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COMMODITY MARKET DYNAMICS

A SYSTEMS ANALYSIS OF FUNDAMENTAL RELATIONSHIPS

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COMMODITY MARKET DYNAMICS

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TABLE OF CONTENTS

LIST OF TABLES

Table | Page

LIST OF FIGURES

Figure | Page

SUMMARY

An investigation into the dynamic nature of the pork production-consumption system has been undertaken. The purpose of this investigation was to provide insight into how the long-term pork system dynamics are dependent on the information feedback structures which control the system's important flows and accumulations. This knowledge is needed to understand better the fundamental relationships and interactions among production, storage, processing, distribution, consumption, and pricing activities within the pork market.

Cyclical patterns with an average duration of 48 months and amplitude variations of from ± 25% to ± 60% characterize the long term behavior of the pork system. Large variations in hog supplies and prices create problems such as resource allocation for the producer, plant utilization for the meat packer, product availability for the retailer, and proper pricing of pork products for the consumer.

The study examined the way in which important pork system variables change and interact, and thereby create the cyclical patterns. An industrial dynamics model was developed and used to demonstrate which control loops and coupling loops were critical to the pork system's performance. Model variables reacted to imbalances in system conditions, and tended to amplify the step disturbance and

to create unstable behavior. Variations in the receipt of pork supplies were amplified by the meat packers through their delayed responses to a new input rate of pork supplies and their inventory control policy. Amplification in the producers' operations occurred because of the variable feeding delay and an over-responsive production policy.

Relative to the purpose and objectives of the investigation, the feedback model was determined to be representative of the actual pork system structure. Drawing upon the model analysis, several specific conclusions were evident and recommendations for further study were suggested. The pork system gave rise to its own unstable behavior and the closed loops involving the meat packers and hog producers were found to be the primary determinants of the behavior. The model was used to demonstrate that in the pork system consumer responses, retailer inventory control and ordering, and producer capacity adjustments have little influence on the cyclical patterns. However, the cycle's period is sensitive to the coupling delay which connects hog prices to the producers' production response. Similarly the period is sensitive to the producers' hog inventory adjustment time. Amplitude characteristics of the model's behavior are sensitive to the meat packers' price adjustment parameter, and the producers' hog inventory adjustment parameter.

Recommendations were offered for further research into the short-term effects of seasonal breeding considerations, the impact of a more dominant, quality and price conscious retailing sector, and the inclusion of feeding costs and alternative profit opportunities of the producers. So far as implementing the research results, recommendations were made for some type of vertical integration in order to reduce supply variability in the flow of pork supplies. In addition, recommendations concerning the study of hog prices were made for further analysis of the value assessment policy and forecasting procedure in the meat packing industry.

CHAPTER I

INTRODUCTION

The agricultural environment encompasses an important segment of production and distribution enterprises 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 have persisted over the years.

Research Problem and Objectives

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 $\pm$ 25% to $\pm$ 60% characterize the long-term behavior. The large fluctuations in hog supplies create problems of resource allocation, capacity utilization, and product availability throughout the system. Hog producers' income can be changed 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 unstable 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 pork 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 causal events resulting from a change in price. While many such studies have contributed to a higher level of market knowledge, they appear to have one shortcoming relative to a broad understanding of the pork system. The studies do not penetrate into the nature of the decision-making processes and the way in which these processes effectuate the pork system's dynamic behavior.

This problem central to this research 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 buying decisions. Knowledge about the nature of the 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.

Related to the research problem are a set of specific objectives which will serve 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 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 information feedback structure.

4. To show that the system's response is controlled by certain feedback structures.

Research Approach

The complex environment of the pork production-consumption system can be viewed in terms of control system operations. An agricultural market operates as an information decision-making system. Within a given system accumulations such as capacity, inventories, and earnings have variations which affect the market's stability. System control is accomplished through the information feedback loop. The loop provides a decision-maker with information about the state of an accumulation he wishes to control. The decision-maker interprets this information and determines a decision which alters the flows into and/or out of the accumulation. It is hoped that the action resulting from these decisions will eventually produce the desired changes in the accumulation.

In this feedback systems approach the methods of Industrial Dynamics will be used. An hypothesized structure of the information feedback relationships which control the important accumulations and flows relative to long-term dynamics will be developed. The structure will be transformed into a quantitative model for empirical testing. Because of the complexity of the pork system, digital computer simulation will be used to generate and record model behavior. Simulation experiments with the mathematical model will aid in developing the needed understanding of the real world system dynamics.

Numerous simplifying assumptions relative to the pork production-consumption system will not be required to accomplish the objectives of this research. Rather the research will include an hypothesis and model formulation which corresponds closely to the real world environment. Realism is to be stressed throughout the research effort.

This study will not be directed toward an all inclusive model formulation which accounts for each variable and interaction existing in the actual system. The proper identification and isolation of the feedback structures causing the behavioral patterns will be necessary for the successful accomplishment of the stated purpose and objectives. Therefore, considerable effort will be exerted in defining: (a) the system boundaries (b) the information feedback relationships in the system (c) the important system variables within the feedback structures and (d) the couplings which associate the feedback structures. From this information the research hypotheses of the mechanisms producing the long term hog price movement will be developed and tested.

CHAPTER II

LITERATURE SURVEY

Hog market activities pose fascinating economic questions. A review of the scholarly literature reveals that various statistical approaches have been employed in numerous hog market studies. These studies set out to establish numerical estimates of fundamental market relationships with the aim of forecasting future events. There are two types of studies; short-term studies and long-term studies. Short-term forecasts are typically based on a single equation model. In the model, one assumes that a variable, such as price or quantity, can be predicted with several known independent variables. Long-term studies typically require the simultaneous consideration of many interrelated variables.

Economists and agricultural specialists have studied the hog industry for nearly one hundred years. In 1876 Benner pointed out the regularly recurring hog price cycles (1). Warren, in 1914, demonstrated the tendency for regularity in the hog production cycle (2). Furthermore, Warren emphasized the relationship between abnormal corn crops and subsequent hog price movement.

Wallace was the first researcher to apply precise statistical methods to hog market analysis (3). Wallace stressed the relationship between corn prices and future hog prices, and he performed multiple correlation studies on the relationship between hog supply and hog prices.

Warren and Pearson demonstrated that hog production follows changes in the hog-corn ratio (4). They state that the ratio was probably the dominant element in creating price changes.

Drawing on the techniques of multiple regression analysis, Haas and Ezekiel found the dominant influences in the hog market to be the supply of hogs, quantity of pork products in storage, general price level, general business conditions, and the prices of alternative meat products (5).

The study by Harlow in 1959 discussed the principal economic forces affecting the hog industry and quantified those forces into a statistical model (6). Harlow stated that the model produced good results for predicting changes in the direction of the dependent variables in the four quarters immediately following the period of fit in 1960; however, the model performed poorly in the succeeding four quarters of 1961.

In 1967, Meyers and Havlicek focused their attention on the development of theoretical notions for analyzing monthly aggregate supply response of live hogs for slaughter (7). They synthesized a total supply function which included producer price expectations, but no empirical test was made on this function.

Many of these studies have been instrumental in discovering key market relationships. In general, the econometric studies were limited to simple linear supply and demand relationships among a few variables. However, many important relationships are not linear, and significant interactions influence the activities within the pork system.

The nonlinear, interacting segments can be studied via systems analysis. Systems analysis can offer convincing evidence of the true cause and effect relationships in the pork system. Such evidence should contribute to a better understanding of the basic forces interacting in the market.

In this thesis research emphasis is placed upon determining the types of processes within the pork system. This emphasis is contrary to the statistician's interest in ascertaining the correct parameter values for specified system processes. The process itself is of interest in this thesis because processes determine the nature of the decision mechanisms, and the decision mechanisms control the pork system's performance. Moreover for the properly defined and modeled system, a wide range of parameter values can be used in the system processes without altering the basic behavioral characteristics.

Larson developed a simple model for studying the production cycle in the hog industry (8). Criticizing the theoretical approach of The Cobweb Theorem, he modeled the production decision in terms of the percentage by which production activity should change and not the absolute level of production as suggested by the cobweb model. After applying a sophisticated seasonal and trend removal technique he fitted cosine curves to monthly data and postulated three linear differential equations as a production model of the hog industry. The harmonic oscillations of the actual data are generated by the model's solution set. His model includes the concept developed by Lorie in 1947 (9) - that the period of cyclic movement is four times the fixed production lag.

In a recent article, "The Quiddity of the Cobweb Theorem", Larson offered additional criticism of the cobweb model (10). He asserted that because economists have been unwilling to dispense with the supply curve concept, the cobweb model stands as a rigid theoretical model of cyclic behavior. However, he states that "the result has been that the theoretical construct of the cobweb theorem has done as much to mislead empirical research workers as it has done to direct them to a true understanding of the phenomena under study." (11, p. 171)

Frequently, one has the impression that a system approach will necessarily involve all of the systems variables and relationships. However, successful research in any complex system requires a reduction of the complexity to a manageable portion. This study accomplishes this reduction by selecting only those variables and feedback relationships which give some indication of creating the market's symptomatic behavior. In this way a large confusing structure is avoided.

CHAPTER III

DESCRIPTION OF THE PORK SYSTEM

This chapter describes the dynamic behavior and structure of the pork production-consumption system.

Behavior

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 12 months. Certain features of the time history behavior are of particular interest in this study. These features are presented in the following sections.

Pork Processing, Distribution and Consumption

The data in Figure 1 reveals that frozen and cured inventory holdings are small compared to monthly production and consumption activities. An average of 10-12 days' supply of pork products comprises the normal safety stock. Since the consumers demand fresh pork, the packers attempt to clear the market of available supplies,

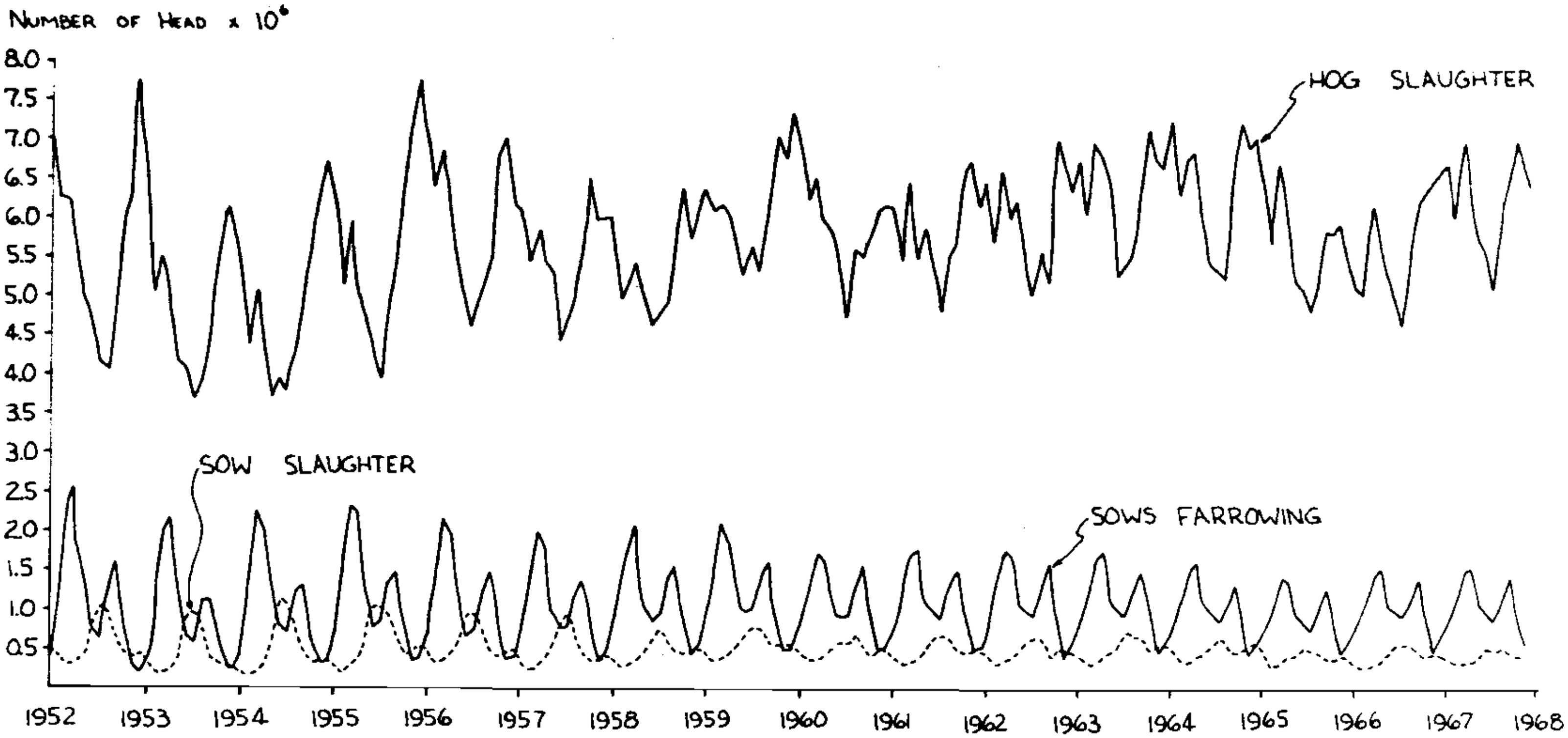

Figure 1. Pork Distribution Data

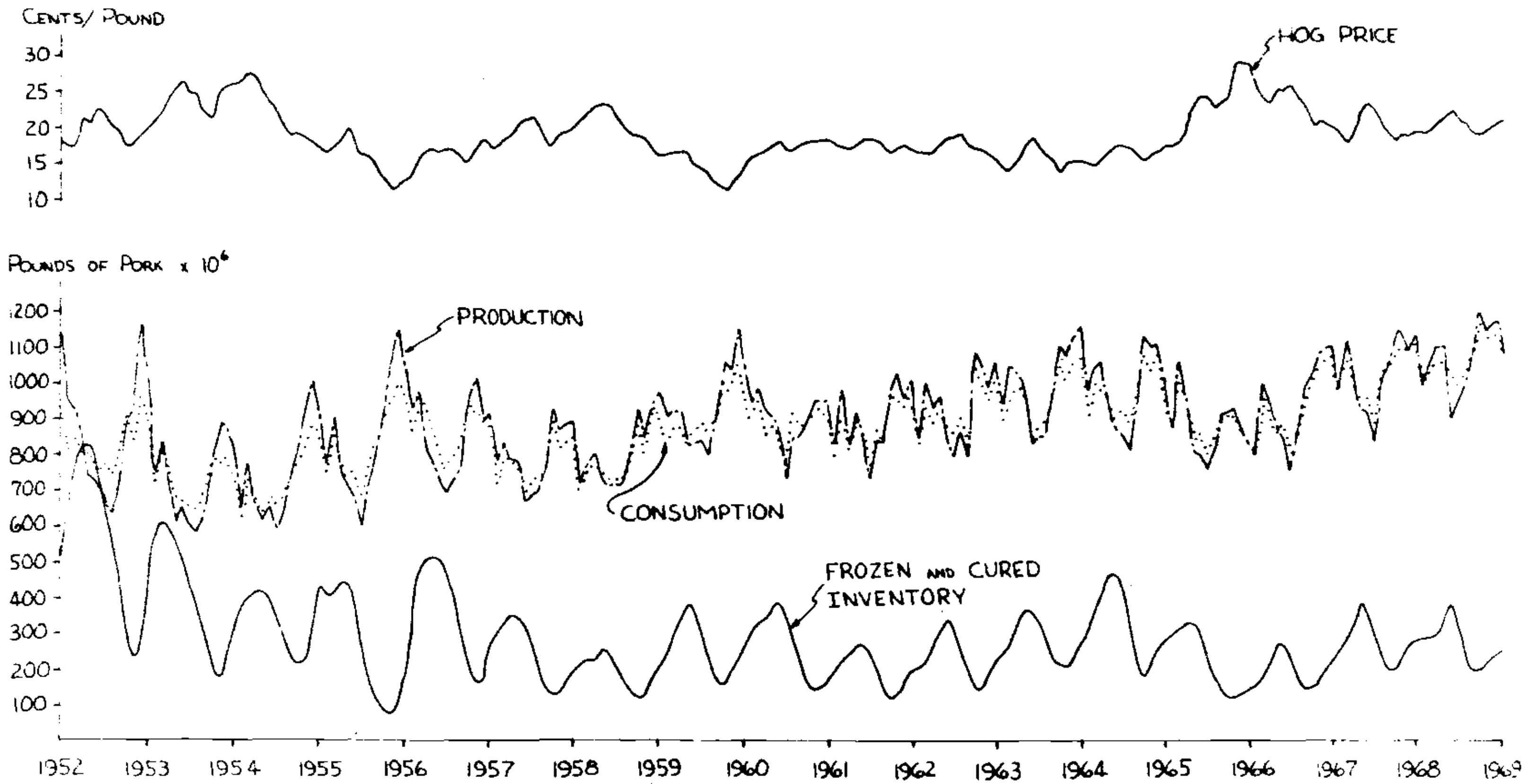

Figure 2. Hog Production Data

leaving only a small carryover as frozen or cured products.

