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A Revision of Harlow's Recursive Cobweb Model for the Hog Industry from 1960 to 1968

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A REVISION OF HARLOW'S RECURSIVE COBWEB

MODEL FOR THE HOG INDUSTRY

(TITLE)

FROM 1960 TO 1968

BY

JAMES DAVID STEWART

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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

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INTRODUCTION

The problem of recurrent cycles in the production and prices of various agricultural commodities and livestock, along with the consequent distortion of optimal resource allocation and inefficiency, forms the basic framework of this paper.

Specifically, the objective of this study is to develop a recursive system of equations which will explain a major part of the variation in price and production levels for the hog industry. The value of such a model will be evident as an explanation of the structural behavior of the hog cycle and as an aid in accurate forecasting.

The cobweb theorem, which is hypothesized as the theoretical explanation of the hog-cycle, will be discussed in the first chapter of this thesis.

Following a review of the origin, assumptions, limitations, and criticisms of the cobweb theorem in Chapter I, the second chapter will describe specific applications of the theorem to certain agricultural commodities and livestock. In addition, major studies, conducted by prominent agricultural economists and statisticians, will be reviewed as background for the revised model developed in the latter part of this paper.

The third chapter will be devoted to a brief explanation of Harlow's original model and a description of the variables and sources of data used in the revised model.

After introducing Harlow's original recursive model, Chapter IV presents a discussion of the expected results along with supplementary material. Immediately following the expected results, Chapter V presents the fitted regression system. The actual results are explained by a series of summary tables for each equation in the system.

Finally, Chapter VI summarizes the major results, and draws conclusions and implications from this study. As will be evident to the reader, the problem of uncertainty, resulting from unpredictable prices and quantity fluctuations, will also be considered in terms of recommendations advanced by prominent economists.

CHAPTER I

A REVISION OF HARLOW'S RECURSIVE COBWEB MODEL FOR THE HOG INDUSTRY FROM 1960 TO 1968.

The Origin, Underlying Assumptions, and Limitations of the Cobweb Theorem

Disequilibrium, rather than equilibrium, characterizes the actual state of affairs in most markets of a private enterprise economy. A state of equilibrium specifies the condition under which wants and scarcity are precisely balanced by the market mechanism; while disequilibrium or instability implies that adjustments are not rapidly occuring in response to changing market conditions. This concept appears to be valid, considering the fact that some disturbances persist for long periods of time before an equilibrium is attained, or continue indefinitely without ever reaching a stable equilibrium.[1]

Recurrent cyclical fluctuations in the prices and production of certain agricultural commodities or livestock have been recognized for more than fifty years, but the mechanism responsible for this behavior was not explained until three economists from Italy, Holland, and the United States independently formulated a theoretical explanation. Due to the appearance of its graphical pattern, formed after connecting associated price and supply points, this theoretical explanation was termed the "Cobweb theorem."

While the Cobweb theorem was originally expounded in 1930 by H. Schultz, J. Tinbergen, and O. Ricci, subsequent research and publications by Moore, Hanau, Leontief, Kaldor, Frisch, and Ezekiel served to clarify and strengthen the theorem. The classic paper on the Cobweb theorem did not appear until 1938, when Mordecai Ezekiel presented its origin, assumptions, and limitations.[2]

Dynamic states of cyclical behavior, associated with the Cobweb model, are caused by shifting demand curves, which reflect changes in tastes and incomes; and by shifting supply curves, which reflect changes in technology and resource limitations. As a result of this continuing process, price and output levels may fluctuate widely over time.[3]

According to Cochrane, the Cobweb theorem is a semi-dynamic type of supply and demand analysis which has been applied to selected agricultural commodities and livestock. Two central concepts relating to supply over time must be recognized. First, a supply relation must exist which describes planned production at various prices or, in other words, a schedule of intentions to produce. Secondly, there must be a supply function to indicate quantities available for market at various prices. Since it is assumed that most farm products are perishable and storage facilities are relatively scarce, the latter supply function or market supply curve, must be highly inelastic with respect to price changes.[4]

Assuming the basic concepts previously discussed, the three original theorists each presented an analytical model. Schultz was the first to formulate a simple model of the convergent case, while Tinbergen and Ricci presented complete models of the convergent, continuous, and divergent types. The three theorists, however, failed to recognize the broader relationship of the Cobweb theorem to economic theory in general. Since the theory was formulated, it has remained substantially unchanged in the form stated by its originators.[5]

Before introducing the three cases, it is necessary to review the following required conditions: (1) Production must be solely determined by producers' responses to price under conditions of pure competition; (2) Production plans are formulated on the basis of continued price levels, and on the assumption that these plans will not materially affect the market; (3) The time required for production is set and cannot be varied for a minimum of one period after definite plans have been formulated; and (4) Price is determined by the available supply.[6]

After reviewing the underlying theoretical assumptions, three distinct cases of the Cobweb theorem will be defined and described in terms of the elasticity relationship of supply and demand. They are classified as being either the continuous, convergent, or divergent types. For purposes of illustration, each case will also be presented graphically. The models and associated explanations were obtained from Agricultural Price Analysis, by Geoffrey Shepherd, a noted economist in the field of agricultural marketing and price policy.

The first pattern to be reviewed is the continuous case shown in Figure 1-1 below.

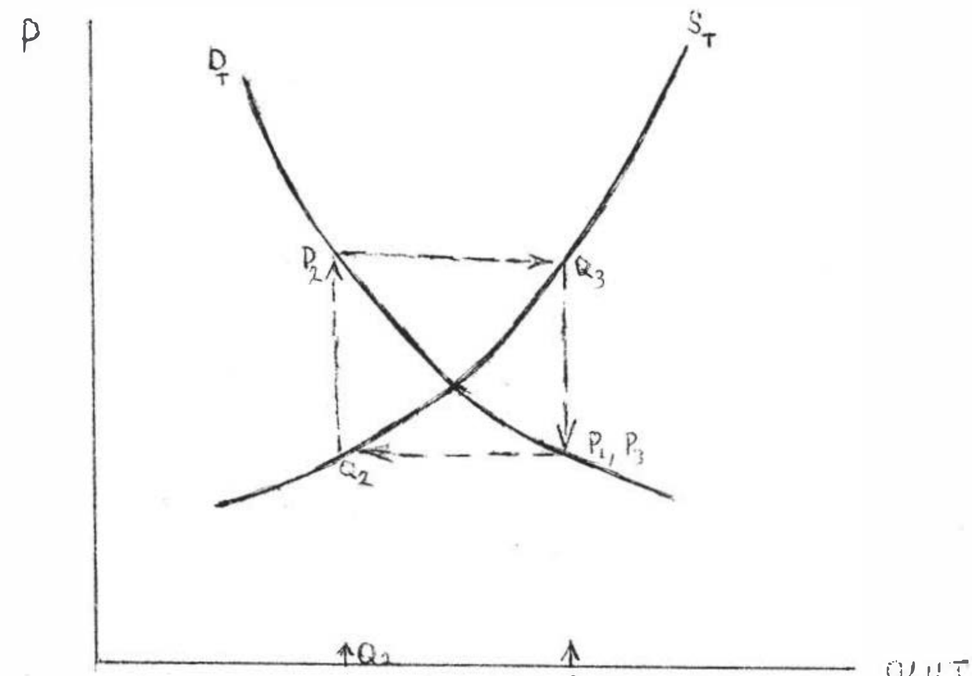

FIGURE 1-1

CONTINUOUS CASE OF THE COBWEB THEOREM

Assuming a large quantity, Q_1, in the initial period, a relatively low price, P_1, is determined at the point of intersection with the demand curve. This low price, at its intersection with the supply curve, induces a relatively short supply, Q_2, in the second period. Since the short supply intersects the demand curve at a high price, P_2, it consequently causes an increase in production to Q_3, with its corresponding low price, P_3, in the third period. As shown in Figure 1-1, price in the third period, P_3, is identical to the original price in the first period, P_1. Thus, production and prices in subsequent time periods can be expected to follow this continuous pattern.

