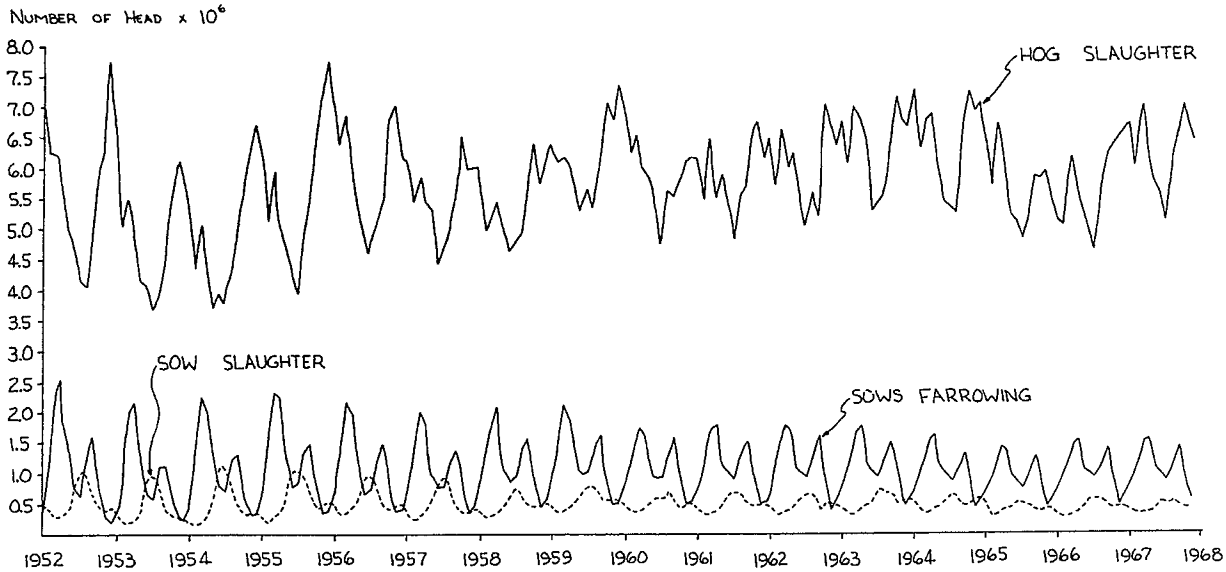

Figure 2. Hog Production Data

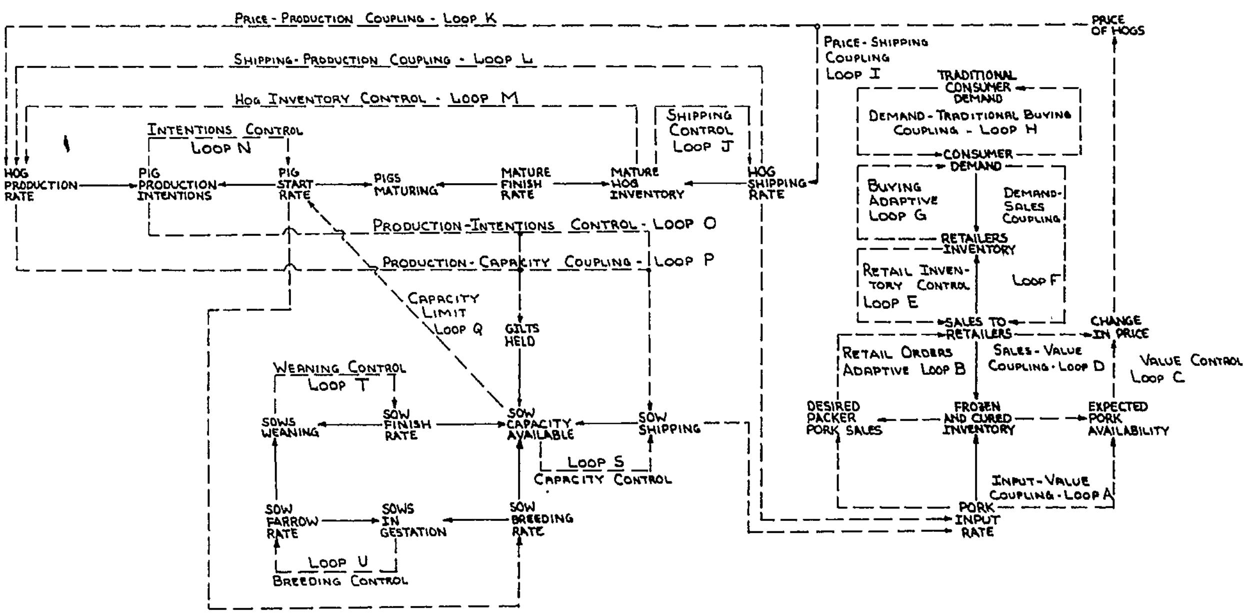

Figure 3. Hypothesized System of