The phasing and amplitude relationships of pork production and retail sales determine the variations in the packers' frozen and cured inventory. Inventory builds as long as production is greater than sales and declines when sales exceed production. Figure 1 does not include the data for retail sales. But, the graphic relationship between packer production, frozen and cured inventory, and consumer demand serves as an approximation of the phasing and amplitude characteristics in the meat packers' sector.

Pork production and consumption are almost exactly in phase and production varies over a larger amplitude than consumption. While storage data appears to be smooth in Figure 1, production and consumption data appear to be much noiser than the storage data.

In addition to the characteristics relating to production, inventory and consumption, hog price data displays symptoms of the research problem. First, cyclic price fluctuations do not occur with exactly the same 48 month period over the years of plotted data. Second, 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¢/lb. for a time period of 29 months and then fell for 19 months back to 11.5¢/lb. 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 month period of fluctuation.

In an attempt to plan for production operations and hog costs many meat packers forecast their future pork production. At various times, the accuracy of the forecast can modify the basic price-making forces in the system. Forecasted pork production and actual pork production data in three-month segments is plotted in Figure 3. The forecasted data was derived from information published in Livestock and Meat Situation reports (12). During certain periods of the time, the forecasted three month data and the realized production data correspond closely. Conversely, the two sets of data differed considerably during other time periods. For example from late 1960 to late 1962, the two variables corresponded closely. During that same time period live hog prices fluctuated over a small range. Conversely, in the period 1965 and 1966, forecasting errors existed and hog prices fluctuated over a large range.

Hog Production

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. The price

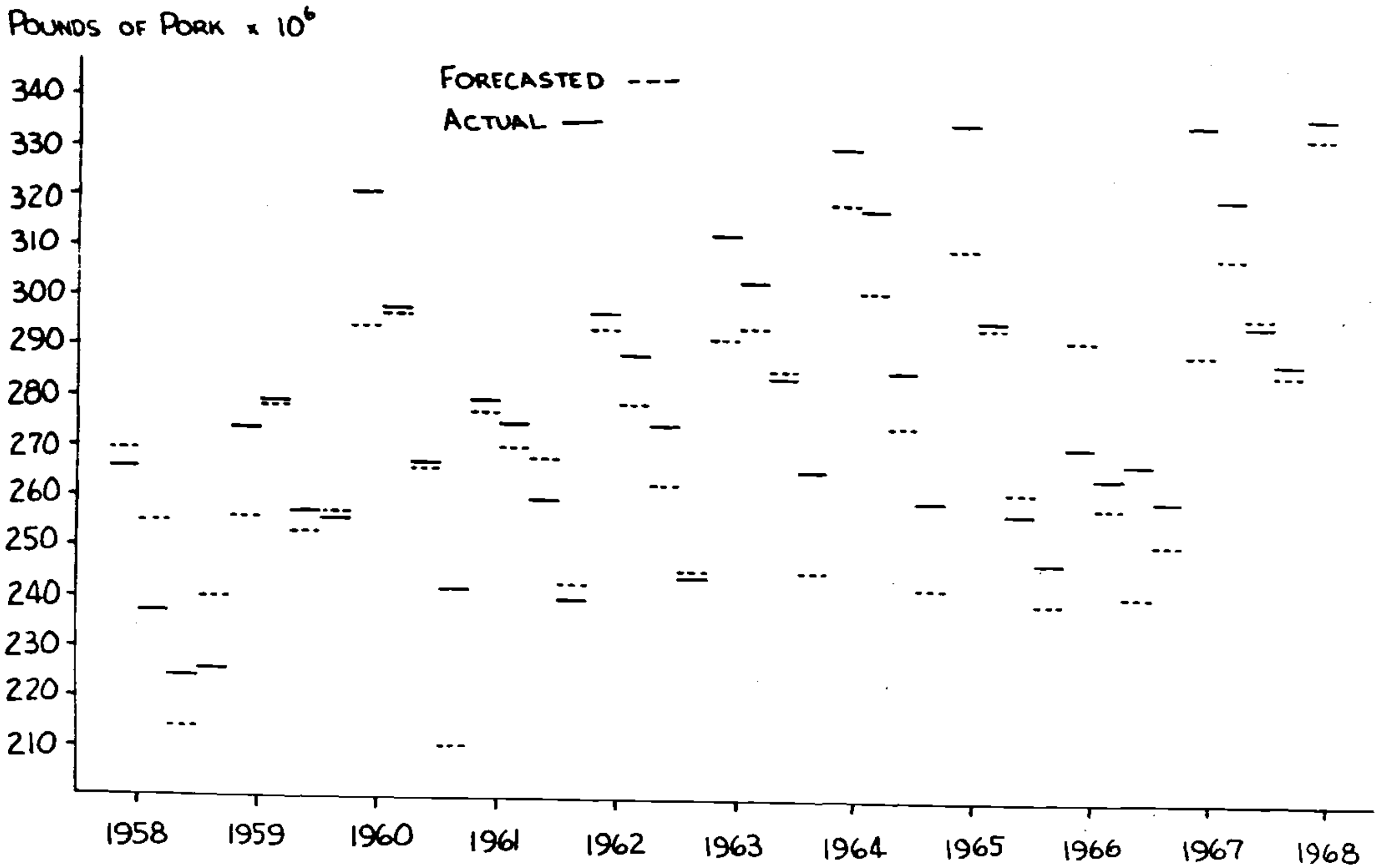

Figure 3. Forecasted vs. Actual Pork Production Data--
Three-month Totals

cycle runs opposite to the production cycle: when production is increasing prices are declining. After a time these movements will reverse themselves and prices will rise as production falls.

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.

A pronounced seasonal pattern exists in the hog industry data. That pattern is also reflected in the data of Figure 1. Much of this seasonality is produced by the climatological and physiological factors which the producers face. Production expenses such as feed, shelter, and death losses are greater during cold weather than during warmer weather. Since the producer is limited to breeding his sows two times a year, the majority of producers breed their sows to farrow in the spring and fall. Thus, two seasonal peaks in sow farrowings occur. As hogs are usually marketed six to eight months after farrowing, the seasonal patterns in slaughter and hog prices are largely determined by the pattern of farrowing.

Although attention has been called to the seasonal changes in farrowing, slaughter, and price, seasonality is not one of the focal points of the system problem under study. The model developed and tested for this research will be shown to generate short term frequencies of variation which approach the period of the seasonal patterns. If an exogenous seasonal factor were forced on the feedback model, the seasonal patterns displayed in Figures 1 and 2 could be generated. However, the forced seasonal considerations were not believed to be important in the system of feedback relationships that determine the long term hog price movement.

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 hog price has passed from above an equilibrium value, where it has 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 where price has been rising or falling at its greatest rate. During those times the holding of gilts or shipping of sows re-enforces the rate of change in price. Although there is no data available on gilts retained for herd build-up or for sow replacement, the available data on sow slaughter indicates the tendency for producers to reduce their herds after prices begin the cyclic decline.

Structure

Hog production enterprises are of substantial importance in the farm economy, and pork is a regular meat item in the consumer's food purchases. The system structure which produces, processes, and distributes pork can be segmented into four sectors:

(a) Production

(b) Meat Packing

(c) Retailing

(d) Consumption

Both pork and information flows link these sectors together. In the following section, several important structural characteristics are presented for each sector.

Production

The quantity of hogs produced depends upon the decisions of many individuals. Hog production is basically a small farm enterprise. (13) A large number of geographically dispersed farms produce almost all of the pork consumed in the United States. Only a small quantity of pork is imported.

Varying amounts of time elapse between the production decision and the availability of hog supplies. The producer can alter the feeding period for raising market weight hogs; however, most hogs are marketed between the ages of six and eight months. The six-to-eight-month feeding period coupled with the four-month gestation period delays the market impact of a production decision.

Although ten to twelve months are required to convert production plans into market hogs, production clearly responds to price levels. The large number of geographically dispersed farms and the long production period result in problems in coordinated production response.(14) The hog industry over-adjusts its operations relative to changes in live hog prices, and over-adjustment leads to cyclic behavior.

Producers decide on a production quantity by considering such factors as past and current hog prices, supplies and prices of feed, labor costs, and alternative livestock profit opportunities. Harlow (15) shows that the hog-corn ratio has been an "extremely reliable" indicator of the direction of change in the number of sow farrowings. However, the proportional relationship between the ratio and the number of farrowings varies considerably. Since World War II the relationship has been less consistent because government price supports and storage programs for corn have tended to stabilize corn prices by reducing effects of variations in corn production. As a result hog prices have assumed a more prominent role in determining the quantity of hogs produced. (16)

To transform their production plans into market hogs, producers must determine the number of sows to breed. If the proper sow capacity is not available, female hogs are withheld from the market shipments of mature hogs. If excess capacity exists, producers ship the extra sows to market.

Meat Packing

Hog producers usually have several channels for marketing their livestock--public terminal stockyards, local auction markets, direct sales to meat packers, or sale to livestock dealers. In 1964, packers purchased 63 percent of their hogs directly from producers and dealers. (17)

Compared to the number of hog producers, which numbered 1,847,000 in the 1959 Census of Agriculture, the number of meat packing companies is small. (18) In 1964 forty companies slaughtered and processed 76.9 percent of the total commercial livestock slaughter. (19)

The range of activities in the meat packers' sector includes converting the live hog to a carcass, dividing the carcass into pork cuts, processing pork cuts, and preparing pork products. Once the hog is slaughtered, fresh pork cuts and pork products must be moved quickly to the retailing sector, as consumers prefer fresh pork supplies. (20)

In general meat packers can sell up to 90 percent of their production to their regular customers. (21) The portion that remains has to be sold to the packers' less regular customers. Pork prices to the packers' customers are generally formed from a pricing base - the "Yellow Sheet". Formula pricing closely follows the patterns of hog price movement. Although the packers can generally sell all of their pork supplies, price concessions are usually necessary. Thus the meat packers are committed to moving their pork inventories with little bargaining strength in their sales market. Unable to exert much selling pressure, the meat packers attempt to control their raw material costs-live hog prices.

Packer bidding for live hogs reflects the value which the meat packers attach to hog receipts. That value is determined from the expected pork sales to retailers relative to the expected hog supplies from the hog producers. Any increase or decrease in the normal flow of market hogs alters the packers' assessed value of future pork supplies and creates a rapid change in the bidding strength for live hogs. Thus, the average paying price for live hogs is closely associated with the packers' sales and production expectations.

As the general conditions of pork supply and demand change, the meat packers' efficiency and profitability are affected. Like the producers, the meat packers must continually adjust their operations to new levels as market conditions change.

Retailing

Retailers buy a combination of hog carcasses, pork cuts, and processed products from the meat packers. Buying with significant market power, the retailers have become important customers to each of their meat packer suppliers. (22) The retailers take advantage of an oversupply situation by adjusting their normal purchases to the available supplies and offering special pork sales to the consumer. Conversely, a shortage in pork supplies causes the retailer to shift the promotional interests to another meat product and adjust pork purchases downward.

Retailers do not adjust the selling price of pork to their purchase cost as rapidly as the meat packers' selling price adjusts to live hog costs. The influence of a retailers' purchase price change is usually distributed over a six-week period. (23) Thus retailers are able to dilute the pressures of increased or decreased supplies by maintaining both purchasing and pricing control in their operations.

Consumption

Pork consumption is clearly the reflection of hog production rather than the reflection of a change in basic demand. The basic demand for pork has not grown on a per capita basis like that for other meat products. (24)

Consumer purchases depend on the consumer's traditional buying habits and the availability of pork supplies. When promotional sales are offered, consumers tend to adjust their purchases to the level of available supplies. Since retail prices are the primary promotional attraction, the retailing pricing mechanism must function to establish the proper price relative to the available supplies of the retailer.

CHAPTER IV

RESEARCH HYPOTHESIS

The behavioral characteristics and organizational structures relating to the research problem have been described in the previous chapter. Understanding how those characteristics and structures relate to one another helps to provide insight into the systems nature of the long-term price movements. In this chapter a system of feedback relationships is hypothesized to underlie the dynamic behavior of the pork system. Based on the research hypothesis a qualitative description of the feedback model is included to provide the reader with a grasp of the system considerations believed to be important.