A continuous rotating pattern will be present only as long as price is completely determined by current supply, and supply is completely determined by the preceding price. Fluctuations in price and output will continue in this pattern indefinitely, unless disturbed by outside influences, without an equilibrium ever being attained. In this case, the demand curve is the exact reverse of the supply curve, so that at their overlap each has the same absolute elasticity value.[7]

When the elasticity of supply is greater than the elasticity of demand, cyclical reactions fit the divergent case shown in Figure 1-2. Assuming a moderately high level of output in the first period, Q_1, and its associated price, P_1, the second period exhibits a slightly reduced supply level, Q_2, with its correspondingly higher price, P_2. As a result of the higher price, supply increases substantially to Q_3, followed by a reduction in price to P_3. This is followed by a sharp decline in supply to Q_4, and a higher price, P_4, in the fourth period. The process of expanding supply or output continues in subsequent periods, assuming the previous conditions. Thus, the situation may grow increasingly unstable until price falls to absolute zero, or production is discontinued, or until the amount of available resources is exhausted.[8]

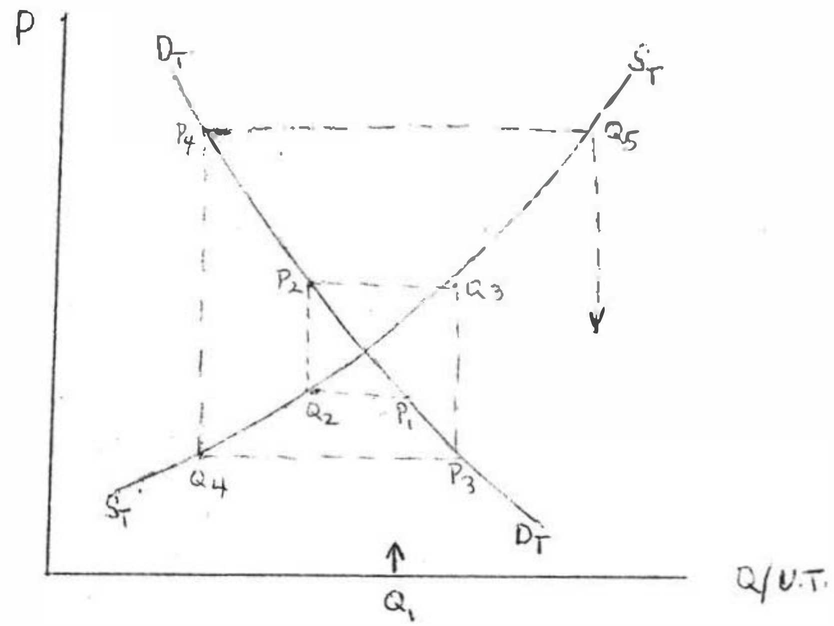

FIGURE 1-2

DIVERGENT FLUCTUATIONS UNDER THE COBWEE THEOREM

If the reverse situation occurs, where supply is less elastic than demand, the convergent pattern illustrated in Figure 1-3 appears. Assuming a large supply in the initial period, Q_1, and its associated low price, P_1, a very short supply, Q_2, and high price, P_2, can be expected in the second period. As a result, production expands to Q_3, in the third period, and becomes moderately lower than the first period. A reduction in supply, Q_4, with its corresponding price, P_4, is called forth in the next period. Continuing periods of price and output fluctuations cause a net movement toward equilibrium, where no further changes result. As illustrated by its graphical pattern, this case most closely fits the classical equilibrium state.[9]

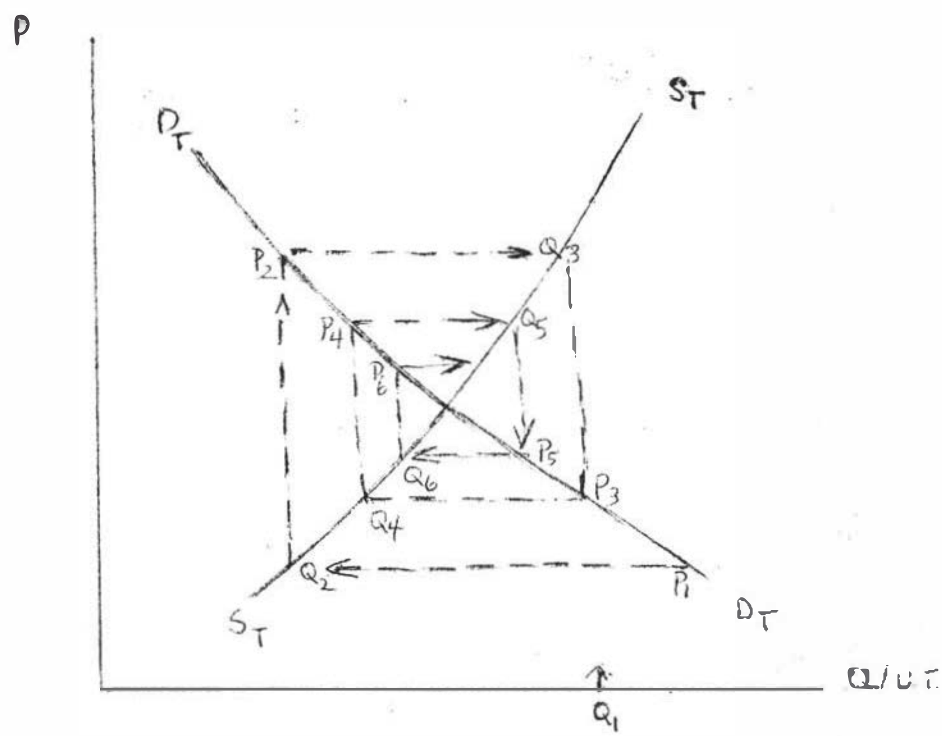

FIGURE 1-3

CONVERGENT PATTERN OF THE COBWEB THEOREM

Each pattern depends upon the initial position of the supply and demand curves, and the presence of time lags in response to market changes. The initial position of the supply and demand curves determines the slope and range of a cycle, while the length or duration is determined by lags between the price and marketing of products.[10]

In many instances, existing lags are caused by producers' expectations. For example, assume that a farmer produces a certain commodity and sells it at a given market price. If he expects this price to remain at its present level in the future, his production plans will respond accordingly. If, however, the price is believed to be only temporary, the farmer's response in terms of production will be slight or nil. In other words, the effect of current prices on producers' decisions may vary greatly in intensity over a given time period. Thus, price during one year may influence production decisions in subsequent time periods, as well as affecting immediate production plans.[11]

After considering the three cases of the cobweb theorem, it is necessary at this point to discuss the rather rigid limitations of the theorem. Since some commodities have either price or production set by administrative decisions, or are highly responsive to changes in demand, they cannot exhibit the true Cobweb pattern. Even for commodities which approximate its strict assumptions, the Cobweb model must be modified. Although future production cannot be increased once plans are made, the potential supply may be reduced by deliberately destroying crops or letting them go unharvested, or by slaughtering livestock instead of fattening them for market.

In fact, few commodities can be expected to precisely exhibit one-period, two-period, or even throe-period supply reactions. Production may be partially influenced by previous commodity price levels and by the price level of essential inputs, such as corn in the production of hogs. Perhaps a more serious limitation, however, is reflected by the production process itself. For example, total crop yields depend upon weather conditions and yields per acre, as well as total acreage. Natural variations in production may result in abnormally high or low yields, and may cause new cyclical reactions. In some cases, a combination of crop failures with the Cobweb reaction leads to instability, thereby reinforcing cyclical fluctuations.[12]

A final limitation of the Cobweb theorem is that no commodity presently exists whose supply alone determines its selling price. In fact, many commodities, especially farm products, exhibit great variations in price and output levels due to the influence of external factors other than supply changes alone. Tariffs, quotas, freight rates, weather conditions, and style changes are examples of additional factors which contribute to cyclical reactions.[13]

Suggesting the value and limitations of the theory, Mordecai Ezekiel made the following statement:

> The Cobweb theorem . . . should be used as an hypothesis in studying the interactions of supply and demand only for those commodities whose conditions of pricing and production satisfy the special assumptions on which it is based, not as a blanket explanation of all industrial cycles.[14]

While the Cobweb theorem is generally considered valid under its assumptions, a few economists such as Gustav Akerman have criticized Ezekiel and his predecessors for not being precise in stating the causes for disturbances from an original equilibrium state. Akerman contends that Ezekiel and others mention only in passing the general causes of disturbances. For example, unusual weather or the prosperity of consumers, which would presumably affect all farm products similarly, should not produce a Cobweb pattern. Thus, according to Akerman, only when selected commodities reveal exceptionally strong or reduced demand will production be expanded or contracted, thereby causing the Cobweb pattern to appear.[15] The principal difference between Akerman and Ezekiel appears to involve the definition of a market supply curve. The following statement by Akerman indicates the nature of his criticism:

> All the . . . students of the Cobweb phenomena have operated with one unique normal supply schedule without distinguishing between short and long-term schedules. This is the main reason whythey have ascribed quite exaggerated properties to the Cobweb phenomena.[16]

The definitional differences between Akerman and Ezekiel certainly do not invalidate the Cobweb theorem, and at best they might only weaken the theory as an explanation of cyclical behavior for certain commodities. Rather than a perfectly inelastic supply curve assumed by Ezekiel, Akerman assumes a highly inelastic, but less than perfectly inelastic supply curve in his analysis.[17]

CHAPTER II

Applications of the Cobweb Theorem to Certain Agricultural Commodities and Livestock

After discussing the theoretical aspects of the cobweb theorem, it seems appropriate at this point to explore its possible applications to various selected commodities. Rather than generating actual prices and quantities produced of a commodity, the cobweb theorem's applicability is generally limited to describing general price-output patterns over a range of time. In order to generate actual prices and quantities, a model expressing three functional relationships must be accurately derived: (1) the demand schedule for the commodity; (2) the schedule of intentions to produce; and (3) the market supply curve. In addition, these functions must shift over time according to external forces which operate continuously in the market.[18]

The cobweb analysis has been used to conceptualize the price-output behavior of potatoes, beef, hogs, and to a limited extent, milk, over time. The major studies which apply the theorem to these commodities will be briefly reviewed herein. A two-year model for potatoes, derived by Milton Shuffett, appears consistent with the potato growth period. Since potatoes are planted, grown, and sold in one year; and it is assumed that prices in the previous year, or the previous two years affect current potato production, the model reasonably approximates the commodity's structural characteristics.[19]

The slopes of the demand function and the schedule of intentions to produce created a slowly converging pattern in which the prices of potatoes oscillated about the general price level in a wide orbital pattern. Comparing the pattern for potatoes to that for milk and hogs, the price out-put patterns for potatoes seems significantly wider in orbit. This behavior may be explained by the relatively low elasticities of demand and the schedule of intended production, and by the assumption of a completely inelastic market supply function. Thus, the three relations, expressed within a dynamic recursive model, provide an adequate explanation for the relatively wide price fluctuations.