Feedback Relationships

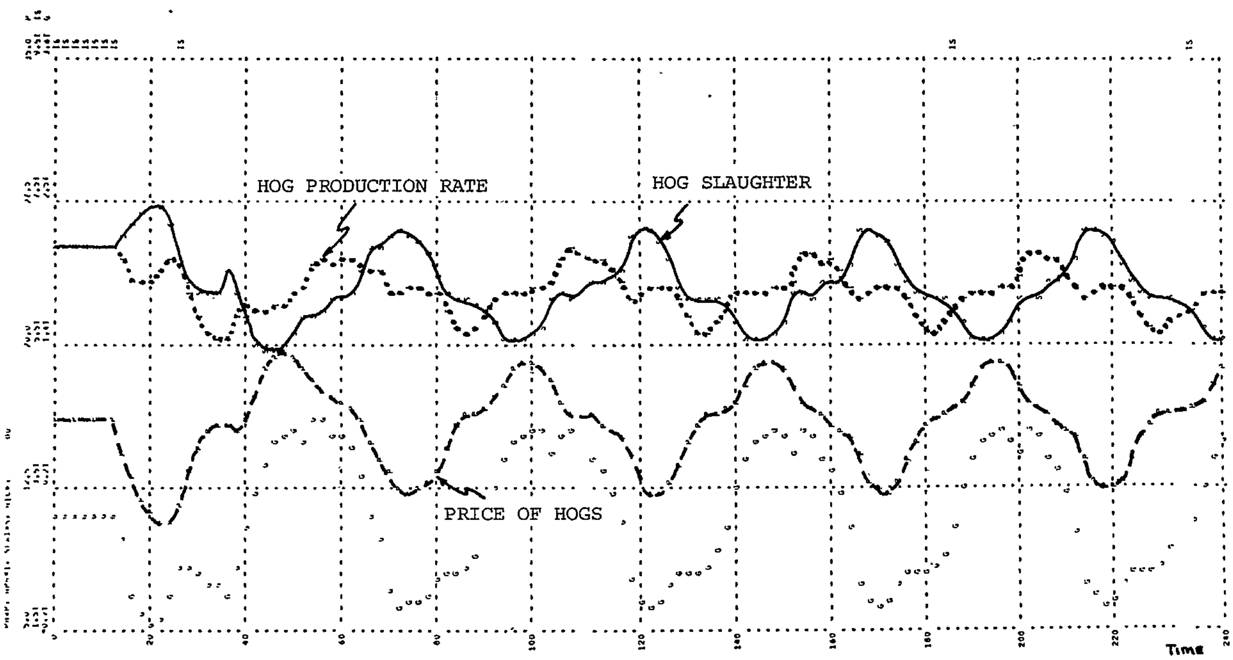

Figure 4. Basic Model, 10% Step Input, Hog Production Variables