Hypothesized Feedback Structures

The hypothesized system of feedback relationships is shown in Figure 4. 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 retailer's 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 raw material input costs. Thus reduced pork values cause lower prices to be bid for live hogs. The meat packers attempt to increase their sales to the retail outlets; yet, packer sales are largely unaffected by sales pressure 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

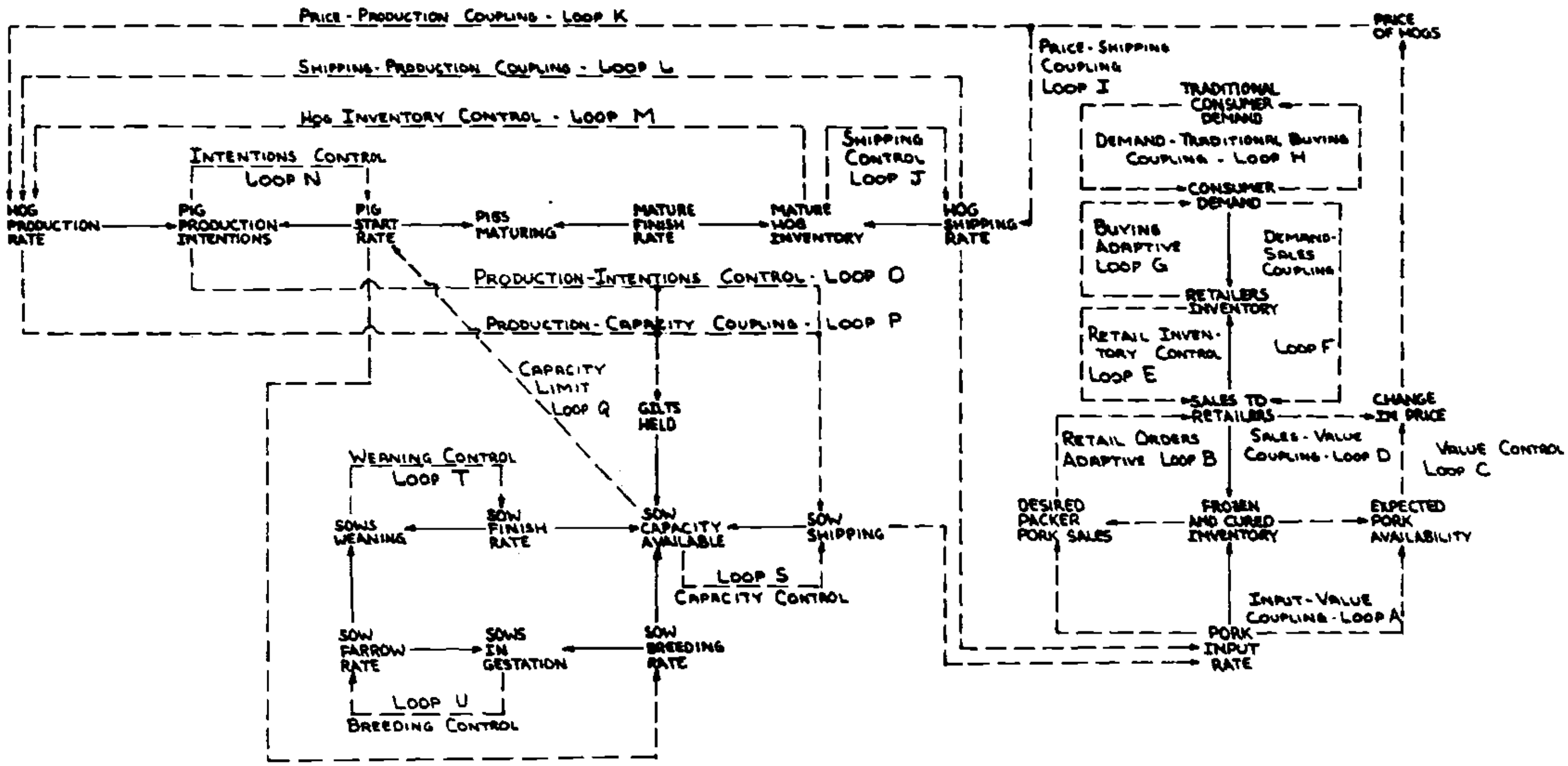

Figure 4. Hypothesized System of Feedback Relationships

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 (Loops 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 (Loops L and M). Correspondingly, price declines cause cutbacks on the available sow breeding capacity (Loops 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 productions cutbacks are felt in the market, the pork values increase in the meat packers' sector. 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 purchases 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 creates pork value.

Qualitative Description of the Feedback Model

The feedback loops and the sequence of events in those loops described in the previous section constitute the research hypothesis. In this section a qualitative description of the feedback structures provides the reader with a grasp on the system mechanism believed significant. The description is divided into three sections:

1. Production Control
2. Sow Capacity Control
3. Distribution Control

The model flow diagram of Figure 5 displays the system structure in terms of conventional industrial dynamics flow symbols.

Production Control

Producers determine a Hog Production Rate which flows into a backlog of Pig Production Intentions. When Sow Capacity is available, the Production Start Rate transforms the intentions into the Pigs Maturing. A gestation delay of four months and a minimum market weight delay of five months must occur before the hogs flow into the Mature Hog Inventory. After a delay for feeding the hog to market weight the hogs are shipped to market. The feeding delay is dependent upon the average level of hog prices in the market.

The producers' decision variable--Hog Production Rate--has

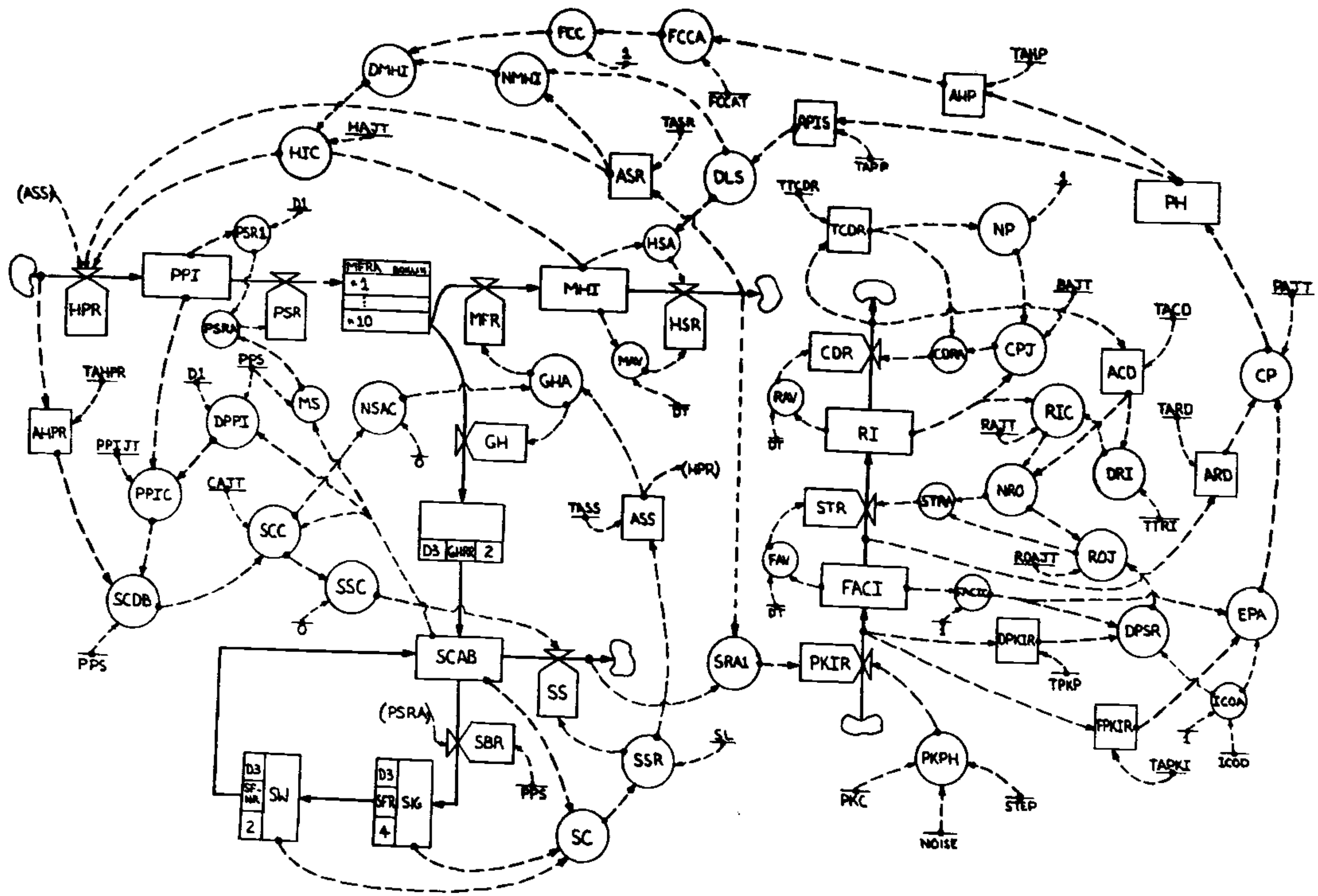

Figure 5. Flow Diagram of the Model Structure

been formulated to represent the aggregate actions of the numerous market producers. One component, Average Sow Scrap, places pigs into production based on the average level of sow replacement due to old age. A second component, Average Shipping Rate, represents the throughput of market hogs. The throughput concept relates to the producer's desire to conform to his past production practices. The final component, Hog Inventory Correction arises from two separate and critical system conditions. First the producer must control the number of hogs in the Mature Hog Inventory. The need for control arises from the producer's financial resources, space, and labor availability.

Secondly, Hog Inventory Corrections are dependent on Average Hog prices. High prices stimulate expansion of past production. Correspondingly, a low profit level stimulates contraction. Expansion or contraction changes are signaled by a nonlinear dependency on Average Hog Prices (Figure 6). The normal stocks of mature hogs are formulated from the Average Shipping Rate and the stock's turnover time. Using the Fraction Change and the Normal Hog Inventory Level, a Desired Mature Hog Inventory is calculated. Comparing the actual stocks of mature hogs with the desired level of stocks, the producer adjusts the difference over a period of several months. The Hog Adjustment Time represents the desired delay

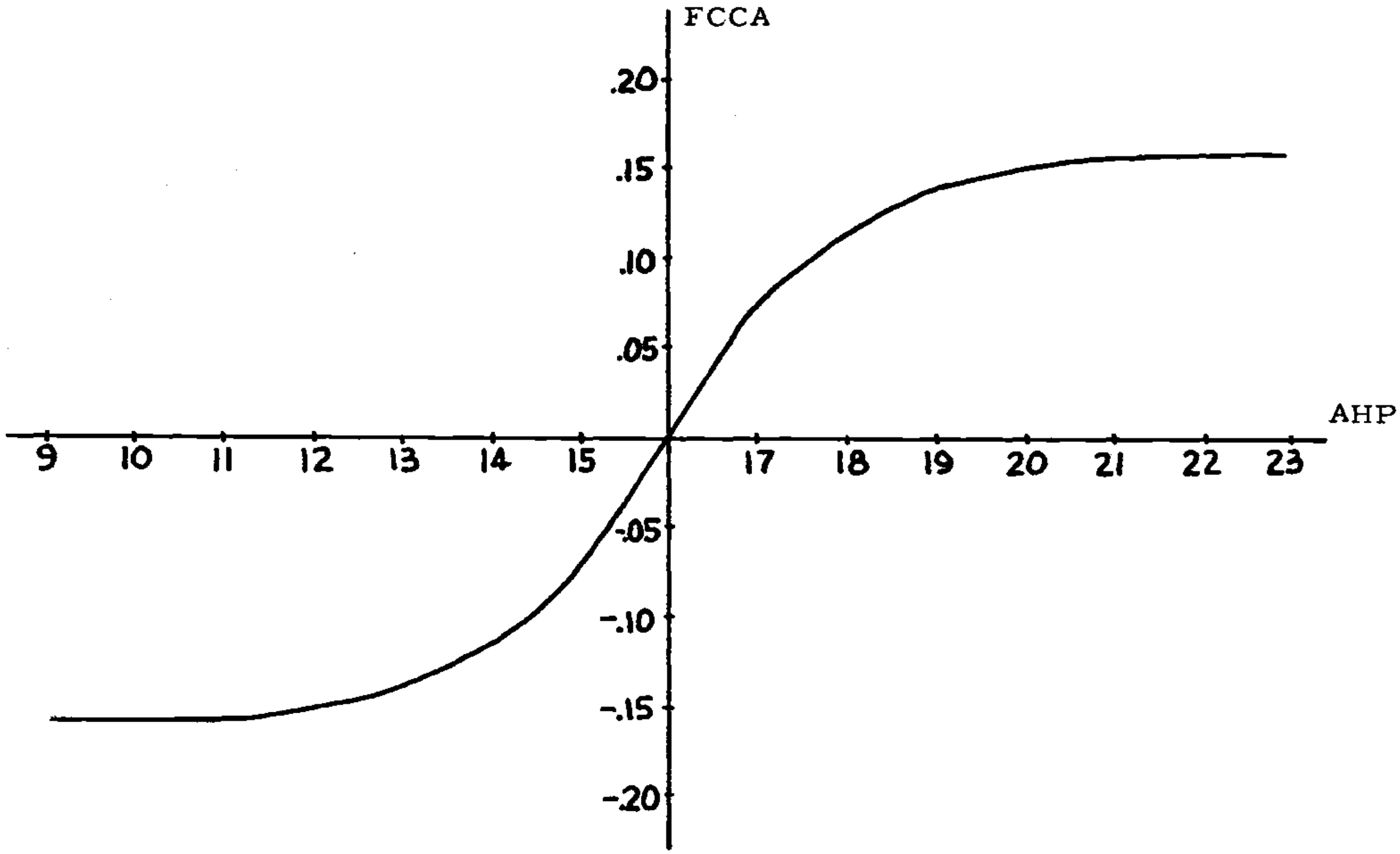

Figure 6

Fraction Change in Production vs. Average Hog Price over which the producer wishes to correct the observed difference. As the adjustment time increases, the Hog Production Rate decreases, and vice versa.

Sow Capacity Control

In the model structure relating to sow capacity the producer regulates his breeding stock through Sow Shipping and Gilt Retention activities. Maintaining idle capacity is expensive due to feeding costs and ease of obtaining new capacity. Consequently, producers tend to hold only those sows needed to fulfill their current hog production activities. Capacity changes result from the producers' desire first to maintain sufficient capacity to meet the Average Hog Production Rate and secondly, adjust the Pig Production Intentions to a desired level. Gilts Held reduce the flow of hogs into the Mature Hog Inventory. Correspondingly Sow Shipments increases the flow of hogs to the market. The sow capacity structure is coupled to the main flow path of hogs through information about the producers' Hog Production Rate. Using averaged information one component of the Sow Capacity Desired For Breeding is formed by the ratio of Average Hog Production Rate and the Pig Per Sow constant. The second component of desired capacity represents the sow capacity needed to correct any imbalance in the Desired Pig Production Intentions and the actual Pig Production Intentions within the adjustment time PPIJT.

Desired Pig Production Intentions can be satisfied with the Sow Capacity Available For Breeding, the required breeding delay, Dl, and the Pigs Per Sow constant, PPS.

Sow Capacity Corrections adjust the available breeding capacity. Depending upon the relative magnitudes of the Sow Capacity Desired For Breeding and the Sow Capacity Available For Breeding, producers act to retain gilts through New Sow Added and to market sows through Sow Shipments. The replacement of old sows through Average Sow Scrap makes up the remainder of the capacity decision.

Sow Breeding Rate is implied by the Production Start Rate. After a gestation delay of four months and a weaning delay of two months, the Sow Finish Rate adds to available capacity. Sows Shipments drain the available capacity as sows are marketed.

The sow capacity sector and the production sector are coupled through the Production Start Rate and the Mature Finish Rate. At times the magnitude of the available capacity can limit the Production Start Rate and thus alter production sector's response to the Hog Production Rate. At the Mature Finish Rate, young female hogs are withheld in accordance with the producer's capacity decision to replace old sow, and build his breeding levels.

Distribution Control

Taken together the production and capacity structure contain the production activities of the pork system. The distribution structure contains the activities of three system sectors--meat packing, retailing, and consumption.

Meat Packing. The primary decision being studied in the Meat Packer sector concerns hog pricing. The packer has practically no bargaining strength over the retail segment. Pork supplies must be moved quickly into the distribution system. As available meat supplies fluctuate packers sense different values for the live hog. For example, reduced supplies of pork create higher values of meat, thus, the packers tend to bid livestock prices higher. On the other hand, increased supplies reduce the value of their product and prices for hogs are lowered. In essence the packers cannot exert pressure upon the retail industry but can control the prices paid for live hogs.

To control the prices paid for hogs, bidding strength depends on the imbalance of Forecasted Pork Input Rate, Desired Carry-over, Frozen and Cured Inventory and in addition, to the Average Retail Demand. The net difference represents the value of the packers' meat supplies. Changes in the hog prices are derived from a ratio of the net difference to the Price Adjustment parameter.

Retailing. In the retail sector the primary decision being studied is retail ordering. The retailers determine their order rate to the meat packers based on a desire to meet the Average Consumer

Demand and control the pork supplies in Retail Inventory. The difference between the Desired Retail Inventory and the actual Retail Inventory is corrected over the Retailers' Adjustment Time. In addition, orders generated by the retailers respond to the pork supplies which are being offered for sale by the meat packers. The retailers recognize the merits of special sales or de-emphasis of pork products during those times when pork supplies are abnormal; hence retailers determine the Retail Order Adjustment based on the imbalance between Normal Retail Orders and the Desired Packer Pork Sales. Any imbalance is adjusted over the Retail Order Adjustment Time.