The potato model previously discussed converges and eliminates price variations about the general price level. Although this process might elapse over a considerable length of time, it would ultimately occur unless other external factors disturbed the original relations. Obviously, the cobweb model does not precisely generate such a pattern of actual price fluctuations. Historically, potato price variations have not fallen into regular two-year cycles; instead, they have exhibited unpredictable patterns of two, three, or even four-years' duration.[20]

Over a period of time, the cobweb model for potatoes deteriorates yielding an irregular pattern of price variability for a number of reasons. First, a common cause involves a change in the demand for the commodity. If, in fact, the demand for potatoes changes during its growth period, the price-output pattern will certainly be disturbed. Secondly, any changes in the schedule of intentions to produce from one year to the next, which might result from technological advancement, can also break the recurrent cobweb cycle. Thirdly, the assumption that planned production will be realized in each case may not be valid under actual conditions. Variations in weather, soil fertility, or other factors may account for this disturbance. For the previously stated general reasons, evolving out of several specific causes, the recurrent price-output path of the cobweb model may be broken.

Another agricultural commodity, milk, fits the cobweb pattern poorly compared to other commodity and livestock types. While the analysis generally assumes a distinct growth or production period between decisions to produce and sell, milk production is continuous, with the exception of limited seasonal variation. Thus, the major problem, according to Cochrane, involves the selection of an appropriate time period to construct the model.[21]

A six-month cycle, consisting of two sub-periods, has been employed to remove some of the limitations imposed by the structural nature of milk production. All prices and quantities are seasonally adjusted to remove other factors from the analysis. The results indicate that the model is not consistent with distinct production periods, because none exist in this case. The analysis is not rendered useless, however, because milk prices in one three-month sub-period influence output in the succeeding period. The analysis revealed that a perfectly inelastic market supply curve is reasonable for a highly perishable commodity such as milk.

Estimates of the demand function and the schedule of intended production in the analysis also seem reasonable based on past experience. The interaction of an inelastic demand relation with an extremely inelastic schedule of intentions to produce creates a rapidly converging cobweb pattern . Therefore, year-to-year or season-to-season price variations about the general farm price level are minimized.[22]

While the cobweb analysis has been applied to livestock such as beef and hogs, more research has been focused on the production and price cycle for hogs. One of the earliest studies concerned with the hog industry was conducted by Cox and Luby for the period encompassing 1931 to 1942, and 1947 to 1952. Using a least squares estimation procedure, they developed a prediction model to explain price and production patterns associated with the hog cycle. Since government price controls interferred with normal or free price fluctuations during the war years, this period was omitted from their analysis. The explanatory variables included consumer disposable income, percentage changes in corn prices and supplies, percentage changes in pigs saved, cold storage holdings of pork, and the average price received by farmers for hogs. It is noteworthy at this point to mention that these same factors, plus other variables, will be used in the derivation of the revised model presented in this paper.

During the sixteen years studied, only nine (three annual per three seasons) of the forty-eight forecasts failed to predict the actual direction of price movement. Although this study would be considered rough by current standards, it represents a pioneering effort to explain and predict the direction of price and quantity movements associated with the hog-cycle.[23]

According to another study, conducted by Dean and Heady, the cobweb relationship appears valid as a theoretical framework for explaining recurrent cycles in the price and production of hogs in the United States. Their study focuses on assumed shifts in the supply elasticity for hogs as a possible explanation of cyclical fluctuations. Since the cobweb theorem indicates that a reduction in demand elasticity or an increase in supply elasticity, with other things remaining constant, leads to relatively wider price fluctuations, the authors hypothesized that the elasticity of supply for hogs had increased and the demand elasticity had decreased in recent years.

The hypothesis of an increased supply elasticity for hogs suggests that farmers may be more flexible in shifting between enterprises, especially during periods of substantial price fluctuations. Improvements in facilities, and technical skill and equipment developments, combined with a reduction in required production time, have contributed to the increased supply elasticity suggested by Dean and Heady. The rationale underlying such a lower demand elasticity for hogs is directly related to changes in consumer preferences for various types of meat. In recent years, pork has been a less acceptable substitute for beef, poultry, and other competing meats.[24]

To allow for possible structural changes in the hog economy over time, Dean and Heady divided their study into two periods from 1924 to 1937, and from 1938 to 1956. Using a least squares statistical method to fit the system of multiple regression equations, the authors developed a model to explain the hog-cycle. Explanatory variables such as the number of spring farrowings, the hog-corn price ratio, stocks of related grains, average beef cattle prices, and the ratio of beef cattle to hog prices were included in the analysis.

After interpretting their results, Dean and Heady reached the following conclusion:

> The study provided support for the hypothesis of an increase over time in the supply elasticity for hogs, at least with regard to the number of sows farrowing in response to hog prices at breeding time. A decrease in the demand elasticity for hogs over time also was estimated. Therefore recent observed wide fluctuations in hog prices may be explained, in part, by both an increase in the supply elasticity and a decrease in the demand elasticity for hogs.[25]

A two-year cobweb model for hogs, developed by Elmer Learn, does not appear consistent with the correct time periods involved in producing and marketing bogs. The relative elasticities of supply and demand in this analysis yielded a convergent price-output path. If left undisturbed, this pattern would eventually converge on the general price level, thereby eliminating any further fluctuations. From experience, however, price variability for hogs does not fall into regularly recurring two-year cycles. Hog price movements may vary through unpredictable patterns of four, five, or as much as seven years' duration.[26]

The reasons accounting for a deterioration of the cobweb pattern are similar to those previously discussed for the potato cobweb cycle. It is unreasonable to assume that the demand relation and the schedule of intended production remain fixed over a period of strictly four or five years. Under realistic conditions, the demand relation may be expected to shift frequently, and the schedule of intentions to produce would shift according to technological factors and price expectations. In addition, the market supply curve for hogs may not be perfectly inelastic; instead it may assume a negative slope during times of high or rising prices, when farmers tend to withhold sows from the market for breeding. Conversely, during periods of low or falling prices, farmers might transport their breeding stock to market for sale and slaughter.[27]

Another econometric model, which estimates demand and price relationships for pork and beef, was developed by Wilbur Maki. His study served as a basis for forecasting quarterly price fluctuations, and encompassed a 32 quarter period from 1949 to 1956. A least squares technique was also employed to fit the model demand and supply relationships. Explanatory variables in this study included consumer disposable income, time, pre-determined price levels, and quantities of pork produced. Accurate price forecasts were based on estimates of per capita production and net quarter-to-quarter variations in cold storage holdings of beef and pork. Given expected changes in beef and pork supplies, Maki's model accurately forecasted the wholesale prices of beef and pork with the standard error for each commodity equal to only five per cent of the average 1949 to 1956 wholesale price level of that commodity.[28]

Maki found that commercial hog slaughter depends upon the degree of variability in sows farrowing approximately seven months earlier, and on variations in hog and corn prices of the preceding six-month period.[29] In addition, Maki found that over 94% of the quarterly variation in wholesale pork prices may be attributed to changes in the quantities of beef and pork and to changes in disposable personal income and tastes of consumers.[30]

Several shorter-term studies of the hog-cycle have been made by Raymond Leuthold, an agricultural economist at the University of Illinois. He developed a recursive cobweb model which identifies and estimates the principal factors affecting weekly and daily fluctuations in the hog market. From Leuthold's research, it appears that more information concerning the demand and supply functions is needed to improve public policy formation and producer-decision-making.

One major point noted in Leuthold's study concerned the acute responsiveness of hogs marketed to the previous day's price in the daily market. This determines the quantity of hogs to be marketed during the following days. On the other hand, offering prices, responded only slightly to daily quantity variations. As a result of slight price responses and large quantity responses, considerable fluctuations may be experienced over time. These fluctuations, depending upon the degree of severity, may increase uncertainty, thereby causing unnecessary costs in planning, financing, and risk aversion. According to Leuthold, these undesirable consequences may call for public or private action to reduce such costs.[31]

As will be evident to the reader in the latter part of this paper, many of the same concepts, techniques, and variables cited in the previous discussion of hog-cycle research were employed to develop Harlow's original model. These factors will be used for the revised model presented later in this thesis. The objective of this, and the preceding chapter, have been to acquaint the reader with the theoretical aspects and methods used in previous studies in order to provide an introduction to the recursive model which follows in the next chapter.