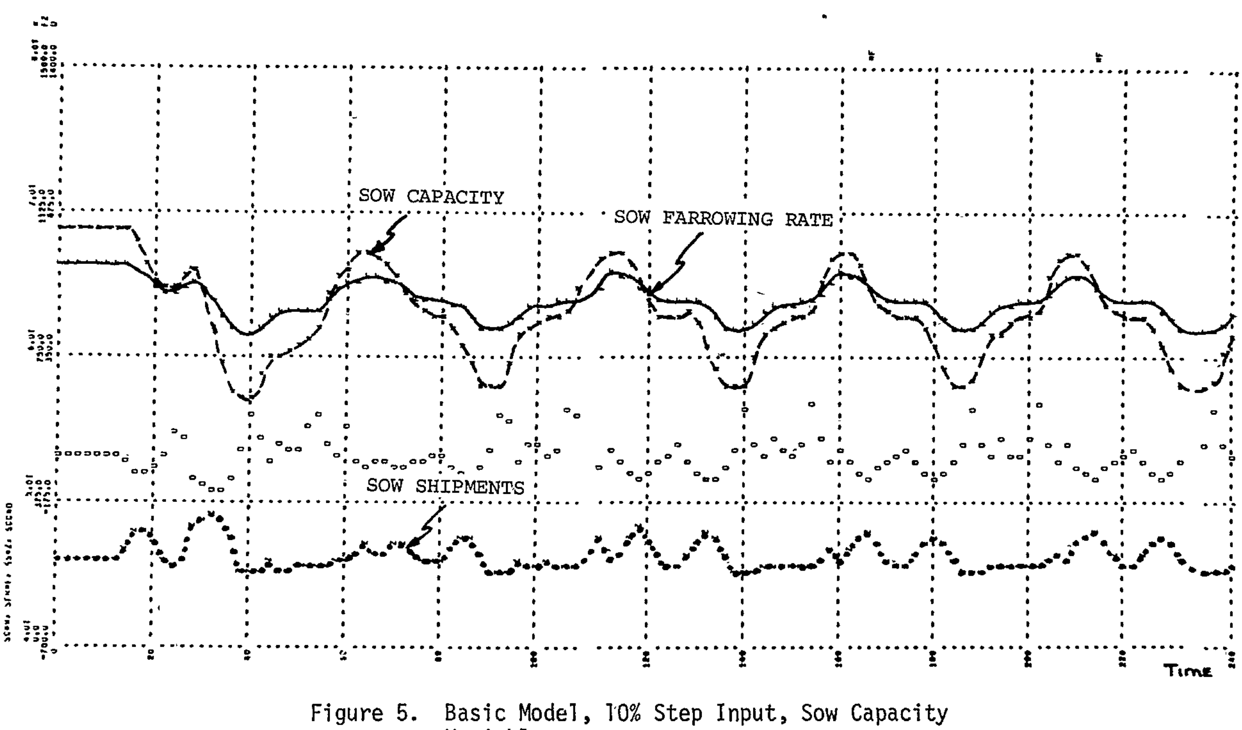

Figure 5. Basic Model, 10% Step Input, Sow Capacity Variables

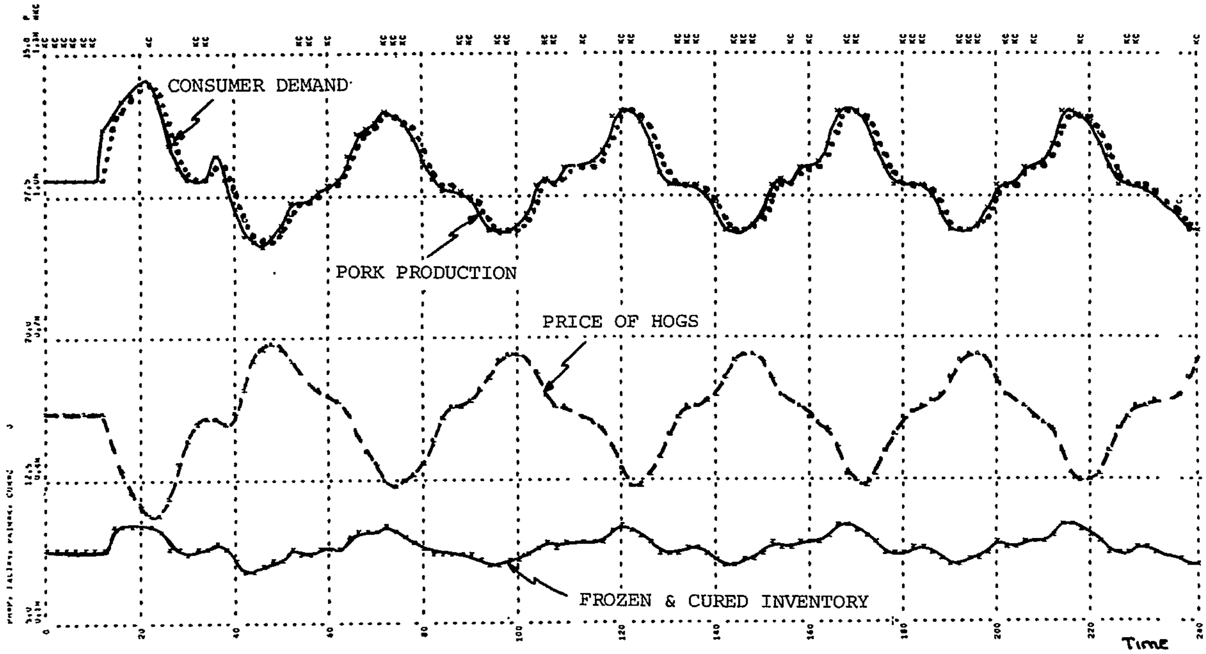