Consumption. The primary decision in the consumption sector concerns consumer buying of pork products. The decision mechanism responds to Traditional Consumer Demand and Consumer Purchase Adjustments. Consumers buy their Normal Purchases adjusted either higher or lower in response to available supplies. Adjustments are made over the Buying Adjustment Time.

Quantitative Model

The feedback model described qualitatively was transformed into a system of first order difference equation for the purpose of testing the research hypotheses. Nonlinearity and complexity of the system of equations necessitated model synthesis and experimentation based on computer simulation. With the aid of the Dynamo language, the system of equations can be solved sequentially over time and the resulting system behavior studied.

Model synthesis was a goal seeking activity. The goal sought was a feedback structure which realistically produced the characteristic behavior being studied. To reach this goal various loop configurations, parameters, and couplings were chosen relative to the symptomatic behavior.

The model structure in Figure 5 displays the end product of the synthesis process. A complete listing of the model's equations, system delays, constants, adjustment times, and variable identification is provided in the Appendices.

CHAPTER V

MODEL ANALYSIS

This chapter develops an understanding of the pork system's cyclic movement and causal mechanisms underlying the movement. The simulation experiments selected for the model analysis provide (a) a demonstration that the information feedback model generates the desired modes of behavior in a logical and consistent manner and (b) an assessment of each loop's importance in controlling the system's response.

Description of the Basic Model's Behavior

A 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. Table 1 shows the symbolic representation of the model variables which are plotted for illustrative purposes in this chapter.

In the following two sections the model's validity and general behavior are discussed.

Table 1. Model Variable Identification For Simulation Plots

Model Variable*	Symbol	Represented by
Price of Hogs	PH	P
Slaughter Rate Auxiliary	SRA1	S
Hog Production Rate	HPR	I
Hog Inventory Corrections	HIC	G
Sow Farrowing Rate	SFR	F
Sow Shipments	SS	Z
Sow Capacity Corrections	SCC	O
Sow Capacity	SC	W
Frozen and Cured Inventory	FACI	N
Consumer Demand Rate	CDR	C
Pork Input Rate	PKIR	K
Desired Packer Sales Rate	DPSR	D
Average Retail Demand	ARD	R

* Each numerical value, except for PH, must be multiplied by 10^3 before comparison is made to the actual pork system data.

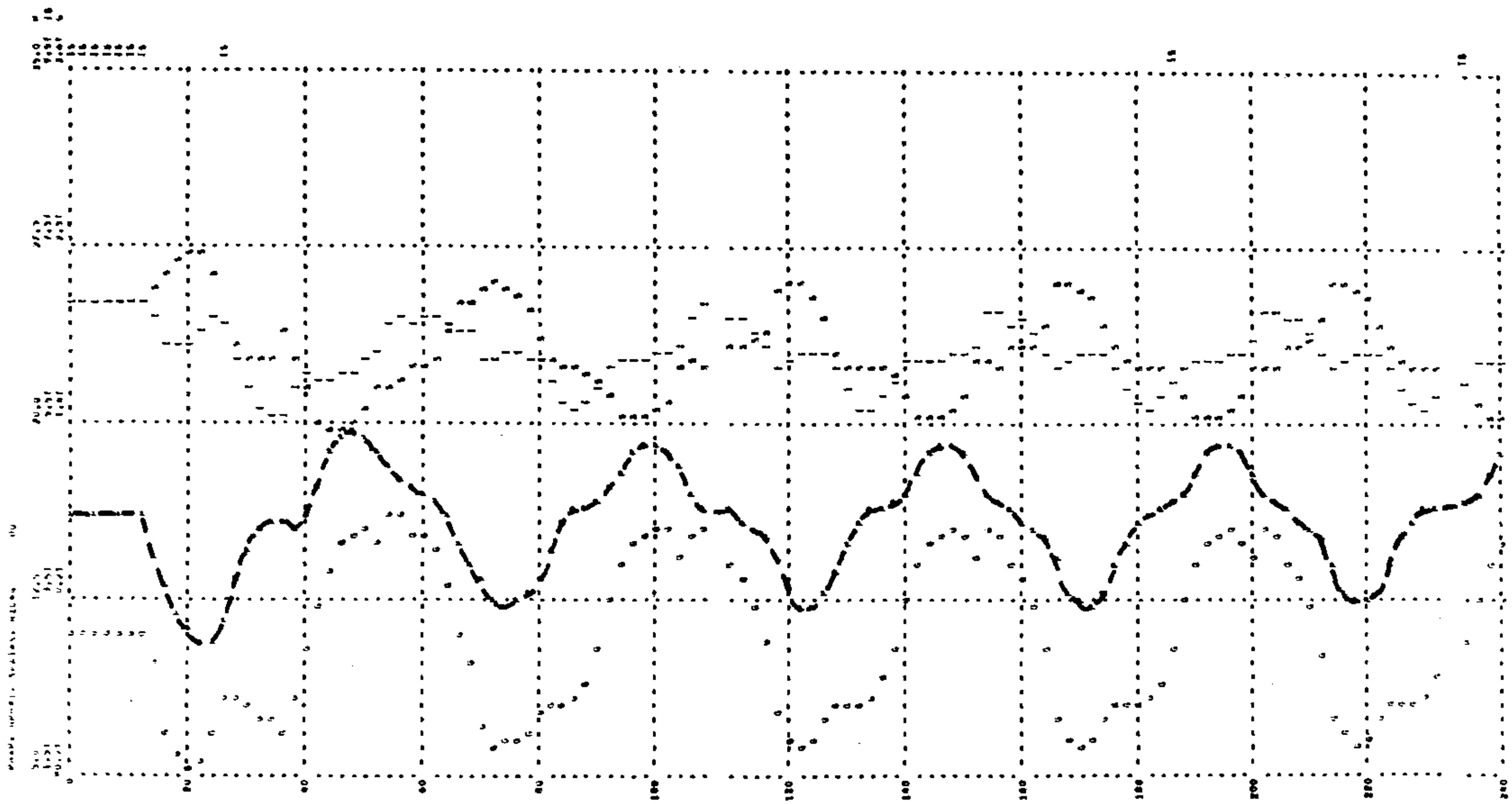

Figure 7. Basic Model, 10% Step Input, Hog Production Variables

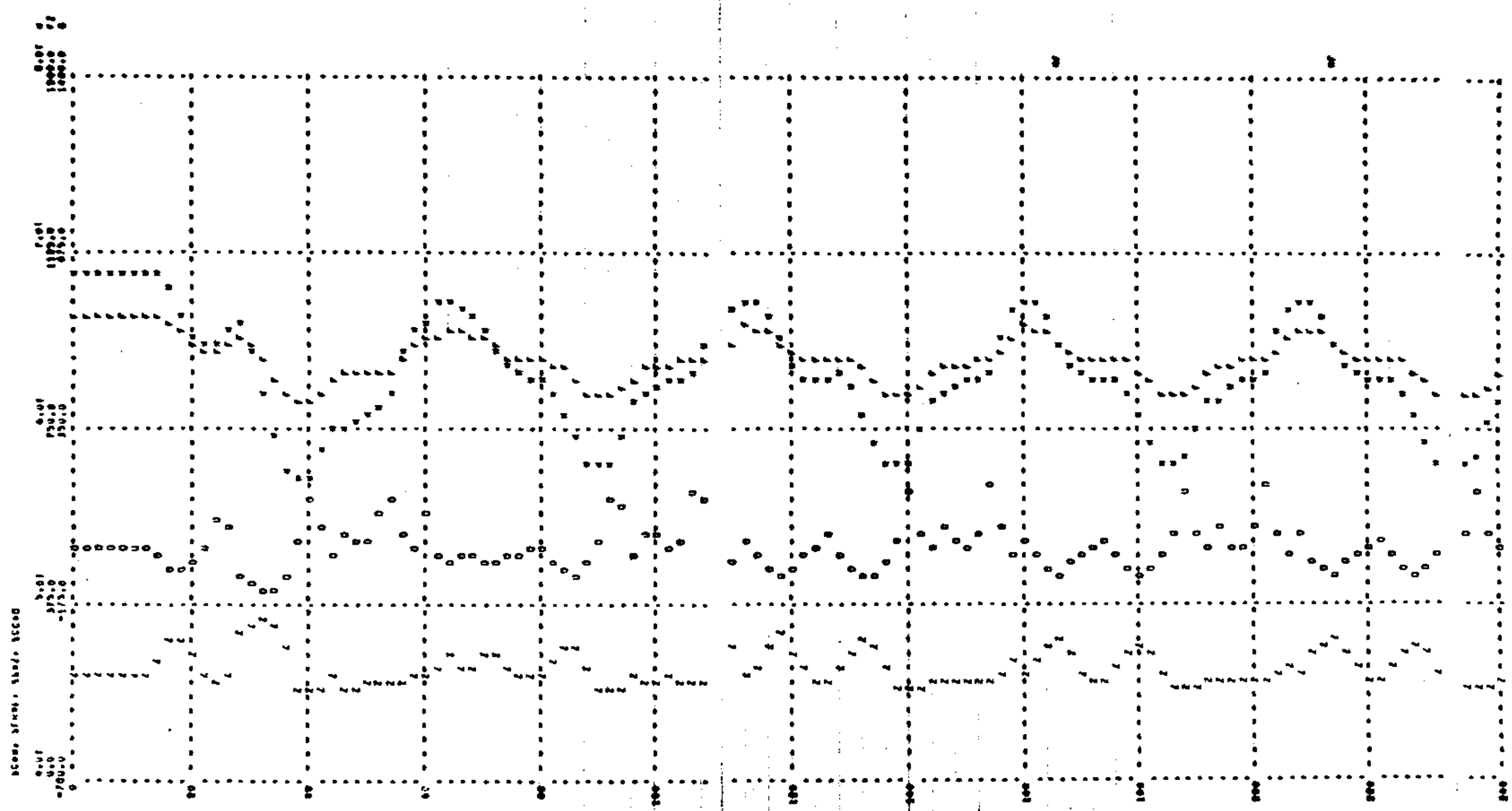

Figure 8. Basic Model, 10% Step Input, Sow Capacity Variables

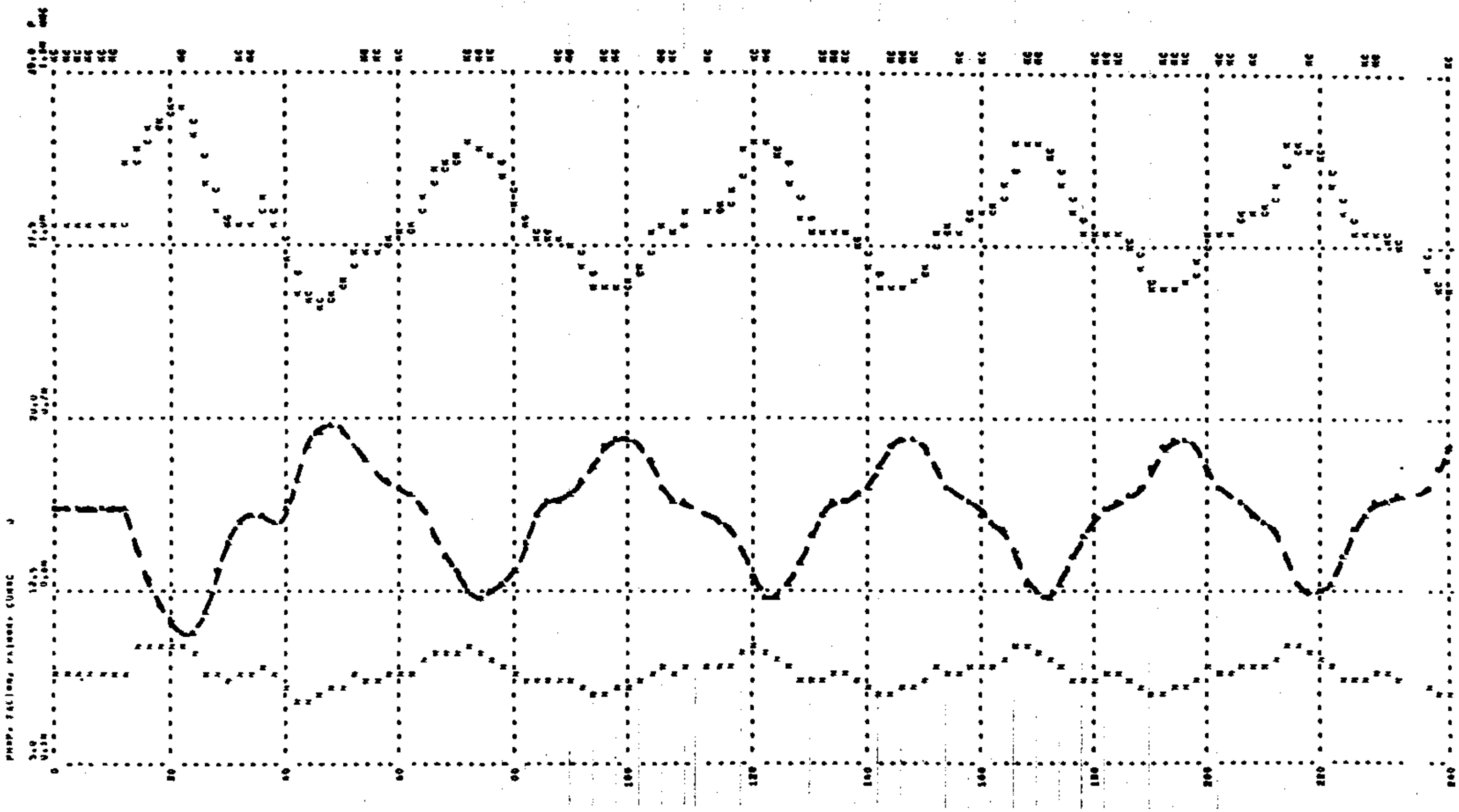

Figure 9. Basic Model, 10% Step Input, Pork Distribution Variables

Construct and Response Validity for the Basic Model

The model generates the pork system's behavior via the structure of information feedback loops identified in the previous chapter. Within the feedback structures, decision-making processes convert information about certain system conditions into sector activities. 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 boundaries of the research problem. System variables were selected and interconnected based on knowledge about the actual system operations and the principles of dynamic systems analysis.

The model's response to the step input test function provides a test of response validity. The model should generate time patterns of behavior that do not differ in any significant way, relative to the objectives of the study, from the actual system. (25) The time patterns of behavior shown in Figures 7, 8, and 9 result from a ten percent step input applied to the basic model (Figure 5 and Appendices). 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:

Variable	Basic Model Performance Range	Average Cyclical Range
Pork Production (lbs/month) x 10^9	8.550 - 1.145	7.850 - 1.140
Pork Consumption (lbs/month) x 10^9	8.500 - 1.140	7.800 - 1.100
Hog Price (¢/lb)	11.50 - 20.00	12.00 - 26.00
Frozen and Cured Inventory (lbs) x 10^5	1.800 - 3.200	1.800 - 3.500
Hog Slaughter (hog/month) x 10^6	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 7, 8, and 9 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 7, 8, and 9 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 Figures 7, 8, and 9, 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 at 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 amplifies the original effects of the step disturbance.