CHAPTER III

Introduction to Harlow's Revised Hog-Cycle Model

As a justification for the cobweb theorem's applicability to the hog industry, Arthur Harlow, a noted economic statistician with the United States Department of Agriculture, contends that the production of hogs probably approximates the rigid assumptions underlying the theorem as well as any agricultural commodity to date. According to Harlow, available evidence indicates that the extension of current prices plays a decisive role in the formation of future production plans; and that production is essentially rigid once sows are bred, at least on the upward side. These concepts are in agreement with the previously mentioned assumptions that: (1) future production plans for the next period are formulated on the basis of current prices; (2) production plans, once finally determined, must remain unchanged until the following time period; and (3) price is determined by the intersection of the demand curve with a vertical supply function.[32]

The price-output relationship suggested by the cobweb model for hogs is extremely simplified. In fact, many external factors may cause fluctuations in pork production and the prices received by farmers over time. For example, the number of sows farrowing, the number of pigs per litter, the availability of feed supplies, and the prevailing climate all act to influence the quantity of pork produced. Storage holdings of pork and pork production influence variations in price, which also affect the numbers of sows farrowing in subsequent periods. These factors, represented in Harlow's general recursive system include the following structural equations: (1) number of sows farrowing; (2) number of hogs slaughtered; (3) quantity of pork produced; (4) cold storage holdings of pork; (5) retail prices of pork; (6) prices received by farmers for hogs.[33]

Three phases of the hog-cycle involve a reaction to price, farrowing and pig crop, and resultant slaughter. The use of annual data tends to obscure producers' responses to changing conditions. Therefore, a quarterly analysis is more appropriate, since intra-year variations in prices and production levels may be just as significant as annual fluctuations. In addition, meat packers, outlook workers, and chain store buyers rely on short-term forecasts for their decisions.

Although the approximate time required to produce a marketable hog, from breeding to slaughter, is only a year, lags in response to price and marketing conditions are more accurately reflected by a four-year cycle. To obtain a four-year cycle, it is necessary to assume one-year lags at each interval between price and pig crop, and between pig crop and slaughter. While the lags are less than the physiological time processes required for gestation, weaning, and feeding to market weight, the yearly lags may be confirmed by past experience. Generally accepted evidence indicates that farmers plan hog production on an annual basis. A second reason involves the statistical limitation imposed by using annual data. Measurements may differ considerably from actual figures on a strict annual basis. For example, the price of hogs after sows are bred affects the number of sows farrowing in the following spring and fall. Actual lags between price, which influence farmers to breed more sows, and the resulting changes in the spring pig crop may occur over a period as short as six months. The actual lag between pig crop and slaughter is significantly less than one year. And since the fall crop, and a portion of the spring pig crop, may be slaughtered in the following year, annual slaughter figures tend to produce a longer lag.[34]

The price of hogs is determined by the interaction of demand and supply. Thus, the factors which influence demand and supply must necessarily affect price levels and quantities produced. On the demand side, the demand for pork depends upon the availability of disposable consumer income and the prices and supplies of competing meats. Many factors influence the supply relation, including farmers' expectations of profitability, the availability and prices of feed, and alternative production costs. According to Harlow, most of the factors associated with hog production are fairly constant and can be estimated with reasonable accuracy by linear trends.[35]

Using a general recursive model and assuming other factors constant, Harlow developed a regression model, consisting of six linear equations, to explain the behavior of the hog economy. A carefully constructured recursive model provides maximum likelihood estimates of the coefficients in each structural equation. In addition, a smaller standard error is realized in comparison to other estimation methods, provided that a large sample is drawn from a normal population. The simple regression equation, which assumes no errors of measurement in the observed variables, may be expressed in the following general form:

$$Y_t = b_1 x_{1t} + b_2 x_{2t} + \ldots b_k x_{nt} + U_t$$

The dependent variable is denoted by Y_t, while the independent variables are denoted by x_{1t}, x_{2t}.... and x_{kt}, respectively. The term U_t is a random variable. Ranging from 1 to n variables, the subscript t indicates an index of time. The "b" terms, which appear in the general equation, are estimated constant coefficients of the independent variables.[36]

A recursive system, like the one originally employed by Harlow and later revised in this paper, yields a set of successive equations, including an additional endogenous variable, which was treated as a dependent variable in prior equations. Entering the system singly, like links in a chain, these explanatory variables become interrelated through lags from one period to the next.

In order to formulate an accurate econometric model, the structure of any economic system to be analyzed should dictate the type of equations employed and the appropriate statistical method used to fit them. For the hog economy, it is hypothesized that the cobweb theorem provides a reasonable theoretical explanation. Therefore, this simplified cobweb model, which describes current production responses to changes in price during the previous period, must include the following general equations:

$$S_t = a_1 + b_1 P_{t-1} + u_t$$

$$P_t = a_2 + b_2 D_t + u_t$$

$$S_t = D_t$$

In the general equations, S_t is the quantity supplied in period t; P_{t-1} denotes the price in the previous period; P_t indicates price in the current period t, and D_t represents the current quantity demanded. Finally, the "a" and "b" terms are estimated parameters, with u_t remaining as a residual or error term.

Quarterly data, rather than annual data, were used in the model because such data are more conducive to recursive systems. The use of quarterly data, however, may result in serial or autocorrelation. Serial or autocorrelation is a term which indicates the existence of a non-independent pattern in the values representing the difference between actual and estimated magnitudes. Its presence can lead to a loss of statistical efficiency, underestimation of the time variance, and a possible indication that relevant explanatory variables may have been omitted. The use of lagged variables represents one method to partially counteract or minimize serial correlation.[37]

Before describing the variables used in this study, a brief review of the technique employed in fitting the model seems appropriate. A statistical technique known as stepwise multiple linear regression was used to fit the equations in the model. In stepwise multiple regression, the dependent variable is expressed as a function of two or more independent explanatory variables, where these independent variables enter the analysis singly according to relative importance. This process continues until the least significant variables are entered into the fitted equation. At the conclusion of this process, a "plane of best fit" is derived and relevant test statistics are calculated. Such statistics include multiple and simple correlation coefficients, t-test values, goodness of fit values, and standard error statistics. These statistics are calculated as a part of the program at each sequence of the stepwise progression. Combining the coefficient values of each variable with the calculated constant term yields a regression equation.

The variables used in this study reflect those factors which are thought to be relatively most significant in terms of explaining the behavior of the hog cycle. The symbols representing these variables and associated definitions are presented as follows:

QUARTERLY DATA, 1960-1968:

F = Sows farrowing (1,000 head)

P_h = Deflated price received by farmers for hogs ($/100 lbs. wt.)

P_c = Deflated price received by farmers for corn ($/bushel)

P_b = Deflated price received by farmers for beef cattle ($/100 lbs. wt.)

G = Aggregate production of barley, oats, and grain sorghum (billions of bushels)

H = Hogs slaughtered under Federal Inspection (1,000 head)

D = Dummy variable representing an unusual marketing period.
  0 = all other quarters
  1 = 3rd quarter

T = Time measured by successive quarters (1, 2, 3...)

Q_p = Quantity of pork produced (millions of lbs.)

S = Cold storage holdings of frozen and cured pork at the beginning of each quarter (millions of lbs.)

P_p = Deflated retail price of pork (cents/lb.)

W = Dummy variable representing seasonal variations in temperature
  0 = first and fourth quarters
  1 = second and third quarters

Q_b/N = Quantity of beef produced per capita (where Q_b = Total beef production in millions of lbs. and N = United States quarterly population)

R = Ratio of pigs saved in the fall of the previous year to those saved in the spring of the current year.

Q_r/N = Per capita quantity of broilers produced in lbs. (where Q_r = total broiler production and N = U. S. quarterly population estimate.)

I/N = Per capita disposable income deflated by the CPI (1957 - 1959 base) (where I = total disposable income and N = U. S. quarterly population estimate.)

M = Marketing margin representing the spread between prices received by farmers and retail prices (deflated by the CPI)

Q_p/N = Per capita production of pork in lbs. (where Q_p = pork production in millions of lbs. and N = U. S. quarterly population.)

S/N = Per capita cold storage holdings of frozen and cured pork in lbs.

Quarterly data for the period encompassing 1960 to 1968 were obtained from a variety of government publications. In most cases monthly data were converted to quarterly series by either averaging or summing the raw monthly figures. Quarterly statistics on sows farrowing, pork production, beef production, hogs slaughtered, cold storage holdings of frozen and cured pork, and pigs saved were obtained from issues of Livestock and Meat Statistics, published by the U. S. D. A. In addition prices received by farmers for hogs and beef cattle, retail pork prices, and marketing margins were also gathered from Livestock and Meat Statistics.[38]

Per capita statistics on beef and pork production were obtained from the Handbook of Agricultural Charts[39], while per capita broiler production was obtained from the Poultry and Egg Situation Reports.[40] Grain data were found in the Feed Situation[41] and Grain Market News-Quarterly Summary and Statistics.[42]

Finally, the monthly consumer price index series, and U.S. monthly population estimates were gathered from the Survey of Current Business[43] and Current Population Reports[44], respectively.

In general, the symbolic method of denoting each variable by its first letter has been employed, with some exceptions to prevent duplication. All price variables are measured in real terms by deflating the raw price data by the consumer price index (CPI = 1957 - 1959 Base). Quarterly data are used, unless otherwise specified. Lagged variables, represented by t-1, t-2, etc., indicate the number of quarterly periods lagged. And yearly lags are designated by the term y-1. As an example, $P_b(4)y\text{-}1$ refers to the farm price for beef in the fourth quarter of the previous year.