Figure 6. Basic Model, 10% Step Input, Pork Distribution Variables

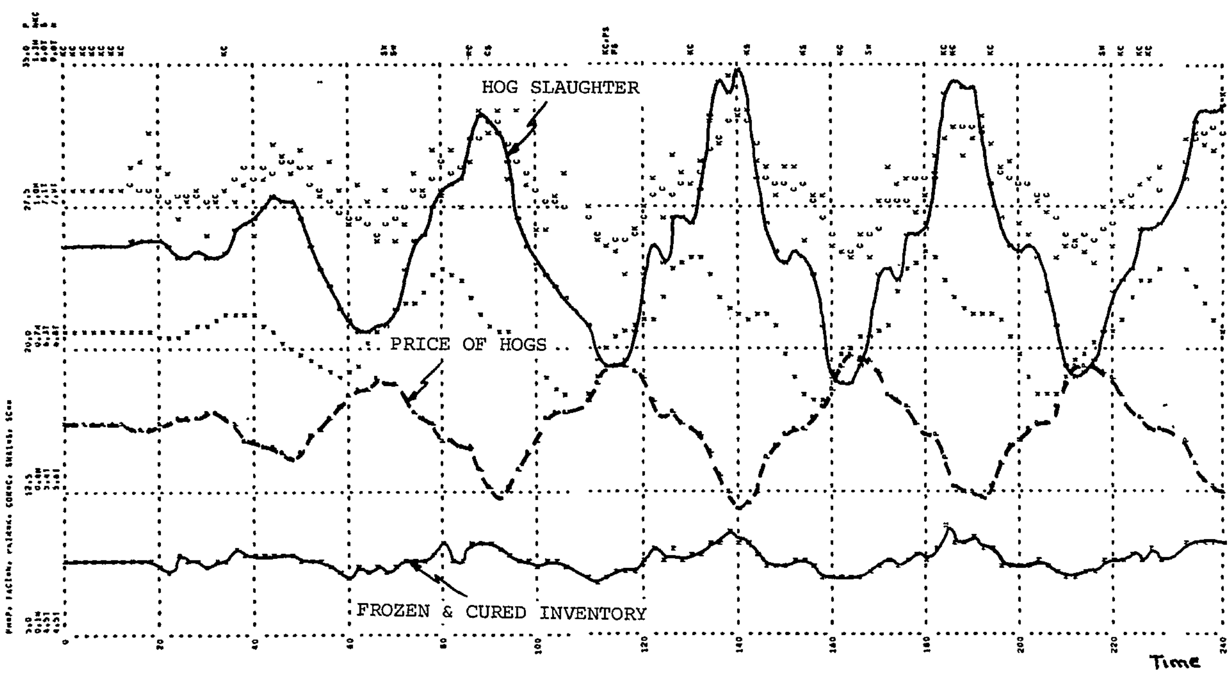

Figure 7. Basic Model, Noise in Hog Weight Parameter