Even though prices continue to decline over a 12-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 producers attempt 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 nonlinear functional relationship of Figure 6 becomes critical during these system conditions. The producers' cutbacks do not change proportionally with the average price level. 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, the nonlinearity in loop K of Figure 4 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 7 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 build-up. 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 10 model behavior with noise shows the 48-month natural period in the pork system. Throughout the model

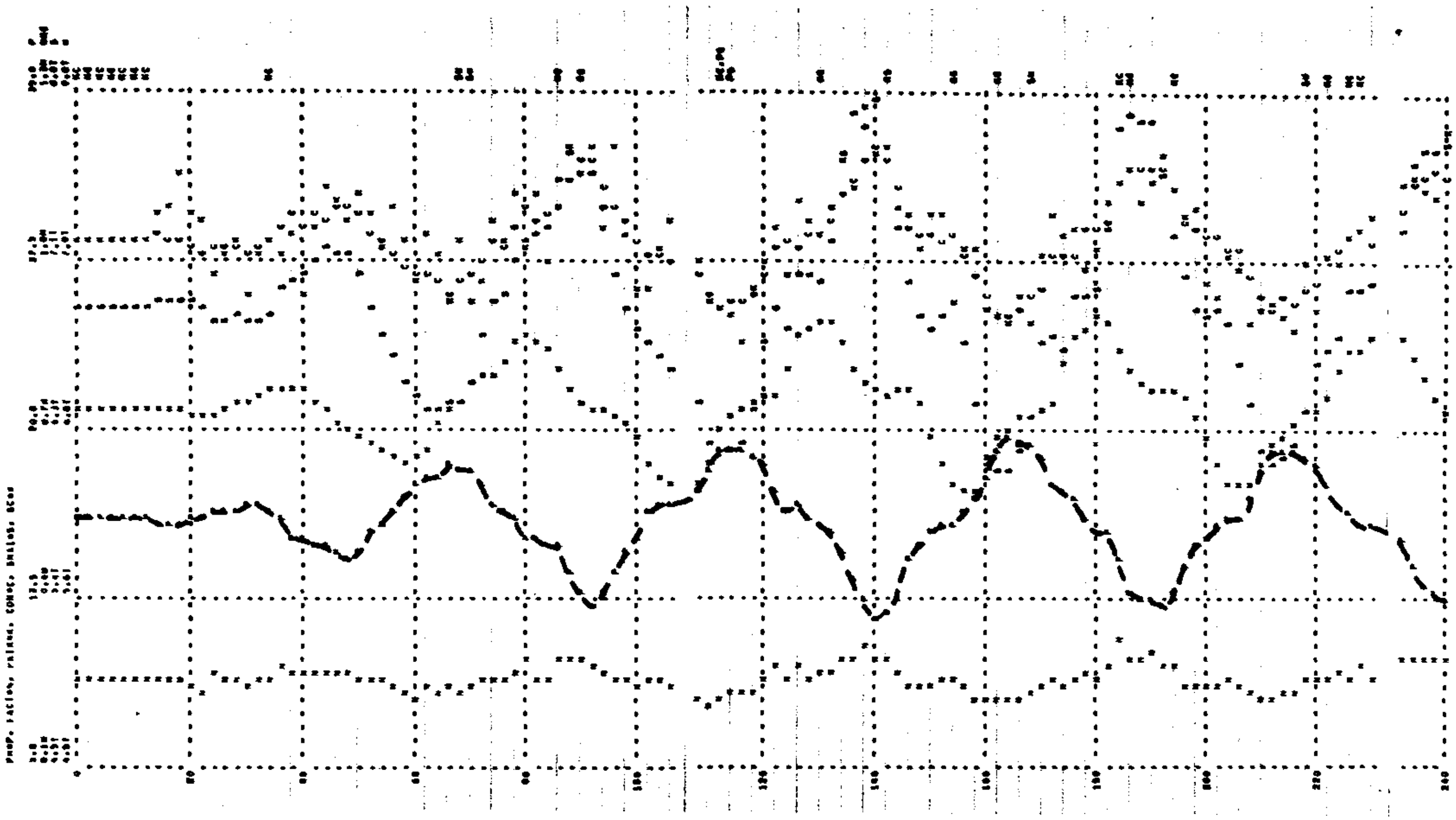

Figure 10. Basic Model, Noise in Hog Weight Parameter

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 7, 8, and 9.

Summary of the Basic Model's Behavior

Construct validity in the feedback model is supported by the realistic representation of the actual pork system processes. Response validity of the performance patterns shown in Figures 7, 8 and 9 is substantiated by similar amplitude, frequency, and phasing relationships evident in actual system data. Model variables react to imbalances in system conditions and tend to amplify the step disturbance and create unstable system behavior. Variations in pork supplies are amplified by the meat packers through delayed reactions of the value assessment policy. Amplification in the producers' sector occurs because of the variable feeding delay and over-responsive production mechanism.

Controlling Features of the Model

The feedback model shown in Figures 4 and 5 has numerous loops and parameters which could be 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.

This section provides an assessment of each loop's importance in controlling system response. Model experiments were made in accordance with the following procedure:

a. For a 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 loop 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 are 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 7, 8 and 9 the system effects can be assessed. The results of the model analysis will be presented for each of the four model sectors - Production, Meat Packing, Retailing, and Consumption.

Production Sector

The first critical area of the model is believed to be the production sector. Response characteristics indicate that producers over-respond to the average price level. Coupled with long production delays the over-responsive producer perpetuates the forces internal to the system and carries the system beyond equilibrium conditions.

Hog Adjustment Time. The producers alter the hog production rate in response to price expectations. Production control is accomplished via the policy mechanisms within the production sector. In the mature hog control loop, the production delays are large compared to a small adjustment time parameter, and stable system behavior cannot be achieved. The long delays and short adjustment time cause an overshoot in the mature hog inventory.

Overshoot occurs because the production adjustments are made without accounting for those adjustments already in production, but not yet in the hog inventory. Producers adjust their production activities until the hog inventory reaches some desired level; however, the quantity of hogs that flows from the production operations after the desired level is attained carries the inventory beyond the desired level.

Relative to the overshoot condition, the hog adjustment time is the most sensitive parameter in the production sector. Model experiments made with alternative values of HAJT reveal varying period and amplitude characteristics in the system's response.

Figure 11 illustrates the model behavior with HAJT = 4. A larger adjustment time causes the producers to place fewer hogs into production prior to the hog inventory reaching its desired level. Since fewer hogs are in the production pipeline, the inventory overshoot is less.

System stability is greatly improved with the longer adjustment time. Damped oscillations in the system variables eventually settle to a steady state condition. Even though stability is improved with the longer adjustment time, system responsiveness is sacrificed. Longer periods of movement occur and smaller ranges of fluctuation result.

Conversely, smaller values of HAJT cause the system to oscillate with large amplitudes and higher order frequencies superimposed on the basic 48-month cycle. The model behavior shown in Figure 12 demonstrates the unstable market activity which results from a parameter value of HAJT = 1. Because the producers react more rapidly to correct the hog inventory, larger numbers of pigs are placed into production before the inventory reaches its desired state. The system attempts to adjust to the producers' over-responsiveness by rapidly changing price levels, supplies offered for sale, forecasts, and buying and ordering patterns. Nevertheless, the continued rapid production adjustments place such large quantities of