CHAPTER IV

Discussion of Expected Results in the Revised Model

After introducing Harlow's recursive model and reviewing the variables and sources of data to be used in the revised model, the expected results will be presented in this chapter. The revised model, patterned from Harlow's original model, represents production as a function of lagged price, and price as a function of current production. The storage equation eliminates the identity of production and consumption. As intermediate steps, equations are derived to estimate the number of sows farrowing, hogs slaughtered, cold storage holdings of pork, and the farm price of hogs.

According to Harlow, since there are no data on the number of sows bred, estimates of the number of sows farrowing, a major portion of bred sows, provide a reasonable approximation. Factors that influence the number of sows farrowing include: (1) facilities available on farms; (2) the expected price of hogs at market time; (3) prices and available stocks of feed grain; and (4) prices of substitute or competing meats such as beef or broilers.[45]

Since various studies show that producers formulate production decisions for the next year during the fall, the prices of hogs, corn, and beef cattle in the fourth quarter of the previous year should be incorporated in the model as explanatory factors. The gestation period for hogs is approximately four months. Therefore, a three-month or quarterly lag would provide a reasonable approximation of the production cycle. Aggregate annual production figures in the previous year for oats, barley, and sorghum were included, because experience shows that the previous year's grain production affects farrowings during the first two quarters, while current grain production affects third and fourth quarter farrowings.[46]

For the first supply equation, in the revised model, lower corn prices in the fourth quarter of the previous year, $P_{c(4)y-1}$, create favorable production conditions in the next year. Therefore, the inverse relationship assumed to exist between farrowings and deflated corn prices should result in a negative sign before the coefficient of the corn price variable. A direct relationship, represented by a positive sign before each coefficient, would be expected for the grain stock variable in the previous year, G_{y-1}; for the price of hogs in the fourth quarter of the previous year, $P_{h(4)y-1}$, and in the previous quarter P_{ht-1} of the current year. Increased grain stocks, as a food source, are naturally favorable to additional farrowings. Similarly, higher farm prices for hogs in the previous year also create an added inducement for producers to increase the number of current farrowings.

Since price increases for beef, a competing meat, would create a favorable demand for pork, assuming other factors constant, the sign associated with the price of beef variable, $P_{b(4)y-1}$, must be positive in order to confirm such a substitute relationship. Finally, to account for the hog production, farrowings in the same quarter of the previous year, F_{t-4}, must be included as an explanatory variable. The direct relationship assumed to exist between current and previous year's farrowings would be indicated by a positive sign before the farrowing variable, F_{t-4}, which has been lagged four quarters.[47]

The second supply equation, which estimates the number of hogs slaughtered, includes several explanatory variables. First, the number of hogs slaughtered, H_t, depends upon the number of sows farrowing two quarters previously, H_{t-2}, and the number of pigs per sow. Since the majority of hogs are slaughtered at 6 to 8 months, a two-quarter lag was used. Recent experience indicates that the number of pigs per sow has been increasing at a steady rate over the past few years. To account for this trend, a time variable, T, was introduced. The use of lagged farrowings creates a disproportionate pattern for the third-quarter slaughter. The predominance of March farrowings in the first quarter, and the tendency for longer feeding before marketing during the spring, means that many pigs farrowed in the first quarter are not marketed until the fourth quarter. To account for this deviation, a dummy variable was incorporated in the model having a value of 1 for the third quarter when fewer marketings occur, and a value of 0 for other quarters when conditions are normal. A positive sign is associated with the lagged farrowing variable, F_{t-2}, and the time variable, T, since they bear a direct relationship to the dependent variable.

In determining the amount of hogs slaughtered, some response to price would naturally be expected. For example, a high price during the previous quarter, P_{ht-1}, should induce farmers to market their hogs at that time. As a result, the number of hogs sold in the current quarter would decline. Conversely, a low price in the previous quarter, P_{ht-1}, should induce farmers to market their hogs at that time. As a result, the number of hogs sold in the current quarter would decline. Conversely, a low price in the previous quarter, P_{ht-1}, might result in the delay of slaughter until the current quarter. To express this inverse relationship, a negative regression coefficient would be expected.[48]

The final supply equation in the revised model includes the quantity of pork produced, Q_p. Pork production depends upon the number of hogs slaughtered and variations in seasonal and year-to year slaughter weight. Year-to-year variations in slaughter weight are caused directly by fluctuating grain supplies, and inversely by grain prices. In addition, spring-farrowed pigs are generally fed to heavier market weights than fall pigs. Pigs farrowed in the fall are marketed during the following spring and summer periods, with a substantial number of spring pigs being marketed in the fall of the same year. Therefore, a ratio of pigs saved in the fall of the preceding year to the number of pigs saved in the spring of the current year, R, is included as a possible explanatory factor. Since the proportion of fall pigs marketed during the year increases and the quantity of pork produced decreases for a given slaughter level, a negative sign before the coefficient of the pigs saved ratio, R, would be expected. A direct relationship between the number of hogs slaughtered, H, and the quantity of pork produced is expected as indicated by a positive sign before the hogs slaughtered variable. Finally, an inverse relationship between pork production and corn prices in the fourth quarter of the previous year, $P_{c(4)y-1}$, should produce a negative coefficient.

As an intermediate step between production and consumption, cold storage holdings of frozen and cured pork, S, were represented in a structural equation. In addition, the level of cold storage pork holdings at the beginning of a quarter, as a potential supply source, naturally influences the retail prices of pork during that quarter. To account for the curing processes and normal delays between slaughter and sale to the consumer, cold storage holdings are lagged one quarter.

Storage holdings are also dependent upon lagged pork production, Q_{pt-1}, lagged retail pork prices, P_{pt-1}, seasonal temperatures, W, and marketing patterns, D.

Cold storage holdings tend to increase following increases in pork production. Therefore, the coefficient associated with the lagged pork production variable, Q_{pt-1}, should be positive. On the other hand, storage holdings would be expected to increase as lagged pork prices, P_{pt-1}, rise in anticipation of further price increases. Since the tendency has been to feed spring pigs longer, a lower marketing level in the fourth period should cause a positive coefficient before the dummy marketing variable, D, and before lagged storage holdings, S_{t-1}, from the previous quarter. Finally, as a result of demand variations, cold storage holdings would be expected to increase as seasonal temperatures declined. Therefore, a negative coefficient is expected for, W_{t-1}, the lagged seasonal dummy variable.[49]

Consideration of demand elements logically follows after reviewing factors related to storage equations. These demand elements, in turn, affect the retail price of pork, represented by P_p in the fifth equation. Factors such as current pork production and storage holdings, consumer disposable income, available supplies of competing meats such as beef and broilers, seasonal temperature variations, and lagged farm pork prices definitely affect retail pork prices. To allow for population increases over time, the storage and production variables are expressed in real terms by deflating the raw prices by the consumer price index.

Since the retail price of pork, P_p, is expected to vary inversely with per capita storage holdings, S/N, pork production, Q_p/N, available beef, Q_b/N, broiler supplies, Q_r/N, and seasonal demand factors, W, the signs before these coefficients should be negative. A direct relationship, indicated by a positive coefficient, would be expected for the lagged farm hog price variable, P_{ht-1}, because retail prices vary directly with farm prices. Finally, the coefficient associated with per capita consumer disposable income, I/N, should be positive, since retail prices and consumer disposable income are positively related.

The last equation in the system follows from the approach that the retail price of pork may be estimated first, and the farm price of pork, P_h, derived from it. Therefore, the farm price of pork, P_h, depends on the retail pork price plus other factors such as, per capita cold storage holdings, S/N, marketing margins, M, and seasonal factors, W. Since retail and farm pork prices generally vary together, a direct relationship would be indicated by a positive coefficient. Since there is usually an inverse relationship between marketing margins and per capita cold storage holdings, the price of hogs may be raised in an indirect manner. For example, whenever storage holdings increase, marketing margins decrease, and consequently hog prices increase.[50]

CHAPTER V

Presentation of the Actual Results

This chapter will be devoted to a discussion of the actual results derived from Harlow's revised hog-cycle model. To facilitate a concise presentation of these results, brief descriptive statements and conclusions applicable to each fitted regression equation will be supplemented by summary tables. The reader is directed to review these tables in making comparisons and inspecting the calculated statistics.

Each table presents multiple correlation coefficients (R), goodness of fit values (F), coefficient signs and values for each variable, t-values, standard errors of estimate, and constant terms. Residual values, used to calculate the Durbin-Watson statistic, are also presented along with multiple coefficients of determination, (R^2). The R^2 values are derived by squaring the multiple correlation coefficient, (R).

It is necessary at this point to briefly discuss each statistic employed in the analysis. First, the multiple coefficients of determination, (R^2), calculated from multiple correlation coefficients, (R), indicate the relative importance of each variable, i.e., the percent of the total variation in the dependent variable explained by the independent variable. Calculated t-values are used to test the statistical significance of the coefficient values for the independent variables. The test involves a null hypothesis that the true coefficient value is not different from zero (H_o: B=0), while the alternate hypothesis specifies that the true coefficient value is significantly different from zero (H_a: B≠0) at a specified probability level. In this analysis, a two-tailed alternative hypothesis was selected, since significant deviations occurring either above or below the true value are relevant. A standard 5-percent level of significance was selected to evaluate each t-value for statistical significance. If the calculated t-value is equal to or greater than ± 2.042 (for 30 degrees of freedom at a 5-percent level of significance), the coefficient is statistically different from zero (H_a: B≠0). Therefore, the null hypothesis would be rejected. If the probability associated with a statistic is less than 1% (.01), the result is termed highly significant. But when the probability is only 5% (.05), the result is considered significant, rather than highly significant.