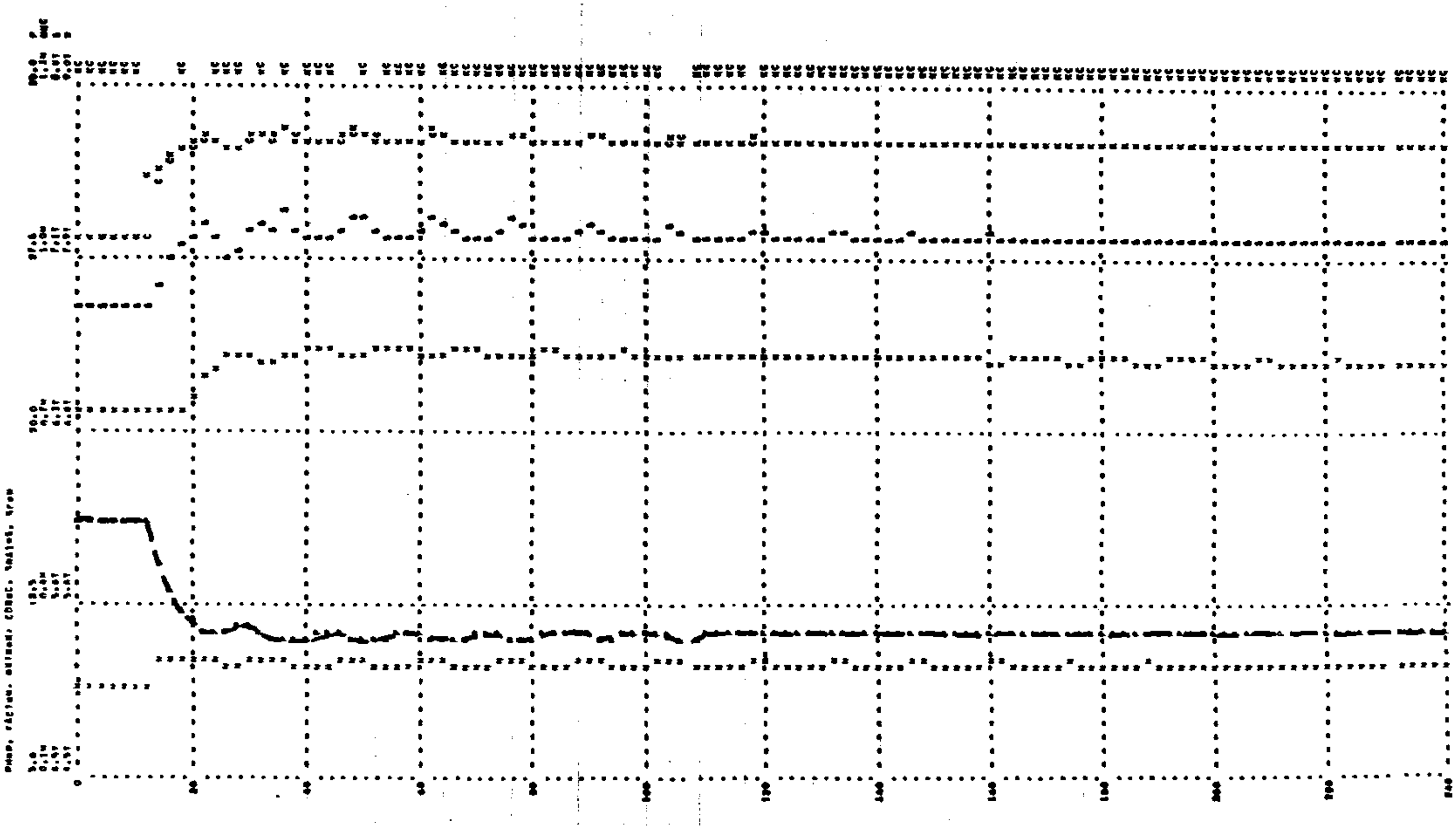

Figure 11. Model, 10% Step, Increased Hog Adjustment Time, HAJT = 4

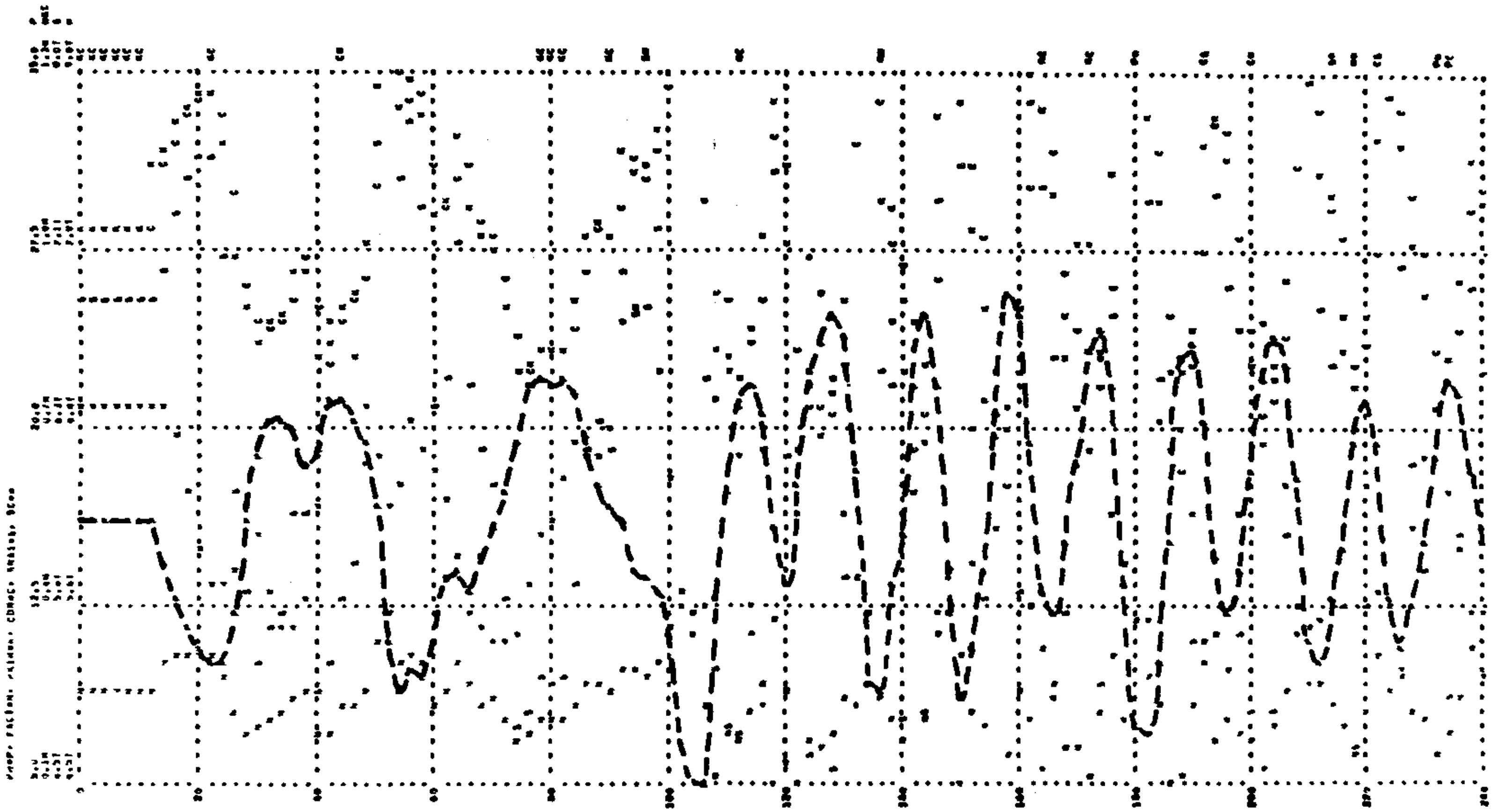

Figure 12. Model, 10% Step, Reduced Hog Adjustment Time, HAJT = 1

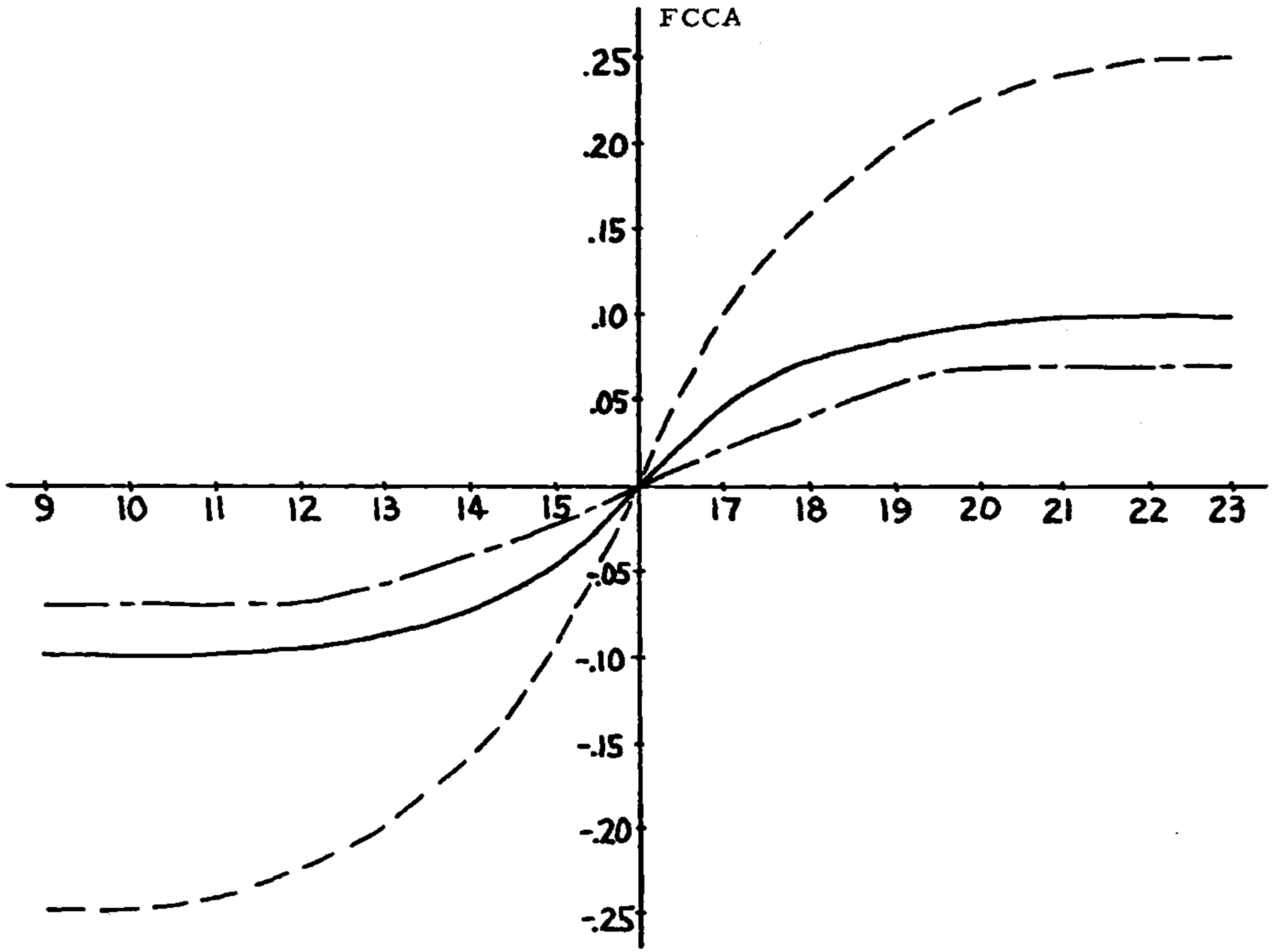

Figure 13

Test Relationships for Fraction Change in Production hogs into the system that the various sectors are caught in a vicious circle of unstable operations.

Production Changes Relative to the Average Price Level. Within the production sector, a functional relationship was assumed to be representative of the producers' reaction to average price levels. The basic model contains a relationship developed from data relating to response activities of the producers. Test runs were made to study other nonlinear functional relationships. Figure 13 illustrates the test relationships. Depending upon the slope characteristic and saturation points tested varying amplitude and dampening characteristerics were obtained.

Changing the slope of the nonlinear component corresponds to the testing of an adjustment time. For example, increasing the slope accomplishes the effect of a decrease in an adjustment time. The steeper slopes create larger production adjustments and makes the system more responsive; however, stability is sacrificed. Conversely, slopes less steep cause the producers to respond over a longer period of time to a given average price level. The corrections made to the hog production operations are thus smaller and the system behavior displays noticeable damped characteristics.

Hog Inventory Control. Although the producers over-respond to price information, the inventory control loop attempts to maintain

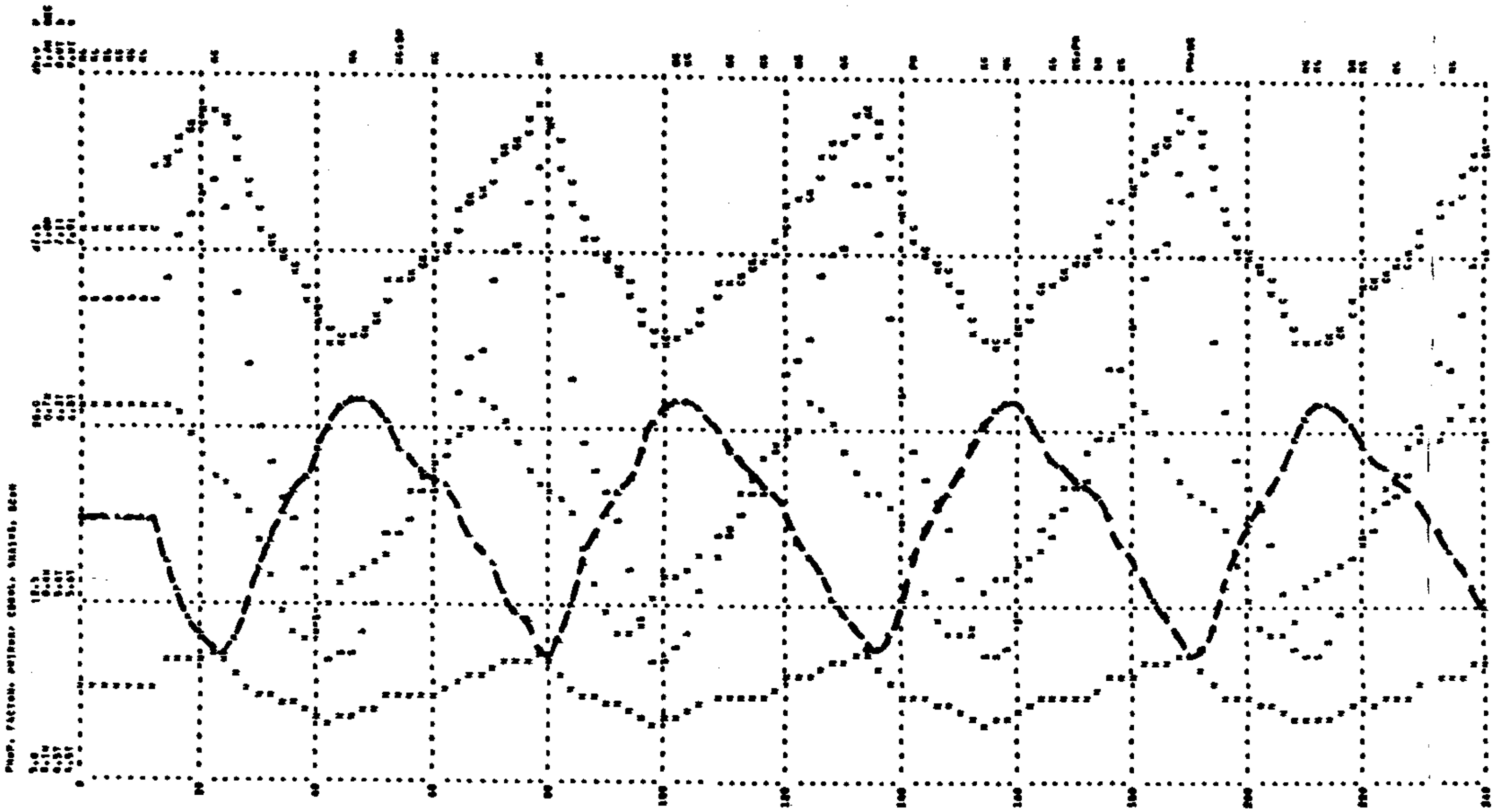

Figure 14. Model, 10% Step, Hog Inventory Control Loop Open

the number of mature hogs within economic bounds. When the control loop is severed, the system oscillates over a wider range of amplitudes. The larger swings in system variables point out the constraining features of the control loop. Model behavior generated without the control loop is shown in Figure 14.

Coupling Delay - TAHP. Model experiments on the production sector confirm the importance of over-responsiveness to price information. In view of this importance, model experiments were performed to determine the system sensitivity to variations in the coupling delay, TAHP. Delay parameters of three, six, and twelve months were substituted for the basic model value - TAHP = 5.

Shortening the coupling delay couples the loops in the production sector more tightly with the loops in the meat packing sector, and as such, the loop interactions are more significant. Comparing the model behavior of Figure 15 with that of the basic model behavior in Figures 7, 8, and 9 reveals that the amplitudes and period of oscillation are increased. Thus the tighter coupling leads to a more rapidly fluctuating behavior mode in the pork system variables. Model runs with parameter values of nine and twelve months show increasingly damped behavior.

Capacity Control. Because of the relative ease of obtaining new breeding stock from the hog inventory or shipping excessive breeding

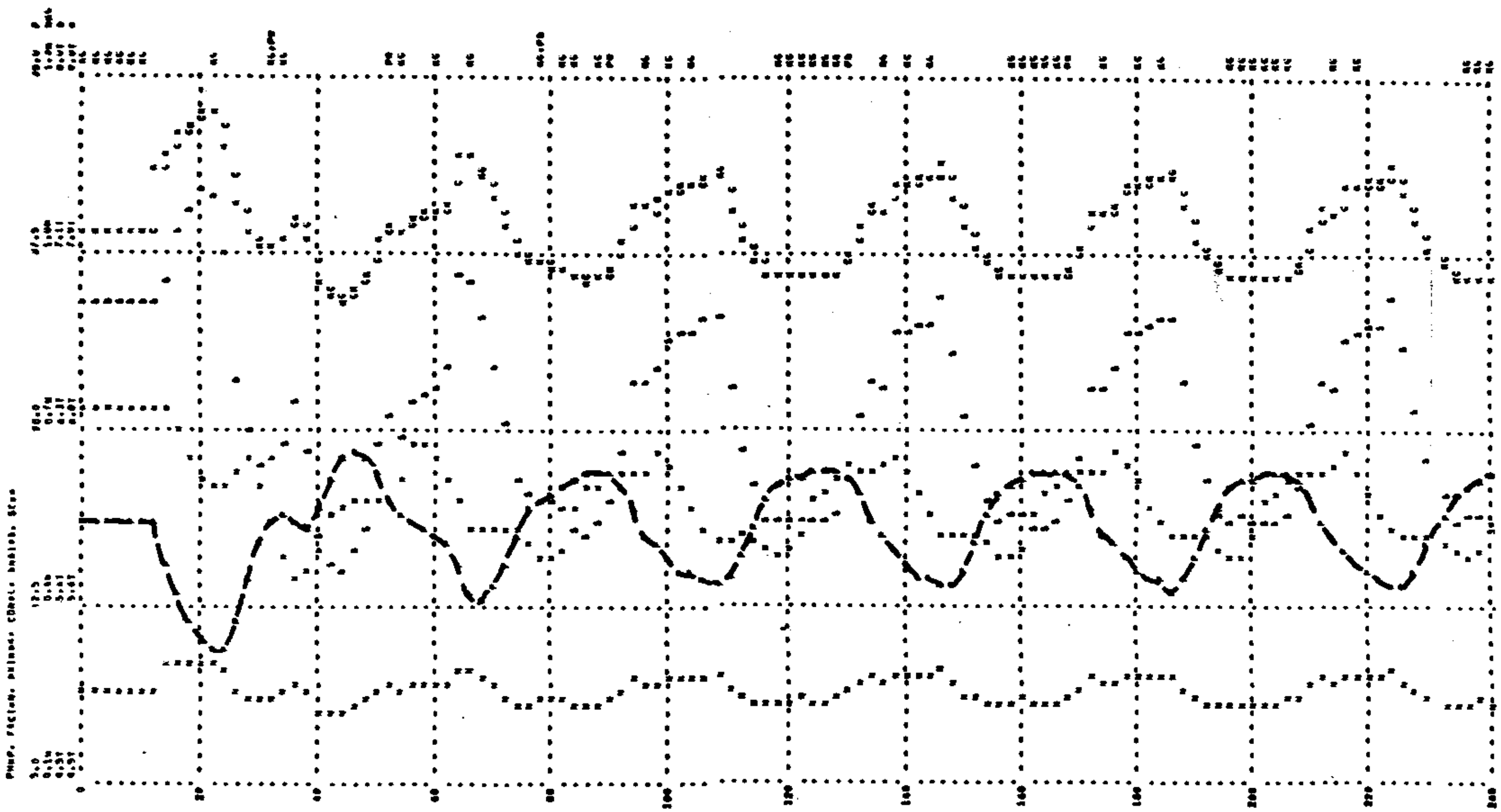

Figure 15. Model, 10% Step, Smaller Coupling Delay, TAHP = 3

stock to market, the control characteristics of the capacity operations are believed to be unimportant. However gilt retention and sow shipping activities alter the normal flow of market hogs in times of capacity expansion and capacity reduction.

Loop analysis confirms the belief that the controlling aspects of the capacity activities are not dominant features of the model. Variations of considerable magnitude were listed in the following capacity parameters:

(1) CAJT = .5, 1.0, and 2.0 months

(2) PPIJT = .5, 1.0, and 2.0 months

(3) TAHPR = 2.0 and 3.0 months

Furthermore, deactivation of the production intentions control loop results in model behavior very similar to the basic model.