The coefficient values and sign for each variable represent numerical values derived from the fitted regression equation. Constant terms are numerical values associated with each fitted equation. To indicate the proximity and statistical significance of calculated values about the fitted surface, goodness of fit values are employed. As a measure of dispersion, the standard error of the estimate indicates the average amount that the computed values vary from the actual values.[51]

Finally, the Durbin-Watson statistic (d) is used to test for the existence of serial correlation in the residual values, (where residuals represent the difference between actual and estimated values). Tests for serial or autocorrelation, a condition defined simply as a non-random relationship between successive residual values, may reveal serious errors or biases if confirmed. While the test statistic is easily calculated, it may offer no clear basis for rejecting the null hypothesis that serial or autocorrelation does not exist. A region of indeterminacy, in which no conclusion is justified, may be present in certain cases.

After calculating the Durbin-Watson statistic for each fitted regression equation, the calculated value, denoted by (d), must be compared to the following table:

TABLE 5.0

Regions of Acceptance and Rejection of the Null Hypothesis in the Durbin-Watson Test

Value of d	0	1 d_l	2 d_u	$(4 - d_u)$	3 $(4 - d_l)$ 4
	Reject the null hypothesis; accept the hypothesis of positive autocorrelation	Neither accept nor reject the null hypothesis	Accept the null hypothesis	Neither accept nor reject the null hypothesis	Reject the null hypothesis; accept the hypothesis of negative autocorrelation

If the Durbin-Watson statistic (d) falls between d_u and $4-d_u$, the null hypothesis of no serial correlation can be accepted; but if (d) lies below d_l or above $4-d_l$, the alternate hypothesis confirming autocorrelation must be accepted. In the event that (d) lies within the interval between d_l and d_u, or between $4-d_l$ and $4-d_u$, the null hypothesis of no serial correlation can neither be accepted nor rejected on the basis of this statistical test.[52]

After discussing the types of statistics used in this analysis, the actual results for each fitted equation will be introduced by a few statements followed by a tabular summary. For the first operation, involving an estimate of the current number of sows farrowing, (F_t), only two variables, farrowings lagged four quarters, (F_{t-4}), and the farm price of hogs lagged to the fourth quarter of the previous year,

($P_{h(4)y-1}$), were significantly different from zero at the 5-percent level. The remaining variables, with the exception of lagged beef prices ($P_{b(4)y-1}$), were far from the acceptable significance level. Perhaps the relatively stable variation, which characterized these magnitudes during the period under consideration, may account for their relative insignificance. The (d) statistic for the Durbin-Watson test shows no serial correlation in the residuals. The fitted equation used to estimate sows farrowing appears as follows.

$$(1) \quad F_t = -2337.71 + .959\ F_{t-4} + 5.59\ P_{ht-1} + 145.54\ P_{c(4)y-1} + 56.86\ P_{b(4)y-1} + 282.83\ G_{y-1} + 42.93\ P_{h(4)y-1}$$

While several of the explanatory variables lacked significance, the equation as a whole explained a major part of the variation in sows farrowing. To support this claim, the multiple coefficient of determination (R^2) was .970, indicating that 97-percent of the total variation in sows farrowing could be explained by the variables used in the analysis. Actually, only two variables, farrowings lagged four quarters (F_{t-4}) and farm prices lagged to the fourth quarter in previous years ($P_{h(4)y-1}$) were the most important explanatory factors.

For the number of hogs slaughtered equation, all four regression coefficients were significant and had the expected signs. The Durbin-Watson statistic showed no serial correlation in the residual values.

TABULAR SUMMARY OF RESULTS—EQUATION 1

Sows Farrowing (Ft)

Table 5.1

Variable	t-Value	Coefficient Value	Expected Sign	Actual Sign	Significant at 5% level	Multiple Corr. Coefficient	Multiple Coeff. of Determination R^2	Percent of total Variation explained
F_{t-4}	23.61	0.959	+	+	Yes	.962	.925	92.5%
$P_{h(4)y-1}$	2.19	42.926	+	+	Yes	.979	.958	3.3
$P_{b(4)y-1}$	1.88	56.857	-	none	No	.984	.968	1.0
G_{y-1}	0.84	282.834	+	none	No	.985	.970	0.2
$P_{c(4)y-1}$	0.34	145.539	-	none	No	.985	.970	0.0
P_{ht-1}	0.24	5.588	+	none	No	.985	.970	0.0
								97.0
							unexplained	3.0
								100.0%

CONSTANT TERM: -2337.71

STANDARD ERROR OF THE ESTIMATE = 141.07

Fitted Regression Equation:

$$F_t = -2337.71 + .959\, F_{t-4} + 5.59\, P_{ht-1} + 145.54\, P_{c(4)y-1} + 56.86\, P_{b(4)y-1} + 282.83\, G_{y-1} + 42.93\, P_{h(4)y-1}$$

FINAL R^2 = .970

d = 1.82*

* No serial correlation in the residuals

GOODNESS OF FIT, $F_{(6, 25)}$ = 133.58#

\# = highly significant fit

Table 5.2 summarizes the actual results for the hogs slaughtered equation which appears below:

$$H_t = 16896.47 + 1.38F_{t-2} - 2897.88D + 74.80T - 272.75\ P_{ht-1}$$

Fitting the quarterly data to the pork production equation resulted in only one significant explanatory variable, the number of hogs slaughtered. The remaining two variables, lagged corn prices, $P_{c(4)y-1}$, and the ratio of pigs saved, R, were quite insignificant. Perhaps the relatively stable corn prices combined with only minor variations in the ratio of pigs saved for the eight-year period considered may account for this relationship. The Durbin-Watson statistic (d) indicates positive autocorrelation. Appearing below is the fitted regression equation for pork production, followed by a summary table 5.3:

$$Q_{pt} = -172.79 + .171H_t - 2.609R + 370.73\ P_{c(4)y-1}$$

In the cold storage equation, only one variable, lagged deflated retail pork prices, P_{pt-1}, was insignificant. The remaining four variables exceeded the 5-percent level of significance, and had the expected signs. Indicating no serial correlation, the Durbin-Watson statistic fell within the acceptable range. Shown below and in Table 5.4, is the cold storage equation:

$$S_t = -106.347 - .372\ P_{pt-1} + .086\ Q_{pt-1} + 99.279D - 127.773\ W_{t-1} + .674\ S_{t-1}$$

TABULAR SUMMARY OF RESULTS—EQUATION 2

Hogs Slaughtered (H_t)

Table 5.2

Variable	t-Value	Coefficient Value	Expected Sign	Actual Sign	Significant at 5% level	Multiple Corr. Coefficient	Multiple Coeff. of Determination R^2	Percent of total Variation explained
Dummy (D)	-8.19	-2897.88	-	-	Yes	.522	.272	27.2 %
F_{t-2}	6.60	1.38	+	+	Yes	.767	.588	31.6
T	4.49	74.80	+	+	Yes	.819	.671	8.3
P_{ht-1}	-4.28	-272.75	-	-	Yes	.897	.805	13.4
								80.5%
							unexplained	19.5
								100.0 %

CONSTANT TERM: 16986.47

FITTED REGRESSION EQUATION:

$$H_t = 1689.47 + 1.38\,F_{t-2} - 2897.88D + 74.80T - 272.75\,P_{ht-1}$$

STANDARD ERROR OF THE ESTIMATE = 827.67

FINAL R^2 = .805

d = 1.98*

GOODNESS OF FIT, $F_{(4, 27)}$ = 27.69*

*No serial correlation in the residuals

= Significant goodness of fit value

TABULAR SUMMARY OF RESULTS—EQUATION 3

Quantity of pork produced (Q_{pt})

Table 5.3

Variable	t-Value	Coefficient Value	Expected Sign	Actual Sign	Significant at 5% level	Multiple Corr. Coefficient	Multiple Coeff. of Determination R^2	Percent of total Variation explained
H_t	21.84	.171	+	+	Yes	.970	.941	94.1 %
$P_{c(4)y-1}$	1.80	370.373	-	None	No	.972	.945	0.4
R	-0.79	-2.609	-	None	No	.973	.974	0.2
								94.7 %
							unexplained	5.3
								100.0 %

CONSTANT TERM: -172.79

FITTED REGRESSION EQUATION:

$$Q_{pt} = -172.79 + .171\ H_t - 2.609\ R + 370.73\ P_{c(4)y-1}$$

STANDARD ERROR OF THE ESTIMATE = 73.77

FINAL R^2 = .947

d = 0.410*

GOODNESS OF FIT, F

$(3,\ 28)$ = 164.75#

= Significant goodness of fit value

* Indicates positive autocorrelation of residual values

TABULAR SUMMARY OF RESULTS—EQUATION 4

Cold storage pork holdings (S_t)

Table 5.4

Variable	t-Value	Coefficient Value	Expected Sign	Actual Sign	Significant at 5% level	Multiple Corr. Coefficient	Multiple Coeff. of Determination R^2	Percent of total Variation explained
P_{pt-1}	-0.146	-.372	+	None	No	.618	.382	38.2 %
Q_{pt-1}	+2.435	+.086	+	+	Yes	.724	.524	14.2
Dummy D	-5.251	+99.279	+	+	Yes	.804	.646	12.2
W_{t-1}	-4.599	-127.773	-	-	Yes	.830	.689	4.3
S_{t-1}	+4.189	-0.674	+	+	Yes	.902	.814	12.5
								81.4
							unexplained	18.6
								100.0 %

CONSTANT TERM: -106.3471

FITTED REGRESSION EQUATION:

$$S_t = -106.347 - .372\, P_{pt-1} + .086\, Q_{pt-1}$$
$$+99.279D - 127.773\, W_{t-1} + .674\, S_{t-1}$$

STANDARD ERROR OF THE ESTIMATE = 35.965

FINAL R^2 = .814

d = 2.36*

* No serial correlation in the residuals

GOODNESS OF FIT, F

$(5, 26)$ = 22.76#

\# = Significant goodness of fit values

Fitting the regression equation to estimate variations in the deflated retail prices of pork, only three significant variables were noted. The remaining four variables were far from the acceptable significance level. The Durbin-Watson statistic (d) showed no auto-correlation in the residual values. Table 5.5 summarizes the relationships for the regression shown below:

$$P_{pt} = 69.355 + .691\ P_{ht-1} - 1.629\ Q_p/N - 3.612\ S/N$$
$$+ .004\ I/N - 1.633\ W_t + .607\ Q_r/N + .039\ Q_b/N$$

The last fitted equation in the revised model estimates the farm price of hogs. For this regression equation, all the coefficients had the expected signs and were statistically different from zero at the 5-percent level. The Durbin-Watson statistic (d) was in the inconclusive range. The fitted equation appears as follows:

$$P_{ht} = -8.174 + .643P_{pt} - .495M + 1.162\ S/N -$$
$$.770\ W_t$$

TABULAR SUMMARY OF RESULTS—EQUATION 5

Deflated retail pork prices (P_{pt})

Table 5.5

Variable	t-Value	Coefficient Value	Expected Sign	Actual Sign	Significant at 5% level	Multiple Corr. Coefficient	Multiple Coeff. of Determination R^2	Percent of total Variation explained
P_{ht-1}	+3.222	+0.691	+	+	Yes	.898	.806	80.6%
Q_p/N	-5.606	-1.629	-	-	Yes	.939	.882	7.6
S/N	-2.193	-3.612	-	-	Yes	.953	.908	2.6
I/N	+0.250	+0.004	+	None	No	.961	.924	1.6
W_t	-1.107	-1.633	-	None	No	.963	.927	0.3
Q_r/N	+0.622	+0.607	-	None	No	.964	.929	0.2
Q_b/N	+0.092	+0.039	-	None	No	.964	.929	0.0
								92.9%
							unexplained	7.1
								100.0%

CONSTANT TERM: 69.355

FITTED REGRESSION EQUATION:

$$P_{pt} = 69.355 + .691\ P_{ht-1} - 1.629\ Q_p/N - 3.612\ S/N$$
$$+ .004\ I/N - 1.633\ W_t + .607\ Q_r/N + .039\ Q_b/N$$

STANDARD ERROR OF THE ESTIMATE = 1.194

FINAL R^2 = .929

d = 1.98*

GOODNESS OF FIT, F

$F_{(7,\ 24)}$ = 44.532#

= Significant goodness of fit value

* No autocorrelation in the residuals

TABULAR SUMMARY OF RESULTS—EQUATION 6

Farm prices received for hogs (P_{ht})

Table 5.6

Variable	t-Value	Coefficient Value	Expected Sign	Actual Sign	Significant at 5% level	Multiple Corr. Coefficient	Multiple Coeff. of Determination R^2	Percent of total Variation explained
P_{pt}	+16.405	+0.643	+	+	Yes	.925	.856	85.6 %
M	-6.495	-0.495	-	-	Yes	.972	.945	8.9
S/N	+2.199	+1.162	+	+	Yes	.973	.947	0.2
W_t	-2.107	-0.770	-	-	Yes	.977	.955	0.8
								95.5 %
							unexplained	4.5
								100.0 %

CONSTANT TERM: -8.174

FITTED REGRESSION EQUATION:

$$P_{ht} = -8.174 + .643\, P_{pt} - .495 M + 1.162\, S/N - .770\, W_t$$

STANDARD ERROR OF THE ESTIMATE = 0.570

FINAL R^2 = .955

d = 1.29*

GOODNESS OF FIT, F

$F_{(4,\ 27)}$ = 139.406#

Significant goodness of fit

* Inconclusive test for serial correlation

CHAPTER VI

Summary, Conclusions, and Implications of the Revised Hog-Cycle Model

The complete recursive system is presented as follows:

(1) Sows Farrowing—

$$F_t = -2337.71 + .959\ F_{t-4} + 5.59\ P_{ht-1} + 145.54\ P_{c(4)y-1} + 56.86\ P_{b(4)y-1} + 282.83\ G_{y-1} + 42.93\ P_{h(4)y-1}$$

$R^2 = .970$

(2) Hogs Slaughtered—

$$H_t = 16896.47 + 1.38\ F_{t-2} - 2897.88D + 74.80T - 272.75\ P_{ht-1}$$

$R^2 = .805$

(3) Quantity of Pork Produced—

$$Q_{pt} = -172.79 + .171\ H_t - 2.609R + 370.73\ P_{c(4)y-1}$$

$R^2 = .947$

(4) Cold Storage Pork Holdings—

$$S_t = -106.347 - .372\ P_{pt-1} + .086\ Q_{pt-1} + 99.279D - 127.773\ W_{t-1} + .674\ S_{t-1}$$

$$R^2 = .814$$

(5) Retail Pork Prices—

$$P_{pt} = 69.355 + .691\ P_{ht-1} - 1.629\ Q_p/N - 3.612\ S/N + .004\ I/N - 1.633\ W_t + .607\ Q_r/N + .039\ Q_b/N$$

$$R^2 = .929$$

(6) Farm Prices Received for Hogs—

$$P_{ht} = -8.174 + .643\ p_{pt} - .495M + 1.162\ S/N -.770\ W_t$$

$$R^2 = .955$$

The hypothesis that the cobweb theorem is applicable to Harlow's original model and the revised version seems valid and the original results of Harlow's model are generally consistent with the revised model. The evidence to support this contention will be reviewed herein.

Due to differences in the type of data employed and slight changes in some variables, such as the seasonal temperature variable, W, no general comparison of the results obtained from Harlow's model to those from the revised version will be made.

Of the six equations presented in the revised model, the Durbin-Watson test statistic revealed no evidence of serial or autocorrelation in four equations; only one case of positive serial correlation; and inconclusive evidence for the remaining equation. The fit for the system as a whole is reasonably good based on the fact that the multiple coefficient of determination (R^2) exceeds .80 for all equations, and is above .93 in four of six equations. In addition, only eleven of twenty-nine regression coefficients are not significantly different from zero at the 5-percent level. Therefore, the revised model estimates the behavior of the six major dependent variables of the hog industry with a reasonable degree of accuracy.

Perhaps improvements in the form of deleting insignificant variables, increasing the time span of this analysis, and continuing the revision process to account for changes in technology, demand, and storage systems would lead to a more accurate system of equations. Improvements in fitting the cold storage and hog slaughtered equations would be particularly desirable, since they constitute the weakest link in the whole system.

As an explanation of his recursive model of the hog industry, Harlow made the following statement:

> The cobweb theorem furnishes a more precise theoretical explanation of the cycle because it includes the demand and supply functions for the industry, which determine the

> amplitude of the cycle, as well as the lag in production responses, which determines the cycle length.[53]

After reviewing and summarizing the results, the remainder of this final chapter will be devoted to a discussion of the major implications drawn from this study. A number of possible causes which may act to perpetuate the hog-cycle will be reviewed.

Cyclical fluctuations in the price and output of selected agricultural commodities of livestock result from one basic imperfection in the functioning of the market mechanism. Alternating periods of oversupply or underutilization of productive resources and equipment lead to increased costs. These undesirable aspects arise from producers' failure to respond appropriately to market conditions. In turn, lack of adequate forecasting is a principal cause of such inappropriate responses. Variations in crop sizes, drought, disease, crop failures, and decreases in demand, all of which are not predictable, are also responsible for perpetuating the hog cycle.

According to most experts, whose separate opinions were presented, the solution to this problem lies in the distribution of accurate and timely market information to livestock producers. The continuation of any cycle along a particular pattern depends upon the behavior of external factors and the degree to which farmers' responses vary. As more and better quality information becomes available, producers will adjust their production according to such outlook information. According to Harlow, if responses would be adjusted to expected prices rather than past prices, the cycle might be dampened or decreased in duration.[54]

Certainly, it is obvious that highly variable or uncertain prices are harmful to producers. This does not necessarily indicate that all price changes are undesirable *per se*. Relative price changes are not only acceptable, they are essential to continued economic growth and development. Working through relative price changes, the price mechanism in the market allocates resources to those areas which are most productive in terms of maximizing society's total utility. Thus, through relative price and demand changes, farmers must respond by shifting their productive resources into the most valued areas.