Meat Packing Sector

The second critical area in the model is believed to be the meat packing sector. Within this sector, the value assessment policy is assumed to depend partly on information about the frozen and cured inventory level. When the inventory information loop is cut from the decision policy, model behavior changes dramatically (Figure 16). Oscillatory behavior remains an important feature of the response patterns; however, the oscillations decay to a steady state condition. The steady state condition indicates improved system stability. Conversely, the behavior of Figure 16 also indicates that the system is

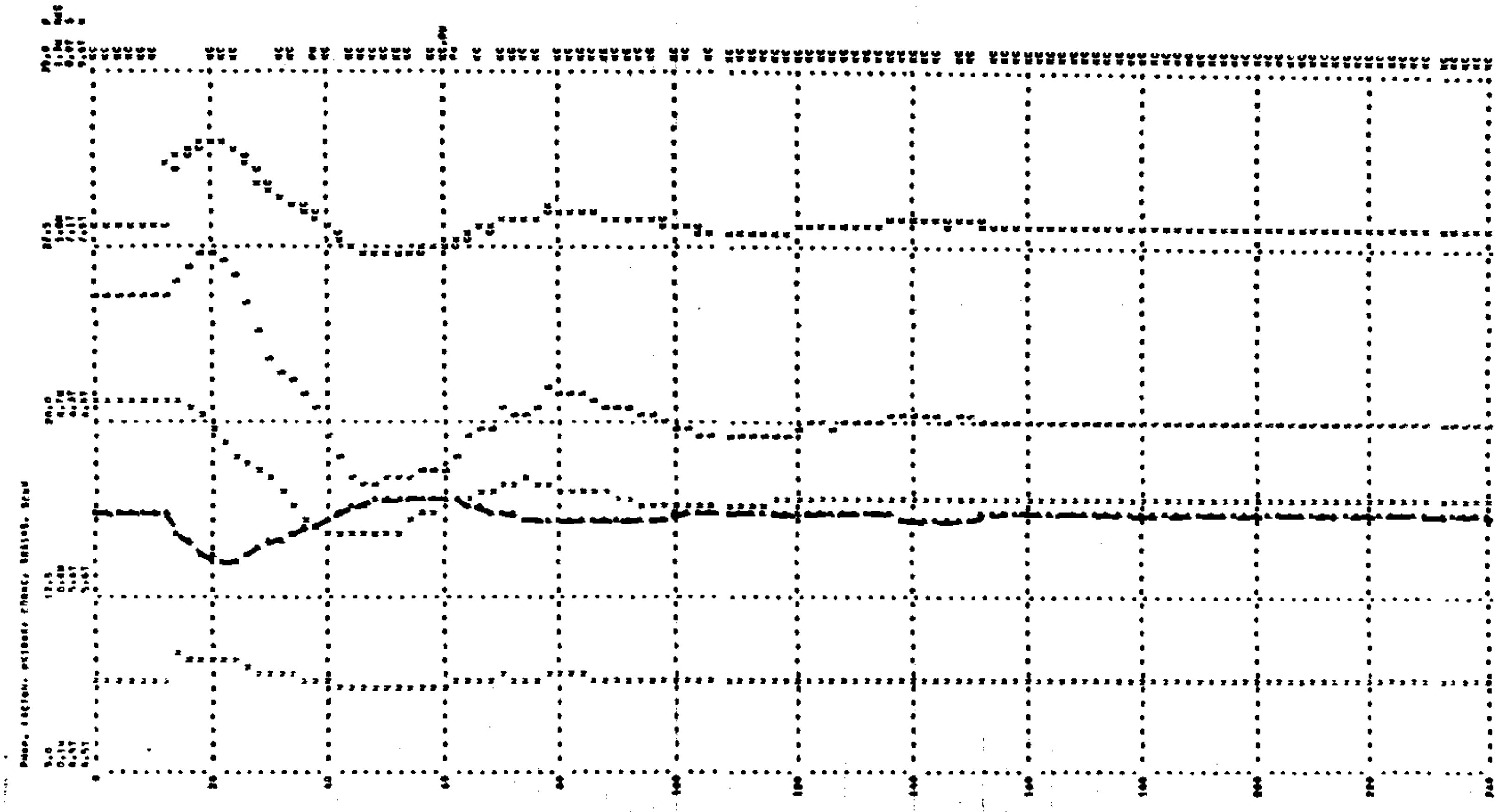

Figure 16. Model, 10% Step, Frozen and Cured Inventory Control Loop Open

less responsive since the period of oscillation is increased substantially. Thus, a trade-off is made between system stability and system responsiveness.

Additional model experiments were made on the meat packers' sector. The price adjustment parameter reflects the packers' pricing responsiveness to a net difference in the average rate of sales and the expected pork availability. Doubling the value of PAJT indicates that the packers are less enthusiastic toward changing their input cost and vice versa. Figures 17 and 18 show model behavior using two different values of PAJT. Under these two conditions the model behavior changes dramatically from that of the basic model. Using PAJT = 100,000 small amplitude variations occur in the price, production, and consumption related variables. Conversely, using PAJT = 37,500, large amplitude fluctuations develop in the model behavior.

Retailing and Consumption Sectors

The retailing and consumption sectors are believed to be relatively unimportant model features. The insensitive nature of the parameter values in the control and coupling loops confirms that a wide range of parameter values can be used in the policy mechanisms without changing the basic behavioral characteristics.

The following values were tested in the parameters of the retailing and consumption sector:

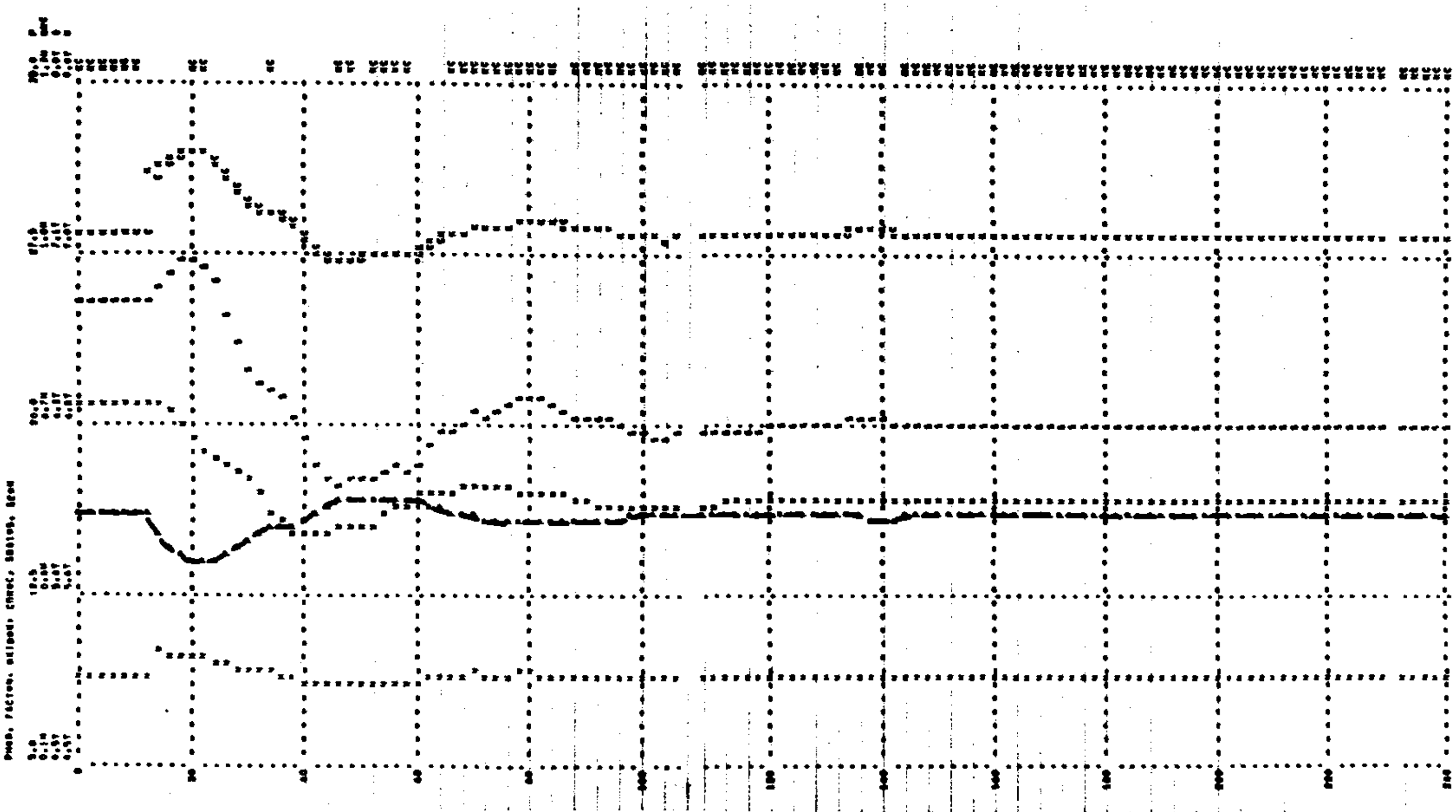

Figure 17. Model, 10% Step, Increased Price Adjustment Parameter, PAJT = 100,000

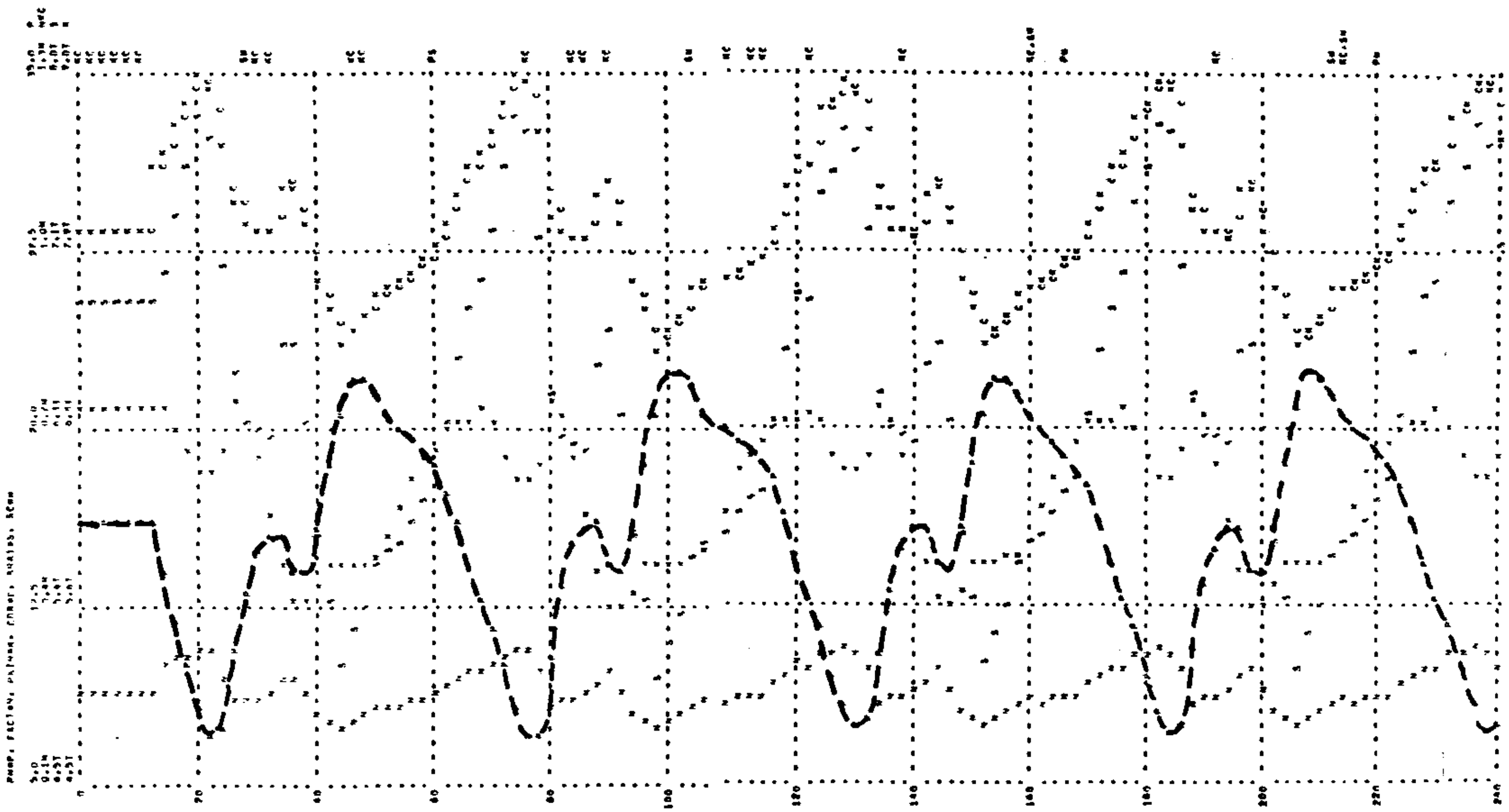

Figure 18. Model, 10% Step, Reduced Price Adjustment Parameter, PAJT = 37, 500

(1) BAJT = .5, 1.0, and 1.5 months

(2) TACD 1.0 and 3.0 months

(3) TARD 1.0 and 3.0 months

(4) RAJT 2.0 and 3.0 months

(5) TTCDR = .5 and 3.0 months

The retailing inventory control loop was taken out of the model in order to test the controlling features relative to retail inventory. Under this model condition, the system behavior remained almost identical.

Only one parameter, ROAJT, was found to be critical in the retailing and consumption sectors. The meat packers attempt to sell all of their pork supplies, with only a small quantity held as a safety stock. Retailers adjust their ordering rate to the pork offered for sale by the meat packers. Variations in ROAJT produce behavioral patterns which begin to deviate from the basic model's performance. The superior bargaining position of the retailers prevents the packers from accomplishing any significant change in the retailers' adjustment response ROAJT. However, if the packers achieve a stronger position in the market system, the parameter will become a more significant feature.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The main body of the thesis develops the research objectives. The model analysis of Chapter V provides insight into the dynamic nature of the cyclic fluctuations in the pork production - consumption system. Drawing upon the model analysis, several conclusions are evident and recommendations for further research and analysis are suggested.

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 importance of the broad conclusions and recommendations is germane to the level of study. One general conclusion and four specific conclusions are presented below. Following the conclusions, three recommendations are presented.

General Conclusion

The purpose of this research was to explain how the long-term dynamics are created in the pork system. To fulfill that purpose 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 research, 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 behavior. 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 marketings being greater or less than needed to maintain equilibrium price conditions. Loop analysis in the hog inventory control loop indicated the sensitive nature of the producer adjustment time HAJT 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 HAJT 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 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, PAJT and to the hog producers' adjustment parameter HAJT.

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 TAHP. Shortening the delay coupled the packers' sector and producers' sector more tightly and vice versa. Tighter coupling led to greater system 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 errors in the meat packers' sector cause 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 supplies 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.

APPENDICES

LIST OF MODEL EQUATIONS

PORK PRODUCTION/CONSUMPTION SYSTEM TEST MODEL

PRODUCTION CONTROL SECTOR

```
RUN
8A      HPR.KL=ASS.K+HIC.K+ASR.K
1L      PPI.K=PPI.J+(DT)(HPR.JK-PSR.JK)
6N      PPI=3448
54R     PSRA.K=MIN(PSRI.K,MS.K)
6R      PSR.KL=PSRA.K
20A     PSRI.K=PPI.K/DI
C       DI=.5
37B     MFRA=BOXLIN(10,1)
36N     MFRA=BOXLOAD(CC,1)
C       CC=6896.6
6A      MFRA*1.K=PSR.JK
7R      MFR.KL=MFRA*10.K*GHA.K
1L      MHI.K=MHI.J+(DT)(MFR.JK-HSR.JK)
6N      MHI=13333.4
20A     MAV.K=MHI.K/DT
12A     HSA.K=MHI.K/DLS.K
58A     DLS.K=TABHL(DLST,APIS.K,10,26,2)
C       DLST*=1/1.3/1.7/2/2.2/2.4/2.6/2.8/3
3L      APIS.K=APIS.J+(DT)(1/TAPIS)(PR.J-APIS.J)
6N      APIS=16
C       TAPIS=6
54R     HSR.KL=MIN(MAV.K,HSA.K)
3L      ASR.K=ASR.J+(DT)(1/TASR)(HSR.JK-ASR.J)
C       TASR=2
6N      ASR=6666.7
58A     FCCA.K=TABHL(FCCAT,AHP.K,10,22,1)
C       FCCAT*=-.16/-.16/-.15/-.14/-.115/-.08/0/.08/.115/.14/.15/.16/.16
7A      FCC.K=1+FCCA.K
12A     DMHI.K=(NMHI.K)(FCC.K)
12A     NMHI.K=(ASR.K)(DLS.K)
21A     HIC.K=(1/HAJT)(DMHI.K-MHI.K)
C       HAJT=2
```