But whenever relative prices vary from one production period to the next in a wide and unpredictable manner, uncertainty occurs. Through expectations concerning future prices, production plans are formulated for the current period. As a result of the uncertainty in predicting whether prices will rise, fall, or remain constant, the price system as a whole ceases to be a useful allocative mechanism; and consequently, producers must rely on speculation or other arbitrary guidelines in formulating their production decisions. In addition, the undesirable elements tend to make rational producers delay investment plans under such risky conditions, thereby causing further delays in technological advancement.

Price and income risks, also associated with uncertainty actually represent a social cost which is borne entirely by the producer. The costs of capital investments are increased as the flow of new capital is retarded. Thus, such extreme fluctuations, arising from a disturbed cobweb reaction, lead to gross inefficiency.[55]

Focusing on the problem of uncertainty, the ability to accurately predict future prices would prove beneficial to producers, marketing agencies, consumers, and governmental authorities. In the livestock and meat processing industry, a knowledge of future prices which affects breeding, feeding, production, and marketing is essential to the process of formulating buying, selling, and storage plans. Finally, even the consumer realized some direct benefits through the increased ability to buy and store meat at the most favorable prices.[56]

Dean and Heady, two prominent agricultural economists, view outlook information as a valuable tool in reducing wide cyclical fluctuations. They also point to the impact of a decreasing elasticity of supply response in creating a more rapidly converging pattern than the conventional cobweb relationship for hogs. Instability in hog prices may be partially reduced by the reaction of farmers to expected rather than actual prices.[57]

Maki also suggests improvements in market forecasting and in the proper use of market information in the decision-making process.

To reduce the amplitude of year-to-year cycles, the amount of under-estimation must be corrected. Another possible method to reduce the fluctuations in production would be related to reducing the total production time period, but this depends upon external technological factors.[58]

Supplementing the previous recommendations, Harold Briemeyer, a noted pioneer in hog-cycle research, outlines the following measures to correct cyclical tendencies in hog production: (1) Further improve the stabilization of corn supplies and prices; (2) Pursue a flexible program of counter-cyclical stabilization; (3) Increase the emphasis on outlook and extension work as an aid to producers; (4) Create contractual or cooperative arrangements as a possible aid to stability; and (5) Apply minimum support prices for hogs as a means of easing hog production cycles.[59]

In summarizing the general value of the cobweb theorem applied to recursive systems of equations, Waugh stated that "the cobweb principle may well become one of the most important tools, not only for practical forecasting, but also for elastic economic theory."[60]

The objectives of this study have been fulfilled by providing a revised model which reasonably explains the major sources of variations in the hog industry and which hopefully lays the foundation for future research.

FOOTNOTES

[1]Donald Stevenson Watson, Price Theory in Action (Boston: Houghton Mifflin Co., 1965), p. 248.

[2]Mordecai Ezekiel, "The Cobweb Theorem," Quarterly Journal of Economics, LII (August, 1938), p. 255.

[3]Edwin Mansfield, Microeconomics: Theory and Applications (New York: W. W. Norton and Company, Inc., 1970), p. 240.

[4]Willard W. Cochrane, Farm Prices: Myth and Reality (Minneapolis: University of Minnesota Press, 1958), p. 63.

[5]Ezekiel, pp. 256-257.

[6]Ibid., p. 272.

[7]Geoffrey S. Shepherd, Agricultural Price Analysis (6th ed.; Ames, Iowa: Iowa State University Press, 1968), pp. 35-37.

[8]Ibid., p. 37.

[9]Ibid., p. 39.

[10]Arthur A. Harlow, "The Hog Cycle and the Cobweb Theorem," Price Theory in Action, Edited by Donald Stevenson Watson (Boston: Houghton Mifflin Co., 1965), p. 169.

[11]Ibid., p. 168.

[12]Ezekiel, pp. 272-274.

[13]Ibid.

[14]Ibid., p. 278.

[15]Gustav Akerman, "The Cobweb Theorem: A Reconsideration," Quarterly Journal of Economics, LXXI (1957), p. 152.

[16]Ibid., p. 155.

[17] Cochrane, p. 67.

[18] *Ibid.*, p. 68.

[19] *Ibid.*, pp. 69-71.

[20] *Ibid.*

[21] *Ibid.*, pp. 76-77.

[22] *Ibid.*

[23] Clifton B. Cox and Patrick J. Luby, "Predicting Hog Prices," *Journal of Farm Economics*, XXXVIII, No. 4 (November, 1956), p. 934-939.

[24] Gerald W. Dean and Earl O. Heady, "Changes in Supply Functions and Supply Elasticities in Hog Production," *Research Bulletin-471* (Ames, Iowa: Iowa State University Experiment Station, November, 1959), p. 576.

[25] *Ibid.*, p. 572.

[26] Cochrane, p. 72.

[27] *Ibid.*, p. 75.

[28] Wilbur R. Maki, "Forecasting Beef Cattle and Hog Prices by Quarter Years," *Research Bulletin—473* (Iowa State University Experiment Station, December, 1959), p. 620.

[29] Wilbur R. Maki, "Forecasting Livestock Supplies and Prices with an Econometric Model," *Journal of Farm Economics*, XLV, No. 3 (August, 1963), p. 620.

[30] Maki, "Forecasting Beef Cattle and Hog Prices by Quarter Years," p. 627.

[31] Raymond M. Leuthold, "An Analysis of Daily Fluctuations in the Hog Economy," *American Journal of Agricultural Economics*, LI (November, 1969), pp. 849, 864.

[32] Arthur A. Harlow, "The Hog Cycle and the Cobweb Theorem," p. 168.

[33] Arthur A. Harlow, "Factors Affecting the Price and Supply of Hogs," USDA Technical Bulletin-1274, (Washington, D. C.: Government Printing Office, December, 1962), p. 2.

[34] Harlow, "Hog Cycle and Cobweb Theorem," p. 167.

[35] Harlow, "Factors Affecting the Price and Supply of Hogs," p. 24.

[36] Arthur A. Harlow, "A Recursive Model of the Hog Industry," Agricultural Economics Research (Washington, D. C.: United States Department of Agriculture, January, 1962), pp. 1-2.

[37] Ibid.

[38] U. S., Department of Agriculture, Livestock and Meat Statistics, 1960-1968 (Washington, D. C.: Government Printing Office, 1960-1968), Tables 26, 101, 180, 182, 210-214, 220.

[39] U. S., Department of Agriculture, Handbook of Agricultural Charts-1966, 1970 (Washington, D. C.: Government Printing Office, 1966 and 1970), Nos. 325, 397, pp. 66-67, 72.

[40] U. S., Department of Agriculture, Poultry and Egg Situation (Washington, D. C.: Government Printing Office), Bulletin Series PES-257, 1960 thru 1968, p. 5.

[41] U. S., Department of Agriculture, Feed Situation (Washington, D. C.: Government Printing Office, 1970), FDS Bulletin-233, p. 33.

[42] U. S., Department of Agriculture, Grain Market News-Quarterly Summary and Statistics (Washington, D. C.: Government Printing Office, 1960-1968), pp. 7-14.

[43] U.S., Department of Commerce, Survey of Current Business (Washington, D. C.: Government Printing Office, 1963-1969 biennial issues), pp. 7, 39-41.

[44] U.S., Department of Commerce, Bureau of the Census, Current Population Reports: Population Estimates (Washington, D. C.: Government Printing Office), Series P-25, No. 417, 1969, p. 2.

45 Harlow, "Factors Affecting the Price and Supply of Hogs," p. 51.

46 Harlow, "Recursive Model of the Hog Industry," p. 5.

47 Harlow, "Factors Affecting the Price and Supply of Hogs," p. 51.

48 Harlow, "Recursive Model of the Hog Industry," p. 5.

49 Harlow, "Factors Affecting the Price and Supply of Hogs," pp. 52-54.

50 Ibid., p. 59.

51 Material in this section was derived from Economics 461 and 566 course notes.

52 Edward J. Kane, Economic Statistics and Econometrics (Evanston: Harper and Row Publishers, 1968), pp. 365-367.

53 Harlow, "Hog Cycle and Cobweb Theorem," p. 169.

54 Ibid., pp. 168-169.

55 Cochrane, p. 71.

56 Cox and Luby, "Predicting Hog Prices," p. 931.

57 Gerald W. Dean and Earl O. Heady, "Changes in the Supply Response and Elasticity for Hogs," Journal of Farm Economics, XL, No. 4 (November 1958), p. 860.

58 Wilbur R. Maki, "Decomposition of the Beef and Pork Cycles," Journal of Farm Economics, XLIV, No. 3 (August, 1962), p. 743.

59 Harold F. Breimyer, "Emerging Phenomenon: A Cycle in Hogs," Journal of Farm Economics, XLI, No. 4 (November, 1959), pp. 767-768.

60 Frederick V. Waugh, "Cobweb Models," Readings in the Economics of Agriculture, Edited by Karl A. Fox and D. Gale Johnson (Homewood: Richard D. Irwin, Inc., 1969), p. 106.

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