CAPACITY CONTROL SECTOR

```
6R      GH.KL=GHA.K
7A      GHA.K=NSAC.K+ASS.K
39R     GHRR.KL=DELAY3(GH.JK,2)
52L     SCAB.K=SCAB.J+(DT)(GHRR.JK+SFNR.JK-SS.JK-SBR.JK)
6N      SCAB=985.22
20R     SBR.KL=PSRA.K/PPS
C       PPS=7
39R     SFR.KL=DELAY3(SBR.JK,4)
39R     SFNR.KL=DELAY3(SFR.JK,2)
7R      SS.KL=SSR.K+SSC.K
8A      SC.K=SCAB.K+SIG.K+SW.K
1L      SIG.K=SIG.J+(DT)(SBR.JK-SFR.JK)
6N      SIG=3940.8
```

```
1L      SW.K=SW.J+(DT)(SFR.JK-SFNR.JK)
6N      SW=1970.4
12A     MS.K=(SCAB.K)(PPS)
52L     AHPR.K=AHPR.J+(DT)(1/TAHPR)(HPR.JK-AHPR.J)
6N      AHPR=6896.6
C       TAHPR=1
13A     DPPI.K=(PPS)(DT)(SCAB.K)
21A     PPIC.K=(1/PPIJT)(PPI.K-DPPI.K)
C       PPIJT=.75
21A     SCDB.K=(1/PPS)(AHPR.K+PPIC.K)
21A     SCC.K=(1/CAJT)(SCDB.K-SCAB.K)
C       CAJT=.75
56A     SSC.K=MAX(0,-SCC.K)
56A     NSAC.K=MAX(0,SCC.K)
20A     SSR.K=SC.K/SL
C       SL=30
3L      ASS.K=ASS.J+(DT)(1/TASS)(SSR.J-ASS.J)
6N      ASS=229.89
C       TASS=2

        MEAT PACKING CONTROL SECTOR

8A      SRA1.K=SSR.K+SSC.K+HSR.JK
12R     PKIR.KL=(SRA1.K)(PKPH.K)
7A      PKPH.K=PKC+PTEST.K
45A     PTEST.K=STEP(15,PIN)
C       PIN=12
C       PKC=145
1L      FAC1.K=FAC1.J+(DT)(PKIR.JK-STR.JK)
6N      FAC1=250000
3L      DPKIR.K=DPKIR.J+(DT)(1/TPKP)(PKIR.JK-DPKIR.J)
6N      DPKIR=1000000
C       TPKP=.75
3L      FPKIR.K=FPKIR.J+(DT)(1/TAPKI)(PKIR.JK-FPKIR.J)
C       FPKIR=1000000
C       TAPKI=2
21A     DPSR.K=(1/ICOA.K)(FACIC.K+DPKIR.K)
12A     FACIC.K=(FAC1.K)(1)
7A      ICOA.K=1+ICOD
C       ICOD=.25
21A     EPA.K=(1/ICOA.K)(FACIC.K+FPKIR.K)
21A     CP.K=(1/PAJT)(ARD.K-EPA.K)
C       PAJT=50000
1L      PH.K=PH.J+(DT)(CP.J+0)
6N      PH=16
3L      AHP.K=AHP.J+(DT)(1/TAHP)(PH.J-AHP.J)
6N      AHP=16
C       TAHP=5
```

RETAILING CONTROL SECTOR

```
54R    STR.KL=MIN(FAV.K,STRA.K)
20A    FAV.K=FACI.K/DT
7A     STRA.K=NRO.K+ROJ.K
1L     RI.K=RI.J+(DT)(STR.JK-CDR.JK)
6N     RI=1000000
12A    DRI.K=(ACD.K)(TTRI)
C      TTRI=1
21A    RIC.K=(1/RAJT)(DRI.K-RI.K)
C      RAJT=1
7A     NRO.K=ACD.K+RIC.K
21A    ROJ.K=(1/ROAJT)(DPSR.K-NRO.K)
C      ROAJT=1
3L     ARD.K=ARD.J+(DT)(1/TARD)(STR.JK-ARD.J)
6N     ARD=1000000
C      TARD=2.5
```

CONSUMPTION CONTROL SECTOR

```
54R    CDR.KL=MIN(RAV.K,CDRA.K)
20A    RAV.K=RI.K/DT
7A     CDRA.K=TCDR.K+CPJ.K
3L     ACD.K=ACD.J+(DT)(1/TACD)(CDR.JK-ACD.J)
6N     ACD=1000000
C      TACD=2.5
3L     TCDR.K=TCDR.J+(DT)(1/TTCDR)(CDR.JK-TCDR.J)
6N     TCDR=1000000
C      TTCDR=2
12A    NP.K=(TCDR.K)(1)
21A    CPJ.K=(1/BAJT)(RI.K-NP.K)
C      BAJT=.5
PRINT  1)HPR,PPI,PSRA,PSR,PH/2)MS,MFR,HSR,ASR,GH/3)SS,SSR,SSC,NSAC,NSAC/4
X1     )MHI,DMHI,NMHI,HI,,FCC/5)PPI,DPPI,PPIC,AHPR,SCDB/6)SCAB,SW,SIG,SC,
X2     SGR/7)SFR,SFNR,SCC/8)SRA1,PKIR,FPKIR,DPKIR/9)STR,CDR,ARD,ACD,TCDR/
X3     10)FAV,STRA,RAV,CDRA/11)FACI,RI,DRI,RIC/12)AHP,ARD,CP,PH,PH/13)RI,
X4     NP,CPJ,DPSR/14)HSA,DLS
PLOT   PH=P(5,35)/FACI=N,PKIR=K,CDR=C(.1E6,1.25E6)
PLOT   SC=W(4000,8000)/SFR=F,SS=Z(0,1500)/SCC=O(-700,1400)
PLOT   PH=P(5,35)/HPR=1,SRA1=S(1500,9500)/HIC=G(-900,3600)
PLOT   PH=P(5,35)/FACI=N,PKIR=K,CDR=C(.1E6,1.25E6)/SRA1=S(1500,9500)/SC=W
X1     (4000,8000)
SPEC   DT=.1/LENGTH=288/PRTPER=24/PLTPER=2
```

LIST OF VARIABLES AND PARAMETERS

Production Control Sector

HPR	- Hog Production Rate (intentions/month)
PPI	- Pig Production Intentions (intentions)
PSRA	- Pig Start Rate Auxiliary (pigs/month)
PSR	- Pig Start Rate (pigs/month)
PSR1	- Pig Start Rate One (pigs/month)
D1	- Delay one (months)
MFRA	- Mature Finish Rate Auxiliary (hogs/month)
FC	- Feeding Constant (months)
CC	- Constant For Boxload (hogs)
MFRA*1	- Mature Finish Rate Auxiliary for Car One (hogs/month)
MFR	- Mature Finish Rate (hogs/month)
MHI	- Mature Hog Inventory (hogs)
MAV	- Maximum Availability (hogs/month)
HSA	- Hog Shipping Auxiliary (hogs/month)
DLS	- Delay For Shipping (months)
DLST	- Delay For Shipping Tab hl (months)
APIS	- Average Price Influence on Shipping (cents)
TAPIS	- Time for Averaging Price Influence on Shipping (months)
HSR	- Hog Shipping Rate (hogs/month)
ASR	- Average Shipping Rate (hogs/month)
TASR	- Time For Averaging Shipping Rate (months)
FCCA	- Fraction Change Auxiliary (1/month)
FCCAT	- Fraction Change Auxiliary Table (1/month)
FCC	- Fraction Change (1/month)
DMHI	- Desired Mature Hog Inventory (hogs)
NMHI	- Normal Mature Hog Inventory (hogs)
HIC	- Hog Inventory Correction (hogs/month)
HAJT	- Hog Adjustment Time (months)

Capacity Control Sector

GHA	- Gilts Held Auxiliary (hogs/month)
GH	- Gilts held (hogs/month)

GHRR - Gilts Held Ready Rate (hogs/month)
SPC - Sow Preparation Constant (months)
SCAB - Sow Capacity Available for Breeding (hogs)
SBR - Sow Breeding Rate (hogs/month)
PPS - Pigs Per Sow (pigs/hog)
SFC - Sow Farrowing Constant (months)
SWC - Sow Weaning Constant (month)
SFR - Sow Farrowing Rate (hogs/month)
SFNR - Sow Finish Rate (hogs/month)
SS - Sow Shipments (hogs/months)
SC - Sow Capacity (hogs)
SIG - Sows In Gestation (hogs)
SW - Sows Weaning (hogs)
MS - Maximum Starts (pigs/month)
AHPR - Average Hog Production Rate (hogs/month)
TAHPR - Time for Averaging Hog Production Rate (months)
DPPI - Desired Pig Production Intentions (intentions)
PPIC - Pig Production Intentions Corrections (intentions/month)
PPIJT - Pig Production Intentions Adjustment Time (months)
SCDB - Sow Capacity Desired for Breeding (hogs)
SCC - Sow Capacity Correction (hogs/month)
CAJT - Capacity Adjustment Time (months)
SSC - Sow Shipment due to Corrections (hogs/month)
NSAC - New Sow Added due to Corrections (hogs/month)
SSR - Sow Scrap from Replacement (hogs/month)
SL - Sow Life (month)
ASS - Average Sow Scrap (hogs/month)
TASS - Time for Averaging Sow Scrap (hogs/month)

Meat Packing Control Sector

SRA1 - Shipping Rate Auxiliary (hogs/month)
PKIR - Pork Input Rate (lbs/month)
PKPH - Pork Per Hog (lbs/hog)
PTEST - Pork Test Step (lbs/hog)
PKC - Pork Constant (lbs/hog)
FACI - Frozen and Cured Inventory (lbs)
DPKIR - Delayed Pork Input Rate (lbs/month)
TPKP - Time for Pork Processing (months)
FPKIR - Forecasted Pork Input Rate (lbs/month)
TAPKI - Time for Averaging Pork Input (months)
FACIC - Frozen and Cured Inventory Carryover (lbs/month)

ICOD	- Inventory Carryover Desired (months/month)
ICOA	- Inventory Carryover Auxiliary (dimensionless)
DPSR	- Desired Packer Sales Rate (lbs/month)
EPA	- Expected Pork Availability (lbs/month)
CP	- Change in Price (cents/lbs-month)
PAJT	- Price Adjustment Parameter (lbs^2/cent)
PH	- Price of Hogs (cents/lb)
AHP	- Average Hog Price (cents/lb)
TAHP	- Time for Averaging Hog Price (months)

Retailing Control Sector

STR	- Sales to Retailers (lbs/month)
FAV	- Frozen Pork Availability (lb/month)
STRA	- Sales to Retailers Auxiliary (lbs/month)
RI	- Retailers' Inventory (lbs)
DRI	- Desired Retailers' Inventory (lbs)
TTRI	- Turnover Time Retailers' Inventory (months)
RIC	- Retailers' Inventory Correction (lbs/month)
RAJT	- Retailers' Inventory Adjustment Time (months)
NRO	- Normal Retail Order (lbs/month)
ROJ	- Retailers' Order Adjustment (lbs/month)
ROAJT	- Retailers' Order Adjustment Time (months)
ARD	- Average Retailers' Demand (lbs/month)
TARD	- Time for Averaging Retailers' Demand (months)

Consumption Control Sector

CDR	- Consumers' Demand Rate (lbs/month)
RAV	- Retailers'' Inventory Availability (lbs/month)
CDRA	- Consumers' Demand Rate Auxiliary (lbs/month)
ACD	- Average Consumers' Demand Rate (lbs/month)
TACD	- Time for Averaging Consumers' Demand Rate (months)
TCDR	- Traditional Consumers' Demand Rate (lbs/month)
TTCDR	- Time for Averaging Traditional Consumers' Demand Rate (month)
NP	- Normal Purchases (lbs)
CPJ	- Consumers' Purchase Adjustment (lbs/month)
BAJT	- Buying Adjustment Time (months)

LIST OF PARAMETER VALUES

The following model parameters were selected as being representative of the physiological production delays, pork processing delays, and averaging and adjustment times within the pork production-consumption system. These values were used in the basic model run of Figures 7, 8, and 9.

Production Control Sector

Parameter	Explanation
D1 = .5 month	Time to prepare and breed a sow
FC = 10 month	Time required for gestation period and feeding a pig to minimum market weight
DLST = TABLE	Table values in months of average time taken to finish feed a hog to market shipping weight (beyond the minimum market weight)
TAPIS = 6 months	Smoothing constant for averaging price influence on shipping
TASR = 2 months	Smoothing constant for averaging shipping rate
FCCAT = TABLE	Expansion and contraction fractions obtained from an analysis of hog price data and production levels
HAJT = 2 months	Time taken to adjust any difference between desired hog inventory and actual hog inventory

Capacity Control Sector

Parameter	Explanation
SPC = 2 months	Time to prepare a minimum weight gilt for breeding

PPS = 7 pigs/sow	The average number of pigs saved per sow farrowing
SFC = 4 months	Time required for gestation period
SWC = 2 months	Time required for weaning period
TAHPR = 1 month	Smoothing constant for averaging hog production rate
PPIJT = .75 month	Time taken to adjust the backlog error of pig intentions
CAJT = .75 month	Time taken to adjust the sow capacity error
TASS = 2 months	Smoothing constant for averaging sow market shipments

Meat Packing Control Sector

Parameter	Explanation
PTN = 12 pounds	Magnitude of a 10% step in the weight of pork yield per market hog
PKC = 145 pounds	Average yield of pork per market hog
TPKP = .75 month	Smoothing constant for averaging pork input and throughput rate
TAPKI = 2 months	Smoothing constant for averaging pork input rate
ICDD = .25 month	Value of desired frozen and cured inventory
PAJT = 50,000 lbs^2/cent	Value of price adjustment parameter
TAHP = 5 months	Smoothing constant for averaging hog prices

Retailing Control Sector

Parameter	Explanation
TTRI = 1 month	Turnover time for retailers' inventory
RAJT = 1 month	Time taken to adjust retail inventory error
ROAJT = 1 month	Time taken to adjust retailers' ordering
TARD = 2.5 months	Smoothing constant for averaging retailers' demand to meat packers

Consumption Control Sector

Parameter	Explanation
TACD = 2.5 months	Smoothing constant for averaging consumer demand to retailers
TTCDR = 2 months	Smoothing constant for averaging traditional consumer demand
BAJT = .5 months	Time taken to adjust consumer buying.

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VITA

Robert Davis Landel was born in Birmingham, Alabama on February 23, 1940. He is the son of Helen Davis Landel and Alden William Landel. He graduated from Shades Valley High School in Birmingham, Alabama, in June 1958.

In September 1958, he began engineering studies at the Georgia Institute of Technology, Atlanta, Georgia. While attending Georgia Tech he was elected to membership in Pi Tau Sigma (honorary mechanical engineering fraternity). He was a member of the Freshman and Varsity Tennis Teams, Sigma Chi Fraternity and the Student Council. He served as vice-president and secretary of Sigma Chi during his sophomore and junior year. In June 1962, he graduated from Georgia Tech with the degree, Bachelor of Mechanical Engineering.

After completing the engineering studies, Mr. Landel entered the graduate program in Industrial Management at Georgia Tech. During his graduate studies he taught in the Industrial Management Department. In December 1963 he was awarded the degree, Master of Science in Industrial Management.

Mr. Landel then joined the Westinghouse Electric Corporation in Pittsburgh, Pennsylvania as a trainee in the Advanced Industrial Engineering Program. After completing this program, he worked as an Industrial Engineer in the Air Conditioning Division, Staunton, Virginia. In this assignment he worked on the analysis and design of a material flow system in the maching and assembly operations. He then was assigned to the Materials Control Department as the Buyer of Raw Materials.

On June 13, 1964, Mr. Landel was married to the former Helen Elaine Brokhoff of Atlanta, Georgia, daughter of Dr. and Mrs. John R. Brokhoff.

In September 1966, Mr. Landel entered the doctoral program in Industrial Engineering at Georgia Tech. With the financial assistance of a National Aeronautics and Space Administration Fellowship, he pursued his graduate studies and research on a full time basis. While a graduate student, he was elected to membership in Alpha Pi Mu (honorary industrial engineering fraternity).

During these years, two children were born into the Landel family - Elizabeth Ann and Julie Lynn.

On September 1, 1969 Mr. Landel was appointed Assistant Professor of Business Administration in the Graduate School of Business Administration at the University of Virginia, Charlottesville, Virginia. In that position he will be teaching in the areas of management systems analysis and operations research.